Small Animal Regional Anesthesia and Analgesia

Dedication

To my dearest wife Ewa for being the most understanding and supportive person in the whole wide world and to my children Kyla and Kian who I love to bits.

Luis Campoy

To my wife, Emma, and my children Grace and Kate for their support and encouragement. There were many days and nights spent working on this book and without their understanding, this project would not have been possible. I also extend my gratitude to Ban Tsui, MD and Vincent Chan, MD for opening the world of regional anesthesia to me and for sharing their enthusiasm for this wonderful specialty. Finally, I would like to thank my partner in this project, Luis Campoy, for his friendship and tireless efforts in getting this book to publication. Cheers!

Matt Read

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Foreword

I am a medical anesthesiologist. My first meeting with veterinary anesthesiology was in 1997. A pet falcon belonging to a medical anesthesiologist friend needed an anesthetic for the fitting of a radio transmitter. The veterinarian who did the anesthetic was Dr. Lynette Bester. The falcon-owning friend next introduced Dr. Bester to me and we began an enduring scientific liaison of lecturing and teaching at scientific meetings we respectively organized. We developed an anesthetized pig workshop as a tool for teaching regional anesthesia techniques to both medical and veterinary anesthesiologists in South Africa.

In 2003 Dr. Bester and I were invited to present a regional anesthesia course in Knoxville Tennessee at the World Congress of Veterinary Anesthesiology.

Attending that WCVA-2003 regional anesthesia course were Drs. Luis Campoy and Matt Read, both of whom I met for the first time. Luis and Matt have told me that the Knoxville WCVA regional anesthesia course was a milestone in their growing passion for regional anesthesia. Subsequently Luis and I jointly organized a veterinary regional anesthesia skills course in Iowa and we lectured together at the regional anesthesia meetings of ISVRA in Italy. It seems a few blinks later Luis and Matt were producing this book and honoring me with an invitation to contribute a chapter and write this foreword. There is a warm story of professional bonds between all of this book's authors and their passion for their work and for regional anesthesia. I hope this book transmits that passion onto the readers.

There are many good reasons to perform regional anesthesia on our patients, both medical and veterinary. The primary outcome is postsurgical analgesia. This reduces patient suffering and facilitates faster return to normal eating, earlier mobilization, and swifter general recovery, which are in turn additional secondary outcome benefits. There are, however, many more secondary outcome benefits. In human studies, evidence strongly suggests that regional anesthesia diminishes chronic pain syndromes, diminishes cancer recurrences, reduces surgical infection, and reduces cardiovascular and pulmonary complications. The addition of regional anesthesia to a general anesthetic also allows significant anesthetic drug dose reduction. Reduced general anesthetic drug doses allow faster patient recovery from the general anesthetic. General anesthesia may seem to be a nontherapeutic specialty that only exists to make surgery possible. Regional anesthesia is different, however, as it offers significant benefits that endure after the surgery.

The first book in medicine devoted solely to regional anesthesia was published in 1917 by Victor Pauchet. Gaston Labat translated Pauchet's book into English in 1924. A generation later in

1953, Daniel Moore took the science further with his legendary book titled *Regional Block*. Moore's book was continually reprinted for another generation of anesthesiologists. The use of ultrasound guidance for peripheral nerve block needle placement became popular after 2005 and this hugely accelerated medical regional anesthesia's growth in popularity. Veterinary regional anesthesia's development is running parallel to medical regional anesthesia development. The two biggest limiting factors in regional anesthesia are lack of technical skill among practitioners and ignorance of surgeons on the risks and benefits. Education is the solution to both. This book will greatly help with that.

The growth in public sentiment and concern for the suffering of animals will also drive the popularity of regional anesthesia as a form of pain control for small animals with injuries and postsurgical pain. Every reason that exists to promote the use of regional anesthesia in humans is as valid to promote the use of regional anesthesia in animals.

Apart from being the historic book it is, I am sure this book by Drs. Campoy and Read will also long remain a definitive text book on veterinary regional anesthesia. The science of veterinary regional anesthesia will accelerate from now forward as much medical regional anesthesia did after the publication of each book by Pauchet, Labat, and Moore. The honor of publishing the first veterinary regional anesthesia book will always belong to editors Campoy and Read and their writing team.

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Preface

Small Animal Regional Anesthesia and Analgesia was written with a wide audience in mind. For many years, local and regional anesthesia in animals was considered to be an "art," with techniques that were developed decades ago still being used without any particular attention being made to advancing the "science" behind the different procedures. Over the last 10 years, rapid advances in human regional anesthesia have started to carry over into veterinary medicine. Recently, many studies have been conducted in small animals to document, describe, and improve local and regional anesthetic blocks in our small animal patients.

The primary goal of this text is to put a large body of information in one place for the first time. Interest in regional anesthesia in animals is not limited to one particular geographic area; as a result, we have invited an international group of authors to share their experience and expertise with us. This text will hopefully have something for everyone – it can be used as a text with complete reference lists and extensive discussion of different topics, or as a quick source of information with procedural checklists, pictures, and diagrams to assist with performance of the various blocks. Our hope is this book will serve as the impetus to standardize the various procedures that are used clinically (so we are all speaking the same language when we talk about these blocks), and will stimulate continued interest in this particular subspecialty of anesthesia and pain management in veterinary medicine.

Although our understanding of regional anesthesia in small animals still has a long way to go, we are on the cusp of some exciting new developments that will undoubtedly contribute to better outcomes and improved patient care.

Luis Campoy and Matt Read

Acknowledgments

We would like to acknowledge the contributions of our coauthors, all of whom had great enthusiasm for seeing this project come to fruition. The energy and time that they poured into this book is easy to see.

We also want to thank the team at Wiley, who provided us with support and mentoring through the entire process. We would like to especially thank Ms. Erica Judisch, commissioning editor at Wiley, for her tireless assistance, patience, and understanding. Without her, this book would never have been completed. We are also grateful for the help of Ms. Susan Engelken and Ms. Carrie Horn at Wiley, Ms. Eilidh McGregor for copyediting, Mr. Pascal Raj Francois for production, and the proofreaders and indexers who helped in the final stages. Finally, we would like to acknowledge our colleague, Dr. Bernd Driessen, for initially bringing us together on this exciting project.

Part 1

Considerations for Loco-regional Anesthesia

1 History of Regional Anesthesia

Kristopher Schroeder

History

The history of regional anesthesia and pain management is filled with fabulous stories and great characters. Ancient Egyptians used a variety of analgesics including hyoscyamine, scopolamine, opium poppy, beer, juniper, and yeast to treat a variety of ailments including "pains within the body." Ancient Indian culture used herbal medicine and yoga to overcome pain and create internal balance, and the ancient Chinese used acupuncture to properly channel negative energies and treat pain. The ancient Greeks gave the world Hippocrates (460–370 BC) who believed in the healing power of nature and focused on a rational approach to diagnosis and treatment rather than one based on superstition (Raj 2010).

Early giants in the field of medicine and philosophy were concerned with characterizing and understanding pain. Early teachings from Aristotle (384–322 BC) described pain as an emotion that was situated in the heart and it was not until Galen of Pergamon (AD 130–201) that people recognized that the brain was the organ responsible for pain sensation. Avicenna (AD 980–1037) described how pain sensation could be altered in various disease states, and Newton (1642–1727) and Hartley (1705–1757) described the potential role of nerves in transmitting noxious stimuli from the periphery to the brain (Perl 2007). Despite these advances in knowledge, the Middle Ages remained an unpleasant period of time in which to require a surgical procedure when even invasive surgeries were performed without anesthesia.

Early attempts at medicinal pain control typically originated from plant material and included opium (*Papaver somniferum*), alcohols, mandrake (*Atropa mandragora*), belladonna (*Atropa belladonna*), and marijuana (Cannabis). Freidrich Wilhelm Sertürner (1783–1841) isolated morphine from the opium plant in 1803. Aspirin (acetylsalicylic acid) was released in 1899 by the Bayer Company and quickly became the common man's "go to" therapy for mild to moderate pain relief (Raj 2010).

The natives of Peru are attributed with being the first to "use" a local anesthetic—the cocoa leaf, known for both its analgesic and hallucinatory properties. During surgical procedures, they obtained local anesthesia by chewing the leaves of the plant and allowing the resulting saliva to run into the fresh incisions. Chewing the leaves of the cocoa plant was also reported to "assuage the hungry,

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invigorate the weary and brighten the depressed." The cocoa plant was also important in the Peruvian natives' religious and political lives (Keys 1942; Fink 1985). The Spaniards who conquered the native Incan people initially described chewing cocoa leaves as the "work of the devil," but when they recognized the profit that could be made, they legalized it and taxed the revenue from plant sales. Bernabe Cobo described the first analgesic use of cocaine in 1653 when he discussed the native Incan practice of using the cocoa leaves to cure a toothache. In 1859, Paolo Mantegazza described Peruvian natives using cocoa leaves for the treatment of "a furred tongue in the morning, flatulence and whitening the teeth." While on a trip to South America, Scherzer noticed that the leaves numbed the tongue when they were chewed, and he went on to become the first person to make a report in the literature about its anesthetic qualities (Keys 1942; Deschner et al. 2007).

A necessary prerequisite to performing regional anesthesia was the development of the hypodermic needle and syringe. In 1836, Lafargue reported injection of morphine paste subcutaneously using a needle trocar. In 1839, Taylor and Washington began the practice of using hypodermic medication for relief of pain when they punctured the skin using lancets followed by injection of morphine solutions using syringes. In 1845, Francis Rynd described the potential benefits that could be obtained from perineural injections of opioids. In 1853, Alexander Wood invented the hollow needle and in that same year Charles Gabriel Pravaz attached an improvised hollow needle to a specially constructed syringe, completing the combination of equipment that we still use today (Raj 2010; Deschner et al. 2007).

In 1855, Friedrich Gaedcke was the first to isolate the active alkaloid from the cocoa plant, naming it "erythrolyxin." In 1860, Albert Nieman (1834–1861) isolated this ingredient in crystalline form (naming it "cocaine") and reported anesthesia of the tongue when it was tasted (Cousins and Bridenbaugh 1988; Deschner et al. 2007). In 1872, Theodor Aschenbrandt, an Austrian army officer, secretly put cocaine into the water of his soldiers and found that it improved endurance (Fink 1985). In 1880, Vasili Konstantinovich Von Anrep (1854–1925) thoroughly studied the pharmacology of cocaine. He developed a solution of cocaine and found that it could both abolish the sensation of taste and create anesthesia when applied to the tongue. Von Anrep also injected cocaine subcutaneously under the skin of his own arm and discovered that he created an area of anesthesia that lasted about 35 minutes. At the same time, others were experimenting with use of cocaine solutions for blocking corneal reflexes in animals and for treating painful diseases of the larynx and pharynx (Keys 1942; Deschner et al. 2007).

With the groundwork completed, all that was now needed was for someone to apply what had been learned about cocaine and apply it to the surgical arena. The development and use of cocaine as a local anesthetic agent is primarily attributed to Karl Koller. While Koller was practicing as a house surgeon at the Vienna General Hospital, his friend Sigmund Freud happened upon the beneficial reports of cocaine and studied its use for curing patients with morphine addiction (Fink 1985). Koller wanted to be accepted into an ophthalmology training program and was well aware of the search for a topical anesthetic to allow surgery to be performed on the eye. Prior to the introduction of cocaine anesthesia into clinical practice, eye surgery was nearly impossible to perform, given that general anesthesia typically induced coughing and vomiting, consequences to be avoided during eye surgery. He had read the reports of cocaine causing anesthesia of the tongue and had even tried it on his own tongue before arriving at the realization that cocaine could be topically applied to the eye. He first applied topical cocaine to the eye of a frog and when the frog did not move in response to touching of its cornea, regional anesthesia was truly born. He reported these findings to the Ophthalmological Congress in Heidelberg in September 1884, and the world's first surgery performed under regional anesthesia was completed as Koller anesthetized a patient's eye with cocaine for glaucoma surgery. Dr. Koller's assistant later wrote of the discovery:

> "We could make a dent in the cornea without the slightest awareness of the touch, let alone any unpleasant sensational reaction."

With that demonstration, the discovery of local anesthesia was complete and cocainization of the eye for production of local anesthesia was generally

adopted. "I rejoice that I was the first to congratulate Dr. Koller as a benefactor of Mankind," wrote an assistant of Koller's (Fink 1985; Leonard 1998; Deschner et al. 2007). Freud referred to his former colleague Koller as "Coca Koller" and Koller described Freud as his "muse" (Fink 1985; Deschner et al. 2007).

In 1884, William Halsted (1852–1922) was the first to describe cocaine application to accessible peripheral nerves to perform dental blocks, thus obtaining "conduction" anesthesia in peripheral regions. The mandibular nerve was the first nerve he blocked. Halsted and Hall also performed a variety of other peripheral nerve blocks on themselves and medical student "volunteers" (Cousins and Bridenbaugh 1988). The next challenge in the evolution of regional anesthesia was to locate and inject a peripheral nerve percutaneously and blindly.

G.L. Corning, a neurologist, was the first to report an intravenous injection of local anesthetic with proximal venous occlusion for distal anesthesia. Corning is also credited with inducing the first spinal anesthesia in a dog, when he injected cocaine into the space between two adjoining spinous processes in a dog in 1885 and uncovered the possibilities of spinal anesthesia. He reported that the injection of a cocaine solution into the space between the spinous processes of two inferior dorsal vertebrae resulted in anesthesia of the dog's hind legs without affecting the anterior extremities. He subsequently performed a similar procedure in a man, resulting in anesthesia to the subject's legs and genitalia (Cousins and Bridenbaugh 1988). He later pondered:

> "Whether the method will ever find an application as a substitute for etherization in genitourinary or other branches of surgery, further experiments alone can show."

Corning is also credited with the first regional anesthetic peripheral nerve block after injecting a solution of cocaine around the median cutaneous antibrachii nerve in 1887 (Fink 1985; Ball and Westhorpe 2003; Deschner et al. 2007).

Carl-Ludwig Schleich (1859–1922) first described a technique for infiltration anesthesia to the German Congress of Surgeons in 1892. Previously in 1869, Pierre Edouard Potain used subcutaneous injections of water to provide skin anesthesia and Schleich described how both water and saline had weak anesthetic properties. Subcutaneous injections of water were associated with significant pain so Schleich took the next step and added cocaine to his injectate solution. Using his low-concentration cocaine solution for subcutaneous infiltration, Schleich was able to perform a variety of peripheral surgical procedures. Two years later, his methods had been widely adopted and were being used in the United States (Cousins and Bridenbaugh 1988; Deschner et al. 2007).

In 1897, Braun demonstrated that the toxicity of cocaine was in proportion to its rate of absorption, and recommended the addition of epinephrine to the solution of cocaine in order to decrease its rate of absorption and increase the duration of anesthesia—something anesthetists still commonly perform today (Braun 1914).

August Bier performed the first spinal anesthetics in 1898 when he injected the spinal canals of animals, himself, and an assistant (August Hildebrandt) with a solution of cocaine. Bier described the procedure of spinal anesthesia on six patients and one colleague in a manuscript written in 1899. First, Bier performed spinal anesthesia with intrathecal cocaine on his colleague Hildebrandt. Bier then subjected Hildebrandt to a series of painful insults including making a small skin incision on his thigh, applying a burning cigar to his legs, and applying strong blows to his shin with an iron hammer, without any apparent perception of pain on the part of Hildebrandt. Bier then went on to describe the problems associated with experimenting on himself and Hildebrandt when he detailed how Hildebrandt later developed pain in the distribution of his legs where "sensibility had been tested by crushing and heavy blows." Bier also described what we would now recognize as postdural puncture pain but attributed it to:

> "…Treating our bodies too lightheartedly. Instead of laying down and resting following the lumbar puncture and injection of cocaine, we went about our avocations, drank and smoked more than was good for us, and performed our normal work the next day."
>
> (Wulf 1998)

Between the time that Bier first performed spinal anesthesia and 1910, the techniques must have

become widely adopted, because in 1909–1910, Tyrell Gray described performing spinal anesthesia in children and explained that his patients were comfortable enough to "eat cake throughout the duration of the surgical procedure" (Brown 2012).

In 1908, August Bier described the first use of intravenous regional anesthesia, the "Bier block" that still bears his name (van Zundert et al. 2008). In 1911, Georg Hirschel described the axillary brachial plexus block and D. Kulenkampff described the supraclavicular brachial plexus block (Cousins and Bridenbaugh 1988). Louis Gaston Labat (1877–1934) further popularized the use of regional anesthesia in the United States by authoring the text *Regional Anesthesia: Its Technic and Clinical Application* in 1920. Despite Labat himself commenting that the text was likely as popular as it was secondary to "the clear, concise descriptions carefully illustrated by half-nude women," his text served as the definitive text on regional anesthesia for 30 years and clearly helped to expand and advance the practice of regional anesthesia (Cousins and Bridenbaugh 1988; Cote et al. 2003).

One of the dangers associated with cocaine regional anesthesia is that the drug has euphoric, hallucinogenic, and, ultimately, addictive properties. Sadly, many of the early names in regional anesthesia that experimented on themselves developed addictions to cocaine. Due to these properties, and with the advances in chemistry and manufacturing, alternative local anesthetic molecules were subsequently developed. Amylocaine was developed as an early alternative to cocaine but it was abandoned when it was found to be an irritant. Procaine was developed in 1904 and was introduced into clinical practice in 1905. Procaine very quickly replaced cocaine in practice but its use was limited by its short duration and the potential for it to produce allergic reactions. Dibucaine (1925) and tetracaine (1928) were synthesized to create local anesthetics of longer duration, but they continued to have unacceptably high allergenic potential. Lidocaine was developed in the mid-1940s, a revolutionary new amide local anesthetic with decreased potential for allergic reactions. Mepivacaine (1957), bupivacaine (1957), prilocaine (1969), and etidocaine (1972) were all subsequently released into clinical practice. Mepivacaine and bupivacaine are still commonly used. Recently, ropivacaine has been developed as another long-acting local anesthetic agent, and, compared to other agents, has less motor blockade and decreased potential for cardiac toxicity (Brown et al. 2010).

The use of regional anesthetic techniques in animals started near the turn of the twentieth century (Lumb and Jones 1973). Cuille and Sendrail induced subarachnoid anesthesia in horses, cattle, and dogs in France in 1901. Cathelin reported the use of epidural anesthesia in dogs in 1901, but it took until the 1920s for this technique to be adapted by Retzgen, Benesch, and Brook for use in large animals. Later, in the 1940s, Farquharson and Formston developed paravertebral techniques for cattle. By the 1960s, local anesthetic techniques were commonplace in veterinary practice and chapters that described their pharmacology and use were included in many veterinary textbooks. Many of the drawings and images that we still use today are based on figures from Wright's *Veterinary Anaesthesia and Analgesia* (first published in 1941, Hall 1966) and Lumb and Jones' *Veterinary Anesthesia* (first published in 1973). Today, the science is catching up to the art, and local and regional anesthetic techniques continue to have an ever more important role in acute and chronic patient management of veterinary species.

Peripheral nerve blocks

Although the practice of neuraxial (spinal, epidural) anesthesia has changed minimally over the years, peripheral nerve blockade has undergone multiple shifts in both philosophy and technique. Originally, correct needle positioning was simply approximated by anesthesiologists who would use their knowledge of anatomy to estimate the locations of target nerves. Later, techniques involved asking the patient to report "paresthesias"—the nerve tingling in the distribution of the target nerve to be blocked after the needle had been inserted close to the target nerve. Anesthesiologists at that time were governed by the words of Moore "No paresthesia, no anesthesia," and they relied heavily on patient feedback to finalize needle position prior to drug administration. Traditional techniques also relied upon the anesthesiologist sensing palpable and subjective "pops" or "clicks" as their needles traveled through various fascial planes, and detecting arterial pulsations transmitted along the length of their

needles as they came in close proximity to major arteries (Dillane and Tsui 2012).

Nerve stimulation

In 1780, Luigi Galvani applied static electricity-charged metal electrodes to frog sciatic nerves and showed that electrical stimulation of peripheral nerves would result in muscle contractions. In 1850, H. von Helmolz investigated isolated nerve-muscle specimens. Based on those studies, he formed the concept that when an electrical stimulus is applied to a nerve, a threshold must first be reached before an action potential can result in creation of a muscle contraction. Georg Perthes first reported the clinical use of electrical nerve stimulation for nerve blocks in 1912 in Germany. In 1962, Greenblatt and Denson reported their use of a portable nerve stimulator for nerve localization, and in 1966, battery powered portable nerve stimulators first appeared in clinical practice (Dillane and Tsui 2012). In 1984, specially designed needles became available for electro-stimulation of nerves. These needles had electrically insulated shafts but naked metal tips that served as electrodes during nerve stimulation (Ford et al. 1984). This technological development resulted in worldwide growth and interest in medical nerve blocks. By being able to "find" target nerves through visualization of motor responses prior to injection of local anesthetic solutions, nerve stimulation was reported to increase the chances of successful nerve blockade while at the same time reducing the volume of local anesthetic that was required. There was a belief that at certain stimulating currents, target nerves could be identified before the needle tip contacted the nerve itself, thus minimizing the risk of patient injury during needle placement and/or injection of the local anesthetic. Nerve stimulation for nerve localization was found to be associated with a decreased incidence of nerve trauma and Gentili and Wargnier coined the phrase "no paresthesia, no dysesthesia" (Dillane and Tsui 2012).

Ultrasound visualization

Ultrasound guidance has become popular as a nerve localization tool in people, and its use during regional anesthesia has recently been called the "new gold standard." The advantage of ultrasound guidance is that variation in individual patient anatomy no longer negatively affects block success rates. As target nerves can be "seen," they can more effectively be located with a needle tip prior to injection of the local anesthetic solution. Compared with the use of nerve stimulation alone, ultrasound guidance has been shown to result in a higher rate of successful peripheral nerve blockade, decreased block set-up times and longer block durations. When Orebaugh et al. (2007, 2009) studied the use of ultrasound guidance versus nerve stimulation for peripheral nerve blockade performed by anesthesia residents, they found that ultrasound guidance resulted in decreased procedure times, needle insertions, and inadvertent vascular punctures (Orebaugh et al. 2007, 2009).

A study by Robards et al. (2009) demonstrated that nerve stimulation might not confer the added safety benefits with which it was initially credited. In their study using combined ultrasound guidance and nerve stimulation to perform sciatic nerve blocks in the popliteal fossa, they found that in 4/24 patients a current of 1.5 mA (a typical current used during regional anesthesia) failed to produce a visible motor response even though needles were placed intraneurally (Robards et al. 2009). Ultrasound guidance has the added benefit of being able to visualize vascular or other anatomical structures that should be avoided during needle placement (i.e. pleura, peritoneum, etc.), but its use is limited by equipment availability and operator skill. In theory, the decreased volume of local anesthetic that is required to block a nerve when ultrasound guidance is used should confer added safety to the patient. However, despite all of these reported advantages, in people there is no definitive evidence to support a safety benefit of using ultrasound guidance versus nerve stimulation, and the debate continues over the role of nerve stimulation and ultrasound guidance in the performance of regional anesthesia (Chin and Chan 2008; Griffin and Nicholls 2010).

Rationale for loco-regional anesthesia and analgesia

Why all of this excitement and interest in the field of regional anesthesia? For many practitioners,

regional anesthesia offers the potential to put the anatomical knowledge that they have acquired throughout the years into practice. The use of regional anesthesia is intellectually challenging and incredibly rewarding. The benefits for your patients are often quite obvious as you take a patient in excruciating pain and make them comfortable when they are in the vulnerable postoperative period.

The anesthesia literature is filled with studies further demonstrating the benefits of regional anesthesia. The list of indications for regional anesthesia continues to expand as the number of regional techniques expands or is improved upon to allow more peripheral techniques to be performed. Pain itself has been demonstrated to have a number of adverse effects throughout the body. It impacts the respiratory system by promoting atelectasis, ventilation-to-perfusion mismatching, arterial hypoxemia, hypercapnia, and pneumonia. In the cardiovascular system, pain has been shown to produce hypertension, tachycardia, myocardial ischemia, and cardiac dysrhythmias. Pain impacts the endocrine system by promoting hyperglycemia, sodium/water retention, and protein catabolism. It can cause urinary retention, decreased clotting ability, impaired coagulation, and decreased immune function (Stoelting and Miller 2007).

Decreases in morbidity and mortality, improved postoperative pain control and decreases in perioperative complications have been listed as potential benefits of regional anesthesia in people. A meta-analysis that compared intraoperative neuraxial to general anesthesia (141 randomized controlled trials, 9559 patients) demonstrated that neuraxial anesthesia was associated with a decrease in mortality from 2.8% to 1.9% (Rodgers et al. 2000). A study evaluating the Medicare claims database found that when an epidural was used for postoperative analgesia, mortality was reduced at 7 days (0.5% vs. 0.8%) and 30 days (2.1% vs. 2.8%) postoperatively (Wu et al. 2004). Another database analysis of 259,037 patients found that epidural anesthesia reduced 30-day mortality from 2.0% to 1.7% (Wijeysundera et al. 2008). Despite the exciting findings of the above-mentioned studies, other investigations have failed to find mortality benefits and it is likely that mortality benefits truly exist only for the sickest patients undergoing high-risk procedures (Peyton et al. 2003). Thoracic epidural anesthesia has been demonstrated to have more clear benefits with regard to perioperative cardiovascular (myocardial infarction and dysrhythmias) and pulmonary (postoperative pulmonary complications, pulmonary infections, and respiratory failure) events. Thoracic epidural and regional anesthesia has been associated with faster recovery of bowel function, improved postoperative rehabilitation, improved pain control, decreased opioid requirements, and fewer opioid-related side effects (Hanna et al. 2009). An exciting frontier of investigation in the world of regional anesthesia focuses on the ability of nerve blockade to attenuate the amount of perioperative immunosuppression typically encountered in the perioperative period. This may have important implications with regard to the incidence of recurrence or metastatic cancer following cancer resection surgery (Exadaktylos et al. 2006).

As with all areas of veterinary medicine, local and regional anesthetic techniques have evolved rapidly over the last 20 years. Veterinarians and their staff are very interested in techniques that contribute to pain management and patient care, and as a result, the use of local anesthesia is being "rediscovered" after playing a secondary role in pain management due to the widespread development and use of opioids and NSAIDs over the last few years. If what physicians have learned about the benefits of local and regional anesthetic techniques has any application to animals (which they would be expected to), then we can look forward to an exciting few years to come!

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2 General Considerations

Luis Campoy and Kristopher Schroeder

Loco-regional anesthesia is used extensively in human medicine to provide intra- and postoperative pain control. The American Society of Regional Anesthesia (ASRA) was founded in 1975 and currently boasts 5000 members in 60 countries. ASRA is the largest subspecialty organization in anesthesia and currently hosts two separate annual meetings that focus on either acute or chronic pain control. Accredited fellowship programs in chronic pain management have been available for a number of years, and recently, fellowship training has become available in regional anesthesia and acute pain management (Neal and Baker 2006).

In recent years, loco-regional anesthesia has also gained popularity in veterinary medicine. With a growing emphasis on improving pain management for animals, loco-regional anesthetic procedures that were originally described for use in people are now being adapted to different animal species with positive results (Campoy et al. 2008; Figueiredo et al. 2008; Bardell et al. 2010; Mosing et al. 2010; Zarucco et al. 2010; Watts et al. 2011). However, the extrapolation and safe use of loco-regional anesthetic techniques (either neuraxial or peripheral) that are designed and reported for one species requires a thorough understanding of the relevant regional anatomy of the new species of interest.

Outline of central anatomy

For the purposes of local anesthetic classification, the nervous system can be conveniently divided into the central (neuraxial) and peripheral nervous systems. The vertebral canal contains the epidural space and the intrathecal structures, which include the spinal cord, the meninges, and the cerebrospinal fluid (CSF). Two distinct nerve roots emerge from each spinal level. The dorsal nerve roots provide afferent information to the spinal cord, whereas the ventral nerve roots provide efferent information from the spinal cord to the effector organs in the body.

The anatomic area that is innervated by an individual nerve root is referred to as a "dermatome." Dermatome maps exist and thorough knowledge of this innervation allows anesthetists to more appropriately deliver their drugs in the epidural or intrathecal spaces (Stoelting and Miller 2007; Cousins and Bridenbaugh 1988).

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Structure of a nerve – *note that all nerves contain both myelinated and unmyelinated sensory and motor fibers (axons)*

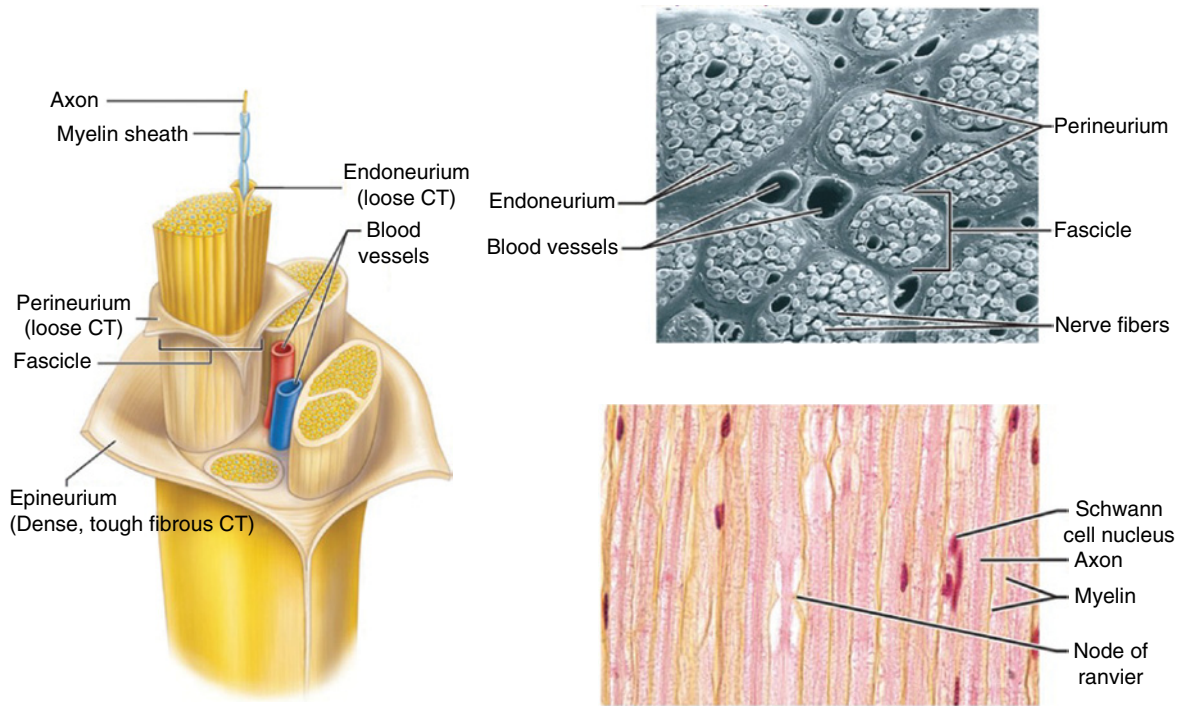

Figure 2.1 Microanatomy of a peripheral nerve. (From: A. Kizirian. http://antranik.org/wp-content/uploads/2011/10/structure-of-a-nerve-perineurium-endoneurium-epineurium-perineurium-fascicle-1024x731.jpg. Used with permission.)

Peripheral nerve anatomy and pain

Individuals who perform regional anesthesia should have a thorough understanding of the microanatomy of peripheral nerves. Although nerves may appear grossly to be large, distinct structures, they are actually made up of many components (Figure 2.1). A peripheral nerve is a structure consisting of nerve fascicles that are held together by the *epineurium*, the outermost layer of connective tissue surrounding a peripheral nerve. The epineurium not only holds the fascicles together in a grossly identifiable structure, but also contains the blood vessels that supply the peripheral nerve. Individual nerve fascicles with in the peripheral nerve are surrounded by the *perineurium*, a multilayered epithelial sheath consisting of several layers of perineural cells. Each fascicle contains many individual nerve fibers and capillary blood vessels. The fascicular bundles are not continuous throughout the peripheral nerve and they divide and anastomose with one another as frequently as every few millimeters (Stoelting and Miller 2007; Cousins and Bridenbaugh 1988). The *endoneurium* is the layer of delicate connective tissue made up of endoneurial cells that encloses the myelin sheath surrounding each nerve fiber.

Loco-regional anesthetic terminology

Topical or surface anesthesia

Topical or surface anesthesia has great theoretical appeal as pain transmission could be halted before it even starts at the site of peripheral injury. Unfortunately, local anesthetics are not readily absorbed across the skin surface, and special formulations are needed for them to be used in this way.

A Eutectic Mixture of Local Anesthetics (EMLA® cream or patches) has been used to decrease pain for a variety of dermal procedures in people, and has been studied in cats to minimize pain associated with jugular puncture (Wagner et al. 2006). EMLA® is a eutectic mixture of equal quantities of lidocaine and prilocaine (2.5% each) and is approved for application to intact, non-mucosal skin (Kundu and Achar 2002). EMLA® is indicated for dermal anesthesia and is reportedly useful for preventing pain associated with peripheral intravenous catheter placement, blood sampling, and superficial skin closure in people. When used correctly, the cream is applied to the skin and it is then covered with an occlusive dressing to facilitate absorption of the local anesthetics. Local anesthetic efficacy is achieved after approximately 60 minutes and lasts up to two hours after the dressing is removed.

Transdermal lidocaine patches (Lidoderm®) were originally developed for treating postherpetic neuralgia pain in people, and their use has recently been studied in horses (Bidwell et al. 2007). The patches contain 5% lidocaine and the penetration of lidocaine into intact skin is sufficient to produce a local analgesic effect, but is less than the amount necessary to produce a complete sensory block. Clinical trials in people have demonstrated that lidocaine patches placed near the site of incision are able to produce prolonged dynamic pain control and can reduce the amount of systemic opioids required for postoperative analgesia (Saber et al. 2009; Habib et al. 2009).

Local or infiltration anesthesia

Local or infiltration anesthesia is an old concept which has gained new followers recently (see Chapter 8). Historically, infiltration of local anesthetics into surgical sites simply involved the one-time injection of the drug into the planned surgical field. Recently, development and use of wound infusion catheters has allowed also for the continuous or intermittent delivery of local anesthetics into surgical wounds postoperatively, greatly improving patient comfort. Use of these techniques following abdominal procedures has been studied in people, with reductions in diaphragmatic dysfunction, rest pain, dynamic pain, opioid consumption, duration of ileus, and duration of hospital admission being reported as benefits (Ganapathy et al. 2011).

Regional or nerve (plexus) block anesthesia

Regional anesthesia is the injection of a local anesthetic solution in the vicinity of a peripheral nerve to temporarily block sensory and/or motor functions for intraoperative and postoperative pain control. There are many peripheral nerves that can be blocked, depending on the region of interest in the body (see Chapters 9–13).

Neuraxial anesthesia

The spinal cord and nerve roots are housed within the bony vertebral canal. Epidural (extradural) anesthesia refers to the administration of a local anesthetic (or other drug) into the epidural space outside of the dura, whereas the administration of a drug into the subarachnoid space is known as spinal, subarachnoid, or intrathecal anesthesia (see Chapter 14).

Intravenous regional anesthesia (IVRA)

Intravenous regional anesthesia involves administration of a local anesthetic into a peripheral vein (see Chapter 15). Prior to drug administration, the distal extremity is exsanguinated by elevating the limb and wrapping it in a tight bandage. A tourniquet is then inflated proximal to the surgical site and the bandage is removed. The local anesthetic solution is then injected intravenously. Anesthesia will soon take place covering an area distal to the tourniquet. Intravenous regional anesthesia has many applications for distal limb surgery of limited duration and, although it was originally described in 1908, it remains elegantly reliable, quick, and simple to perform.

Complications

With proper training and equipment, complications arising from the use of loco-regional anesthetic techniques for pain control are rare. Potential

complications must be fully understood by the clinician and strategies to minimize their incidence, including good record keeping, should be implemented during each and every nerve block.

A number of studies investigating the complications associated with regional anesthesia have been conducted in people (Cazzuffi et al. 1982; Fortuna and Fortuna 1989; Auroy et al. 1997; Brull et al. 2007). Auroy et al. (1997) analyzed the records from 21,278 peripheral nerve blocks to investigate the incidence and characteristics of serious complications in human patients following a variety of regional anesthetic procedures. The incidence of complications was as follows:

- three cardiac arrests (0.014%);
- one death (0.005%);
- 16 seizures (0.075%);
- four neurological injuries (0.019%); and
- four radiculopathies (0.019%).

The incidence of serious complications in veterinary patients is not known, and as we continue to develop these techniques for clinical use, prospective studies should be performed to better identify the risks to our patients.

Complications of loco-regional anesthetic techniques can be broadly categorized as being either systemic toxicities or nerve injuries.

Systemic toxicity

The most devastating complication during the performance of a peripheral nerve block is the intravascular injection of local anesthetic with subsequent signs of systemic toxicity such as muscle twitches, tremors, seizures, tachycardia, hypotension, arrhythmias, cardiovascular collapse, and even death (see Chapter 4). Central nervous system symptoms (i.e. muscle twitches, tremors, or seizures) usually occur before cardiovascular changes take place (i.e. tachycardia, hypotension, arrhythmias, cardiovascular collapse, cardiac arrest), but these changes are usually only going to be observed in awake patients. Under general anesthesia, early neurological warning signs of local anesthetic toxicity are masked by sedatives and inhalant anesthetics, and this manifestation of toxicity will often be missed. For this reason, in people there is controversy over whether or not peripheral nerve blocks should be performed under sedation rather than general anesthesia.

Giaufre et al. (1996) reported no complications relating to intravascular injection of local anesthetic in children following 9396 peripheral nerve blocks, despite the fact that the majority of these procedures were performed under general anesthesia. However, even with recent advances in the use of ultrasonography during performance of regional blocks in people, a recent case report by Loubert et al. (2008) showed that severe adverse toxic effects are still possible as a result of intravascular injections. The authors described how even the slightest amount of pressure applied by the ultrasound transducer can cause veins to collapse and vanish from sonographic view. When this occurs it is possible to inadvertently inject local anesthetic solutions into a vein without knowing.

In veterinary medicine, this controversy becomes moot—we are often forced to perform these blocks in heavily sedated or anesthetized animals because our patients do not typically tolerate these blocks being performed while they are awake. As a result, monitoring of patients for neurological or cardiovascular signs of local anesthetic toxicity during and after performance of the regional block is strongly recommended.

Neurological injuries

In people, the most severe complication of using loco-regional analgesic techniques for analgesia is the risk of permanent neurologic injury. For this reason, a great deal of research has been dedicated towards minimizing this risk. When it occurs, peripheral nerve injury often presents as "neuropraxia," with persistent numbness in the affected area. Fortunately, most of these injuries self-resolve and very few have been found to persist beyond a few months. Short-term complications regarded as being more trivial include: temporary dysesthesias, localized tenderness, and hematoma formation.

Neurological complications are believed to result from one or more of the following causes:

- needle/mechanical trauma;
- neuronal ischemia;

- neurotoxicity caused by local anesthetics;
- drug error; and
- infection.

Needle/mechanical trauma

Needle or pressure-related damage is the most common cause of nerve injury following peripheral nerve blocks. Following neuraxial (epidural, spinal) blockade, pressure-related complications can result from unrecognized hematomas or abscesses, resulting in profound neurological deficits.

In peripheral nerves, the fascicular bundles are not continuous along the length of a nerve. They divide and anastomose with one another every few millimeters along their course. As a result, if a short segment of a nerve is traumatized or compressed (i.e. in the case of an intrafascicular injection of the local anesthetic), the fascicles at both ends of that segment may no longer correspond with one another, leading to conduction deficits in the nerve.

There are a number of safety factors that have been suggested to help reduce the incidence and severity of peripheral neurological complications:

- monitoring the resistance to injection (injection pressure);
- minimizing the intensity of the stimulating current during electrolocation;
- needle design.

Kapur et al. (2007) reported the neurological outcomes following intraneural injections of the sciatic nerves in anesthetized dogs. They found that the worst neurological outcomes were associated with high injection pressures (20–38 psi, ~138–262 KPa), whereas intraneural injections that were associated with moderate pressures (<12 psi, ~82.7 KPa) had a longer than expected duration of nerve deficits, but no other long-term adverse effects. All perineural injections (i.e. those that were performed correctly) were associated with low injection pressures (<5 psi, ~34.5 KPa). This report (and others from this group of researchers) suggests that injection pressure plays an important role in the severity and duration of nerve injury following intra- and perineural injection of local anesthetics.

Chan et al. (2007) evaluated the minimum stimulating current associated with intraneural needle placement in the brachial plexus in pigs. They found that the minimum current that is able to elicit a motor response was 0.43 mA (0.12–1.8 mA) [median (min–max)], and concluded that a motor response above 0.5 mA does not necessarily preclude performance of an intraneural injection.

The use of a short bevel needle (e.g. 30–45° angle) may facilitate the identification of tissue planes and may help reduce the likelihood of impaling a nerve (Chambers 1992).

In order to minimize the chances of an intraneural injection, by general convention, if resistance to injection is experienced, the needle should be repositioned before further local anesthetic is injected. Additionally, when using electrolocation, the current output of the nerve stimulator should be decreased to 0.2 mA and the absence of obvious motor stimulation should be verified. When using ultrasound to perform the block, as the local anesthetic solution is being injected, fluid spreading around the nerves should be observed ("doughnut sign").

The symptoms of a nerve lesion following performance of a peripheral nerve block usually become apparent within 48 hours of the procedure. The intensity and duration of the symptoms vary with the severity of the injury. In human subjects, these may vary from a light, intermittent tingling and numbness to a persistent, painful paresthesia, neuropathic pain, sensory loss, and/or motor weakness lasting for several months or years. In general, it is safe to say that following peripheral nerve anesthesia, if sensory and/or motor functions remain depressed beyond the expected duration of action of the local anesthetic used, potential causes for the neurologic deficits should be investigated.

Treatments most commonly prescribed for paresthesias, neuropathic pain, and other deficits include tricyclic antidepressants (e.g. amitriptyline), serotonin reuptake inhibitors (e.g. paroxetine), anticonvulsants (e.g. gabapentin), opioids (e.g. tramadol), and capsaicin ointment.

Neuronal ischemia

Needle trauma to blood vessels that are closely associated with the target nerve may cause an extra- or intraneural hematoma or edema, leading to degenerative changes or discontinuity of fibers (Chambers 1992).

Neurotoxicity

Local anesthetics and their additives may potentially cause a variety of local reactions. Sodium metabisulfite was formerly added to chloroprocaine, causing several cases of *cauda equina* syndrome when used as a spinal injection (Ravindran et al. 1980). Ethylenediaminetetra-acetic acid (EDTA) added as a preservative to some local anesthetics resulted in severe back pain when these drugs were used for epidural anesthesia (Fibuch and Opper 1989; Stevens et al. 1993). Concentrated, hyperbaric lidocaine has been associated with transient neurologic symptoms (TNS) when used for spinal anesthesia (Schneider et al. 1993). Local anesthetics can also cause myelotoxicity, especially when epinephrine is included as part of the injectate (Benoit 1978a, b; Kytta et al. 1986). When local anesthetic agents are used at the concentrations that are currently used clinically, they are not known to be neurotoxic when applied as peripheral nerve blocks (Chambers 1992). This may not be the case when the intra-articular route is used (see Chapter 13).

Drug error

To date, there are no reports in the veterinary literature of drug mistakes after attempted peripheral nerve blocks. Recently, O'Kell and Ambros (2010) reported the administration of thiopental via the epidural route. Correct syringe labeling and implementation of "time-outs" are recommended in order to minimize the risk of medical mistakes.

Infection

Based on the authors' experiences, infection after injection of local anesthetics is very rare. To date, there are no reports that implicate this mechanism of injury as a cause of peripheral nerve damage. The risk of infection following peripheral nerve blocks still exists, but the consequences are expected to be less severe than when it follows neuraxial blockade. Two cases of discospondylitis have been reported in dogs following attempted neuraxial blockade (Remedios et al. 1996; MacFarlane and Iff 2011). Reports regarding humans can also be found in the literature (Kindler and Seeberger 1996). With the penetration of the skin with regional anesthesia needles, infection remains a possibility. In an era of multidrug-resistant "super bugs," close attention to regional anesthesia-induced infection is even more relevant. Even though the incidence of infection in human subjects is very low (1/1930 to 1/7500 for epidural abscess), the outcomes can be catastrophic. Adherence to strict aseptic technique is therefore required to minimize the risk of infection (Faccenda and Finucane 2001; Aromaa et al. 1997; Wang et al. 1999).

Allergic reactions

Allergic reactions to ester local anesthetics are more common than to amide local anesthetics. Para-aminobenzoic acid (PABA) is a metabolite of ester local anesthetics and is responsible for a large number of allergic reactions. Many patients will present with an "allergy" to local anesthetics that likely represents a prior adverse reaction to an epinephrine-containing injectate (fainting, tachycardia, etc.). Fortunately, true allergies to lidocaine are exceedingly rare in people and animals. Idiosyncratic reactions to the injection of local anesthetics have also been reported (Faccenda and Finucane 2001).

Other confounding complications

It is worth noting that post-block neuropathy may also be associated with confounding factors such as tourniquet ischemia, neuropathy due to positioning of the patient, or nerve damage following surgery. In one study of 3996 patients (Fanelli et al. 1999), no patient had permanent neurologic injury attributed to the regional anesthetic technique itself. Interestingly, the only variable that showed a significant predictive association with post-operative nerve injury was tourniquet pressure greater than 400 mmHg (7.54 psi, 52 kPa).

Successful regional anesthesia service

The implementation of new techniques for providing analgesia and anesthesia can pose multiple obstacles that need to be overcome. The following are a few pointers to consider that may make practice expansion into this area easier:

- The benefits of regional anesthesia need to be conveyed to the entire team. Pain control, side

effect profiles, and studies that convey data regarding rehabilitation goals and length of hospital stay can be invaluable. Having outcome data from your own institution (pain scores, opioid consumption, opioid related side effect data) can be incredibly helpful when attempting to make the case for regional anesthesia. Therefore, good record keeping is essential.

- Clients need to be informed of the potential benefits of regional anesthesia. They need to understand that although there is certainly a cost and risk associated with regional anesthesia, it is likely that it will be "worth it" in the long run if the blocks are able to provide greater comfort to their pets, allowing them to be discharged from the clinic more rapidly. The ability to return to normal behavior from anesthesia and surgery with decreased pain understandably has a large amount of appeal. Success with a regional anesthesia program begets more success as clients, clinicians, referring veterinarians, and others hear about the benefits of these local anesthetic interventions.
- Basic equipment must be obtained in order to have a functional block service. Nerve localization devices (nerve stimulator or ultrasound), needles, syringes, etc., require capital to acquire but are clearly necessary (see Chapters 5–7 for more information).
- Start with those techniques that "always work" while confidence and trust are being gained.
- Implementation of regional anesthetic techniques requires a group of individuals dedicated to pain management and improving the perioperative experience of their patients. At least one member of the team needs to constantly investigate new areas of involvement for the regional team and push the team to offer its services to a wider array of surgical patients. The team also needs to have a postoperative presence in order to evaluate and improve future block performance.

Record keeping

Record keeping and patient documentation is a requirement of any successful regional anesthetic program. Detailed records can help to determine if a given block is successful for a given procedure or if the block procedure needs to be adjusted. Detailed records may also be helpful in the event of an adverse outcome and can help to demonstrate adherence to the accepted standard of care. Records can also be useful if a patient returns for a similar procedure in the future, and can provide useful information such as needle depth, response to dose/volume, duration of block, etc. Data that should be recorded in the patient's chart include:

- type of block;
- drug(s) administered (dose, concentration, volume);
- verification of absence of resistance to injection;
- verification of aspiration prior to injection;
- any elicited responses if electrolocation was used (what was the minimal current?); and
- if ultrasound was used to assist with the block, images can be captured to document the different steps performed (nerves, neural integrity following injection, local anesthetic solution surrounding the nerve, etc.).

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3 Patient Preparation

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Sedation and anesthetic requirements

In small animals, to perform the majority of nerve blocks, the patient needs to be sedated or anesthetized. Patients should be relaxed, easy to manipulate and position, and be either minimally or completely unresponsive to needle advancement, electrolocation, and injection.

To prepare a patient for the procedure, an intravenous catheter should be placed. For sedation, a combination of either intravenous fentanyl (2–5 $\mu g\,kg^{-1}$) or dexmedetomidine (0.5–1 $\mu g\,kg^{-1}$) and propofol (2–4 $mg\,kg^{-1}$) can be administered. Note that the higher doses may be required when electrolocation is used alone (as higher current outputs are used), compared with a combined ultrasound/electrolocation-guided technique.

It is strongly recommended that pulse oximetry, blood pressure, and electrocardiography are monitored during performance and following the regional anesthetic procedure because of the potential for complications that are related to the sedation itself, to the regional anesthetic technique, or to the potential side effects or systemic toxicity from the local anesthetic (see Chapter 4 for more information). In cases where deep sedation is used, oxygen supplementation is recommended in order to minimize the chances of drug-induced hypoxemia caused by ventilatory depression.

In order to increase the patient's tolerance to the procedure, local infiltration with a local anesthetic such as lidocaine (1–2%) at the puncture site may be necessary if the patient is sedated rather than anesthetized.

Finally, during and after the injection, the patient should be monitored for adverse effects such as tachycardia, hypotension, arrhythmias, muscle twitches, tremors, or seizures. Although they are very rare, local anesthetic systemic toxicities are potentially fatal.

Patient positioning

Patient positioning is an important aspect of the procedure—nerves are flexible structures whose locations can vary depending on the patient's position. The approaches that are recommended for performing the different nerve blocks may or may not be possible depending on the patient's position. In some instances, patient positioning may also have an effect on injectate

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migration following injection, as has been reported in people following psoas compartment blockade (Mannion 2004). Using described and standardized positioning may also help to minimize complications.

Aseptic preparation

Recommendations from the United States Agency for Health Care Policy and Research (1993) may be extrapolated for our use, and may therefore be considered appropriate for all regional anesthetic techniques in veterinary medicine.

- Thorough hand washing is considered to be most important in the prevention of cross-infection (Boyce et al. 2002) and should occur before performing any regional anesthetic technique. Soap and water remove bacteria but are not effective for killing organisms (see Skin preparation below). Interestingly, higher microbial counts have been identified in health care workers who do not remove jewelry before hand washing (Salisbury et al. 1997).
- Sterile surgical gloves should be used and considered a supplement to, and not a replacement for, hand washing.
- Saloojee and Steenhoff (2001) showed that the use of surgical gowns does not reduce the incidence of infection any lower than the levels achieved with use of gloves alone.
- Evidence that use of face masks will result in fewer postoperative wound infections is still lacking (Tunevall 1991; Philips et al. 1992).

Important components of aseptic technique (Hebl 2006) (Figures 3.1 and 3.2)

- Removal of watches and jewelry;
- pre-procedural hand washing with antiseptic scrub;
- protective barriers;
- sterile gloves;
- appropriate selection and application of skin disinfectant;
- proper sterile draping technique;
- maintenance of a sterile field; and
- appropriate dressing techniques.

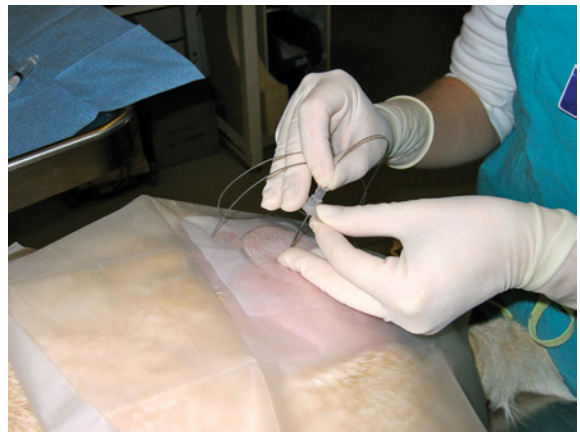

Figure 3.1 An epidural catheter being placed in a dog. Note the different components of performing the block while using sterile technique, including appropriate clipping and skin preparation, and using a fenestrated drape and sterile gloves.

Skin preparation

Infectious complications may potentially occur with any loco-regional anesthetic technique; however, those associated with neuraxial (spinal, epidural) blockade are usually of greatest concern because of their potentially devastating sequelae (MacFarlane and Iff 2011). Fortunately, the incidence of such complications appears to be relatively low.

- The migration of skin bacteria through needle puncture sites is considered to be a major source of epidural colonization (Sato et al. 1996).
- Darchy et al. (1996) reported that infections distant to an epidural catheter site do not increase the likelihood of subsequent epidural infections.

Clipping of the puncture site

Clipping the skin is not recommended at any time other than immediately prior to carrying out the block. Brown et al. (1997) showed that surgical sites clipped prior to induction of anesthesia were three times more likely to become infected. Additionally, clipping should be done carefully to minimize clipper rash, nicks, and cuts that might contribute to bacterial colonization (Hamilton et al. 1977).

Figure 3.2 (a) A dog with an epidural catheter placed prior to bilateral stifle surgery. Note the transparent film dressing (b) used to protect the catheter insertion site.

Skin disinfection

Controversy exists regarding the safest and most appropriate antiseptic solution to use prior to performance of a loco-regional anesthetic technique. Characteristics of an "ideal" disinfectant include:

- effectiveness against a wide range of microorganisms;
- immediate onset of efficacy;
- long-term effect;
- lack of inactivation by organic material (blood, pus, and body fluids); and
- minimal toxic effects to the skin.

Some of the more commonly used solutions include povidone iodine or chlorhexidine gluconate with or without isopropyl alcohol.

Povidone-iodine

Povidone-iodine is a specific type of iodophor. It destroys microbial protein and DNA and is active against a broad spectrum of bacteria and fungi. In order for iodophors to have significant bactericidal activity, two minutes of contact time are required to allow for release of free iodine that is ultimately responsible for the actual antimicrobial activity. Organic compounds such as blood can inhibit the antimicrobial effects of iodophors. Adverse reactions to povidone-iodine include contact dermatitis and impaired wound healing secondary to its cytotoxic effects on fibroblasts and keratinocytes (the predominant cell type in the epidermis).

Chlorhexidine gluconate

Chlorhexidine gluconate acts to disrupt cytoplasmic membranes and is active against a broad spectrum of gram-positive and gram-negative bacteria (including certain strains of *Staphylococcus aureus*), yeasts, and molds. Chlorhexidine is rapid acting and has superior bactericidal effects that extend several hours beyond its initial application. In addition, its actions are not inhibited by the presence of organic compounds at the site of application. However, skin irritation and erythema have been documented with chlorhexidine-based products (Figure 3.5).

Povidone-iodine and chlorhexidine-based products may both be combined with isopropyl alcohol. Isopropyl alcohol is an effective bactericidal agent that disorganizes cell membrane lipids and denatures cellular proteins.

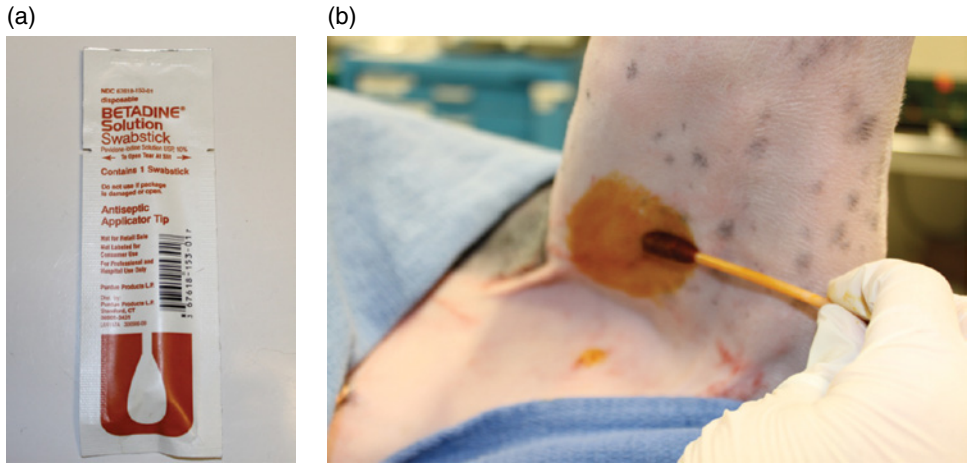

Figure 3.3 (a) Betadine solution 10% swabstick (povidone iodine). This product can be used for final skin preparation following use of an antiseptic microbicidal cleanser (i.e. betadine surgical scrub containing povidone iodine and detergent). (b) Skin final preparation using a betadine solution.

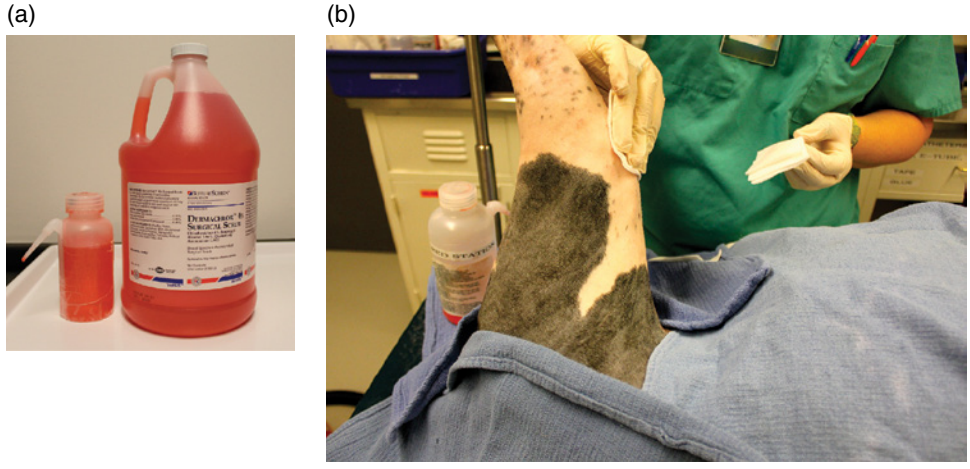

Figure 3.4 (a) An example of chlorhexidine surgical scrub combined with isopropyl alcohol. (b) Skin being prepared with chlorhexidine surgical scrub.

Antiseptic effects

Several investigations have compared the antiseptic effects of chlorhexidine and povidone iodine under different conditions. Use of alcoholic chlorhexidine for cutaneous antisepsis prior to epidural catheter insertion in children reduced the risk of catheter colonization when compared with the use of aqueous povidone iodine (Kinirons et al. 2001). Krobbuaban et al. (2011) investigated the efficacy of alcohol-based chlorhexidine and povidone-iodine solutions for all regional anesthetic techniques in 100 patients undergoing neuraxial blockade. They found that the use of chlorhexidine decreased the incidence of insertion-site-colonization. Darouiche et al. (2010) conducted a prospective study to investigate the incidence of surgical site infections in patients randomly assigned to undergo skin preparation

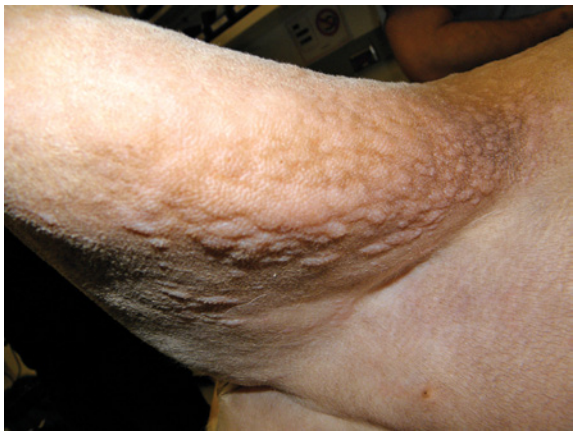

Figure 3.5 Skin reaction to a cleansing solution in a dog following surgical skin preparation prior to stifle surgery. Image by M.S. Hirshenson.

with either chlorhexidine-alcohol or povidone-iodine. In that study, chlorhexidine-alcohol appeared to be superior to povidone-iodine for prevention of surgical-site infections following clean-contaminated surgery.

Complications

The United States Food and Drug Administration (FDA) has not yet approved chlorhexidine gluconate for use before lumbar neuraxial puncture because of the absence of clinical safety evidence. Recently, Sviggum et al. (2012) investigated the incidence of neurologic complications associated with spinal anesthesia after chlorhexidine was used for skin preparation. In their study, the incidence of neurologic complications associated with spinal anesthesia following use of chlorhexidine gluconate was no different, supporting their hypothesis that chlorhexidine gluconate can be used for skin antisepsis before spinal needle placement without increasing the risk of neurologic complications beyond that attributed to the spinal anesthetic itself.

Chlorhexidine-based products appear to be the agents of choice for surgical skin preparation due to their superior antimicrobial profiles when compared with iodophor solutions, resulting in reductions in skin bacterial levels and surgical site infection rates. For this reason, they are very commonly used for skin preparation prior to a variety of procedures in veterinary patients.

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4 Clinical Pharmacology and Toxicology of Local Anesthetics and Adjuncts

Manuel Martin-Flores

Local anesthetics interrupt the generation and propagation of action potentials in neural tissue, resulting in transient loss of sensory, motor, and autonomic functions. This conduction blockade is limited to the area in proximity to the administration of the drug, and is completely reversed once the agent is removed from the site of action.

Physicochemical properties of local anesthetics

A number of agents are commonly used for regional anesthesia techniques, and although they differ in terms of potency, duration of action, risk for toxicity, and chemical structure, they all share the same mechanism of action: Na^+ channel blockade (Table 4.1).

Chemical structure and classification of local anesthetics

A variety of criteria have been used to classify local anesthetic agents, including chemical structure (as esters or amides), onset of action (fast vs. slow acting), and duration of action (short vs. long lasting).

All local anesthetics share a common chemical structure. A lipophilic unit is linked to a hydrophilic unit by an intermediate hydrocarbon chain that contains either an ester or an amide group. The lipophilic group is typically an unsaturated ring (such as a benzene) and gives local anesthetic molecules the ability to cross nerve cell membranes after they are deposited outside the cells. The intermediate chain (either an ester or an amide group) affects the synthesis and metabolism of the drug. It is the make-up of the intermediate chain that serves as the primary basis for local anesthetic classification.

- Ester local anesthetics (aminoesters) are hydrolyzed by the cholinesterase enzyme in the plasma and liver, with cocaine being the exception (cocaine undergoes significant liver metabolism) (Figure 4.1).
- Amide local anesthetics (aminoamides) undergo hepatic metabolism by microsomal enzymes. Compared with ester-linked anesthetics, the metabolism of amide-linked drugs involves more steps and takes longer. As a result, toxicity

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Table 4.1 Physicochemical properties of the commonly used local anesthetics.

	pKa	Ionization (%) (at pH 7.4)	Partition coefficient (lipid solubility)	Protein binding (%)	Relative potency
Esters					
Procaine	8.9	97	100	6	1
Chlorprocaine	8.7	95	810	–	4
Tetracaine	8.5	93	5822	94	16
Amides					
Lidocaine	7.9	76	366	64	4
Mepivacaine	7.6	61	130	77	2
Bupivacaine	8.1	83	3420	95	8–16
Levobupivacaine	8.1	83	3420	97	8–16
Ropivacaine	8.1	83	775	94	–

Adapted from (Hadzic and Vloka 2004).

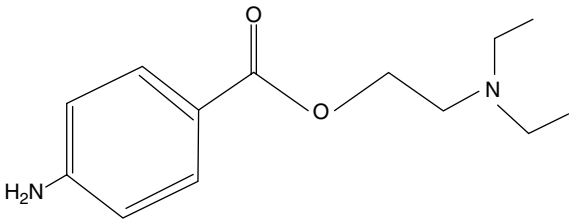

Figure 4.1 Chemical structure of procaine, an ester local anesthetic.

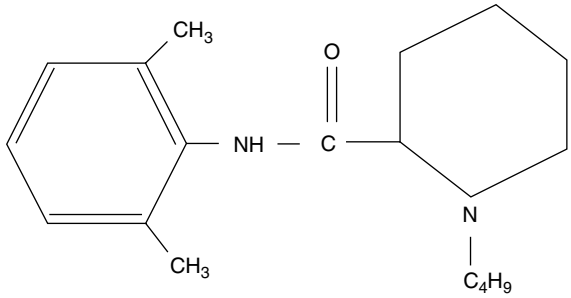

Figure 4.2 Chemical structure of bupivacaine, an amide local anesthetic.

resulting from accumulation of the drug and elevation in plasma levels is more likely to occur when amide agents are used (Figure 4.2).

The amino group is commonly a tertiary amine (NH_2-R) and determines the degree of water solubility for the local anesthetic. This characteristic allows for molecular dissociation and combination with sodium channels.

Properties

The chemical structures of local anesthetics determine their pharmacological effects (Table 4.2).

Lipid solubility

There is a positive correlation between the lipophilicity of local anesthetics and their potency. Potency relates to the amount of drug that is needed to induce a pharmacological effect. In general, potency and lipophilicity increase as the total number of carbon atoms in the intermediate chain increases. Although lipid solubility facilitates penetration through nerve membranes, it also promotes sequestration into lipid-soluble compartments, such as myelin (Gissen et al. 1982). As a result, lipid-soluble local anesthetics are slowly released from the lipid-soluble compartments to which they are bound. Therefore, lipid solubility not only determines the potency of a drug, but it also contributes to the slower onset and longer duration of action of these drugs.

Protein binding

Local anesthetic agents that are more lipid soluble also show a higher degree of protein binding. As is the case with many drugs, only the "free" (unbound) fraction is available to have a clinical effect. Elimination of agents that have high affinity for proteins is slower than for those with low affinity. The degree of protein binding (mainly to

Table 4.2 Onset and duration of action of the commonly used local anesthetics.

	Clinical use	Onset	Duration (hours)
Esters			
Procaine	Spinal (10%)	Fast	0.5–1
Chlorprocaine	PNB (2%)	Fast	0.5–1
	Epidural (2%)	Fast	0.5–1
Tetracaine	Topical (2%)	Fast	0.5–1
	Spinal (0.5%)	Fast	2–6
Amides			
Lidocaine	PNB (1–1.5%)	Fast	1–3
	Epidural (1.5–2%)	Fast	1–2
	Spinal (1.5–2%)	Fast	0.5–1
Mepivacaine	PNB (1–1.5%)	Fast	2–4
	Epidural (1.5–2%)	Fast	1–3
	Spinal (2–4%)	Fast	1–2
Bupivacaine/Levobupivacaine	PNB (0.25–0.5%)	Slow	4–12
	Epidural (0.5–0.75%)	Moderate	2–5
	Spinal (0.5–0.75%)	Fast	1–4
Ropivacaine	PNB (0.5–1%)	Slow	5–8
	Epidural (0.5–1%)	Moderate	2–6

PNB, peripheral nerve block.

α-acid glycoprotein and albumin) by local anesthetics has no correlation with the degree of binding to the Na^+ channel. Furthermore, the interaction (binding and dissociation) of local anesthetics with the Na^+ channel is short lived (seconds), regardless of the degree of protein binding of the agent (Ulbricht 1981).

pKa

pKa (also called the dissociation constant) is the pH at which 50% of a drug is present in its ionized (charged) form and 50% is in its unionized (neutral) form. The ability of a molecule to cross a cell membrane depends on both the degree of its lipid solubility and the molecular weight of the drug. As unionized molecules are more lipid soluble, they are the ones that will have the ability to cross nerve cell membranes. However, once inside the cell, it is the ionized local anesthetic molecule that binds to the sodium channel to elicit the clinical effect.

Local anesthetics have pKa values that typically range between 8 and 9 (Hadzic and Vloka 2004) (Table 4.1). As such, local anesthetics are weak bases, with two forms co-existing at equilibrium; an ionized (charged) form, and an unionized (neutral) form. If the pH of the local tissue environment approximates the pKa of the agent, more of the drug will be in the unionized form and the onset of action will therefore be faster. The opposite scenario is also true—an acidic environment will cause weak bases such as local anesthetics to be primarily in their ionized forms, unable to cross lipid membranes, thus slowing their onset of action. It should be noted, however, that onset does not depend solely on pKa—ease of diffusion through connective tissue also affects the clinical onset of local anesthetics.

Mode of action

Membrane potential

Like many other cells in the body, a neuron's resting membrane potential is negative as a result of the disequilibrium of charged ions across its cell membrane. A membrane protein, the Na^+-K^+-ATPase pump, moves K^+ into the cell and Na^+ out of the cell in an active process that consumes energy (Butterworth and Strichartz 1990). An intracellular-to-extracellular gradient is formed, with approximately 30 times more K^+ inside the cell and 10 times more Na^+ outside the cell. However, due to the selective permeability of the

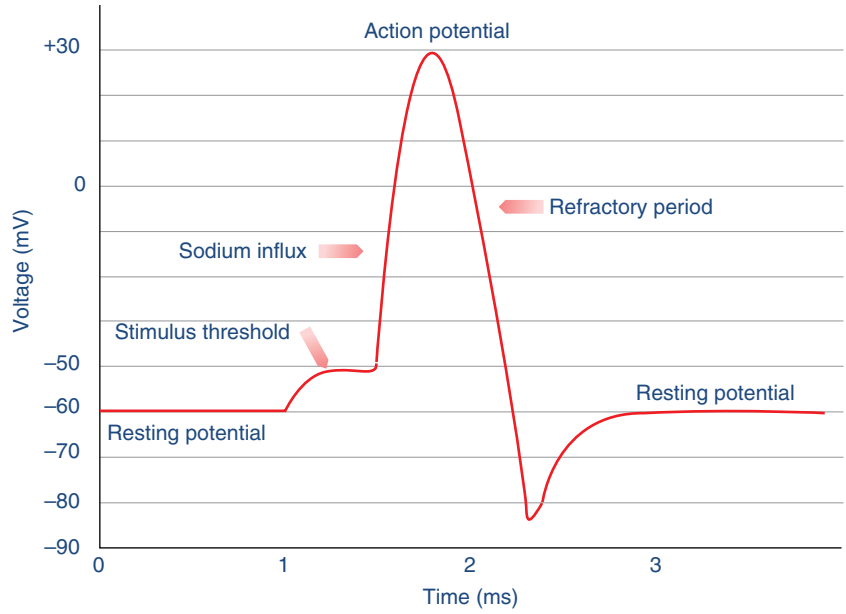

Figure 4.3 When the change in voltage is large enough (at least 15 mV) to open the Na^+ channels on the axon at –60mV, an action potential is produced. When the Na^+ channels open, Na^+ rushes INTO the cell. At the same time, K^+ rushes OUT of the cell. After the action potential is generated, the ions are pumped back to their original concentrations and the resting potential of the membrane is restored.

membrane, K^+ "leaks" out of the cell along its concentration gradient, leaving a net negative charge inside the cell. As a result, the intracellular space is negative relative to the extracellular space, with the resting membrane potential being approximately –60 to –70 mV.

Activation of voltage-gated Na^+ channels is necessary for the generation of an action potential (Figure 4.3). Mechanical, chemical, or electrical stimuli can cause changes in the membrane potential. Resting Na^+ channels become activated when the membrane potential increases above –55 mV (referred to as the cell's "threshold potential"). An influx of Na^+ ions through these channels results in further depolarization of the cell membrane and even more voltage-gated Na^+ channels become activated through this positive feedback loop. Activation of voltage-gated Na^+ channels is very short lived, after only a few milliseconds these channels again become inactive. The process of inactivation is also triggered by the depolarization. After a slight delay, K^+ channels also become activated, leading to an efflux of K^+ ions, which restores the resting membrane potential of the cell. During the process of repolarization, Na^+ and K^+ channels are reset to their resting state.

Voltage-gated Na^+ channels advance through three different states during the cycle. During the resting state, these channels are closed but can be activated. When membrane depolarization activates these channels, they undergo a conformational change and "open" to allow ion flow across the cell membrane. Almost immediately after they are activated, voltage-gated Na^+ channels become inactive; that is, they close and cannot be activated again until they revert to their resting state. This period of time is referred to as the "refractory period" of the cell. Voltage-gated Na^+ channels are either fully opened or fully closed, with no intermediate conductance level (Butterworth and Strichartz 1990; Wann 1993). After an action potential is successfully generated, adjacent Na^+ channels respond in similar fashion and the impulse is propagated along the nerve cell membrane.

Local anesthetics bind to sodium channels that are in their resting/inactive state. When they bind to the channel, they prevent activation and, as a

result, the large sodium influx associated with membrane depolarization is prevented. Because of this effect, the threshold level of the cell is never attained and the action potential is not propagated. As a result, transmission of the nociceptive impulse is prevented, and no pain is experienced by the patient.

Selective block

The characteristics of nerve fiber size and the presence or absence of myelin have been shown to correlate with conduction velocity and function. Most peripheral nerves that transmit information to the central nervous system are composed of a combination of myelinated and non-myelinated cells. These nerve cells can be classified into three groups depending on their diameter and conduction velocity.

- Group A are large, myelinated, somatic fibers that are responsible for transmitting information about touch and pressure (obtained from mechanoreceptors), as well as modulating muscle tone and motor/reflex activity. Specifically, Aδ fibers transmit information about nociception (pain) and temperature.
- Group B are small, myelinated, autonomic fibers that are involved in modulating autonomic functions such as altering smooth muscle tone in the vascular system.
- Group C are small, non-myelinated, fibers that carry information about temperature and pain. Whereas Aδ fibers (above) carry information at a high velocity (fast, sharp, "first" pain), C fibers do so more slowly (slow, dull, "second" pain).

In 1929, Gasser and Erlanger first described the ability of a local anesthetic agent to block some nerve fibers while sparing others, what is now referred to as "differential" or "selective" blockade of nerve fibers. They documented that cocaine induced a reduction in action potential amplitude more rapidly in smaller, myelinated fibers than in larger ones. This evidence has been confirmed many times, and it is now widely accepted that small myelinated fibers (Aδ) are more susceptible to local anesthetic blockade than larger, myelinated fibers (Aα and Aβ) (Matthews and Rushworth 1957; Franz and Perry 1974; Ford et al. 1984; Gokin et al. 2001). This "size principle" is not, however, without exceptions: small myelinated B fibers have been shown to be less susceptible to blockade than larger Aβ fibers (Heavner and de Jong 1974). In addition, C fibers, which lack myelin but are of a smaller diameter than A and B fibers, appear to be either as susceptible or less susceptible than the myelinated but larger A fibers (Rosenberg and Heinonen 1983; Fink and Cairns 1984; Gokin et al. 2001).

The ability of different agents to produce differential block varies and is not based entirely on the "size principle." However, experience

Table 4.3 Summary of nerve fiber characteristics and functions.

Fiber	Diameter (μm)	Myelin	Conduction velocity (ms^{-1})	Innervation	Function	Nerve block onset
Aα	6–20	+++	75–120	Afferent: Spindle proprioceptors Efferent: skeletal muscle	Motor and reflex functions	+
Aβ	5–12	+++	30–75	Afferent: cutaneous mechanoceptors	Touch and pressure	++
Aγ	3–6	++	12–35	Efferent: muscle spindle	Muscle tone	+++
Aδ	1–5	++	5–30	Afferent: pain and temperature	Fast pain. Touch and temperature	++++
B	<3	+	3–15	Efferent: sympathetic	Autonomic	+++++
C	0.2–1.5	–	0.5–2	Afferent: pain and temperature	Slow pain, temperature	++++

and scientific observations provide evidence of differential blockade. Aδ and C fibers are commonly desensitized before Aα fibers. As a result, a preferential sensory block is possible with minimal motor block. Bupivacaine (0.125%), levobupivacaine (0.125%), and ropivacaine (0.25%) are commonly used in practice as they are more capable of producing selective blockade in pain fibers than other agents. However, this effect depends not only on the agent, but also on the dose that is administered as larger doses or higher concentrations will generally block all nerve fibers that are exposed to the drug.

Commonly used local anesthetics

Lidocaine

Lidocaine is one of the most frequently used local anesthetics and is considered to be the prototype of the aminoamide family of drugs. Lidocaine provides quick onset and an intermediate duration of action. It is commonly used for local anesthesia of peripheral nerves, neuraxial anesthesia, local infiltration, intravenous regional anesthesia (IVRA), and even for topical desensitization of mucosa or skin. For surgical anesthesia, concentrations of 1–2% are commonly used. In addition, lidocaine is used systemically as an intravenous agent for its analgesic, anti-inflammatory, and antiarrhythmic effects.

Mepivacaine

Mepivacaine is an amide-type of local anesthetic with an intermediate duration and clinical profile similar to that of lidocaine. Although the onset of mepivacaine is similar to lidocaine, its duration of action is longer. Mepivacaine is commonly used in concentrations ranging between 1% and 2% for peripheral nerve blocks, epidural anesthesia, and local infiltration.

Bupivacaine

Since its introduction into clinical practice in the early 1960s, bupivacaine has become one of the most commonly used local anesthetic agents. Bupivacaine has a relatively slow onset of action, but its anesthetic and analgesic effects extend for a significantly longer time than those of lidocaine or mepivacaine. However, it is significantly more cardiotoxic than other local anesthetic agents. Bupivacaine is frequently used for nerve blocks and neuraxial anesthesia in a wide range of concentrations (0.125–0.75%), allowing for the development of differential blockade (sensory without motor block).

Levobupivacaine

Levobupivacaine is a formulation that includes one of the two enantiomers of bupivacaine, and therefore its actions are similar to the standard racemic mixture. The main advantage to its use is a markedly reduced risk of cardiotoxicity when compared to use of standard bupivacaine. The onset and duration of levobupivacaine do not differ from those of bupivacaine.

Ropivacaine

Ropivacaine is a long-lasting amide-type of local anesthetic. Ropivacaine has lower potential for inducing cardiovascular and CNS toxicity. At low concentrations (0.25–0.5%), ropivacaine has a relatively slow onset similar to bupivacaine. At higher concentrations (0.75%), its onset may be as fast as that of mepivacaine. At concentrations above 0.5%, ropivacaine produces sensory blockade similar to that obtained with bupivacaine, but there is less chance of inducing motor blockade (Hadzic and Vloka 2004). As a result of these favorable characteristics, ropivacaine has gained wide acceptance and is frequently used for conduction and neuraxial anesthesia.

Mixtures of local anesthetic agents

Local anesthetics are commonly combined prior to use in order to maximize the desirable characteristics of individual drugs. As an example, lidocaine (for its quick onset) and bupivacaine (for its longer duration) are commonly mixed in equal parts. There are few data available regarding the safety, efficacy, or potentially altered pharmacokinetics of

mixing local anesthetics. The onset of a mixture of agents may be unpredictable as the resulting pKa of the mixture is unknown. In addition, a 50:50 mixture (i.e. lidocaine 2% and bupivacaine 0.5%) will result in half-strength concentrations of both drugs (new concentrations of lidocaine 1% and bupivacaine 0.25%). It is possible that the lower concentrations of the fast-acting drug and long-lasting drug will result in a slightly slower onset and a shorter duration than either individual agent by itself. This was shown in a study where a mixture of equal parts of chloroprocaine 2% and bupivacaine 0.5% were administered to rats and produced anesthesia with characteristics similar to those of chloroprocaine (Galindo and Witcher 1980). In a study that investigated femoral and sciatic peripheral nerve blocks in people, bupivacaine 0.5%, ropivacaine 0.75%, and combinations of equal volumes of bupivacaine 0.5% and lidocaine 2%, or ropivacaine 0.75% and lidocaine 2% were compared (Cuvillon et al. 2009). Their results showed that when long-acting local anesthetics were mixed with lidocaine, the onset of the block was faster but there was a decreased duration of action.

Due to the lack of evidence showing a consistent advantage of mixing local anesthetics, a better approach is to select a single agent based on its desired predictable characteristics (such as onset time, duration of action, or potential for differential block) and to use it as appropriate to the patient and the procedure.

Adjuvants commonly used to enhance loco-regional anesthesia and analgesia

Adjunct agents are often combined with local anesthetics for techniques such as neuraxial anesthesia or peripheral nerve blockade. In the case of infiltration anesthesia, vasoconstrictors are frequently used. In most cases, these agents do not contribute to the anesthetic effects of the solution itself, with the possible exception of opioids.

Vasoconstrictors

Epinephrine has been administered in combination with local anesthetic agents for over a century. The addition of epinephrine ($5\,\mu g\,mL^{-1}$, 1:200 000) to a local anesthetic solution has several benefits:

- longer duration of blockade;
- increased intensity of blockade;
- reduced absorption of the anesthetic agent due to local vasoconstriction;
- decreased surgical bleeding following infiltrative local anesthesia.

It has been found that administration of epinephrine alone in the epidural space can cause segmental analgesia. The proposed mechanism is by interaction with α_2 receptors in the spinal cord (Curatolo et al. 1997). The increased intensity of blockade when epinephrine is added to a local anesthetic for epidural administration may be therefore be the result of a combination of mechanisms: local vasoconstriction causing reduced uptake of the primary local anesthetic agent into circulation, and a direct analgesic effect of the epinephrine mediated by these receptors.

The addition of a vasoconstrictor for peripheral nerve blocks may have potentially detrimental effects on the perfusion of the vasa nervorum and may have potential for ischemic nerve injury, especially when the integrity of the nerve or its circulation has been compromised. Selander et al. (1979) found that when bupivacaine with epinephrine was administered to intact rabbit nerves, it caused no damage. However, the addition of epinephrine worsened injury following intraneural injection or destruction of the nerve/blood barrier. More recently, Neal (2003) reviewed the existing literature and found that the potential for epinephrine to cause or potentiate nerve injury following peripheral block is exceedingly low in normal patients, where lower-than-normal peripheral nerve blood flow is apparently well tolerated.

In people, combinations of local anesthetics with epinephrine are often used as "test doses" during epidural anesthesia, especially when epidural catheters are used. In this situation, a small volume of the drug combination is administered into the epidural needle or catheter, and any changes in heart rate are monitored. An immediate increase in heart rate suggests that the tip of the catheter may have been inadvertently placed in an intravascular location.

As epinephrine can affect hemodynamics, it is logical to assume that potential toxic effects from epinephrine will be seen if large doses are accidentally administered intravenously. Toxic effects from

epinephrine have also been documented in the spinal cord and peripheral nerves (Neal 2003).

Sodium bicarbonate

Although local anesthetic agents are weak bases, commercial preparations have pH values ranging between 3.9 and 6.7. As the pKa of most local anesthetics is close to 8, when they are removed from the bottle, only a small fraction (~3%) of the drugs exist in their non-ionized, lipid-soluble form. As mentioned previously, it is the lipid-soluble form of the drug that has the ability to cross the nerve cell membrane in order to reach the cytoplasm and the sodium channel on the inside of the cell membrane. In addition, acidic solutions are more painful on injection, an important consideration in awake or lightly sedated patients. For this reason, some anesthetists will alkalinize their local anesthetic solution by mixing it with sodium bicarbonate in order to increase the pH of the solution and increase the fraction of the agent in its non-ionized, lipid-soluble form. Unfortunately, local anesthetic agents cannot be alkalinized to pH values greater than 6–8 otherwise precipitation of the resulting solution will occur. At this level of alkalinization, there is only a modest increase (approximately 10%) in the fraction of the lipid-soluble form of the drug (Ikuta et al. 1989; Peterfreund et al. 1989; Milner et al. 2000). In one study in people, an alkalinized solution (pH 6.4) of 0.5% bupivacaine with epinephrine was compared to a regular solution of the drug (pH 3.9) for performance of brachial plexus blockade (Hilgier 1985). A more rapid onset of action and a prolonged duration of sensory effect was reported. Recently, Hanna et al. (2009) reported the results of a meta-analysis showing that the use of a buffered solution of local anesthetics in people is associated with decreased pain on injection of the solution when compared to unbuffered solutions.

α_2 Adrenoceptor agonists

α_2 Agonist agents are commonly used to enhance the analgesia offered through both epidural anesthesia and peripheral nerve blocks. Clonidine and dexmedetomidine produce analgesia through supraspinal and spinal mechanisms (via adrenergic receptors) and have inhibitory effects on conduction of nerve impulses (Butterworth and Strichartz 1993; Eisenach et al. 1996). Dexmedetomidine enhances local anesthetic action via the α_2 A receptor (Yoshitomi et al. 2008). Brummett et al. (2011) found that the addition of dexmedetomidine prolonged the duration of ropivacaine by blocking the hyperpolarization-activated cation current.

Clinical benefits of the addition of dexmedetomidine to long-lasting amide-type local anesthetic agents have been shown. The addition of dexmedetomidine to ropivacaine administered to sciatic nerves in rats doubled the duration of the ropivacaine blockade (Brummett et al. 2009, 2010). In addition, when dexmedetomidine was added to levobupivacaine, prolonged duration and improved postoperative analgesia were observed (Esmaoglu et al. 2010). When α_2 agonists are administered into the epidural space, quality of anesthesia is improved. In children, the addition of dexmedetomidine to bupivacaine prolonged the analgesic duration from five to 16 hours, and from six to 18 hours in two separate studies (El-Hennawy et al. 2009; Saadawy et al. 2009). No urinary retention was observed, unlike that seen following epidural administration of opioids.

Opioids

The addition of opioids to local anesthetics for neuraxial anesthesia is widely practiced. Used in this way, opioids exert their analgesic actions through a variety of supraspinal and spinal mechanisms, including attenuation of C fiber-mediated nociception that is independent of its spinal actions (Niv et al. 1995). Morphine, fentanyl, and other opioids are commonly added to local anesthetics in order to enhance epidural analgesia. The addition of opioids results in improved analgesia without affecting motor blockade. Morphine is the most commonly used epidural opioid in veterinary medicine, and is used alone or in combination with local anesthetics. Numerous reports have documented the use of morphine as part of a solution administered epidurally in dogs (Hoelzler et al. 2005; Kona-Boun et al. 2006; Campoy et al. 2012). The addition of morphine to lidocaine for epidural anesthesia in dogs results in prolonged analgesia,

without changing the duration of motor blockade (Almeida et al. 2010). Documentation of the use of epidural fentanyl in dogs is scarce; however, this author routinely administers combinations of bupivacaine and fentanyl for epidural analgesia in dogs for a variety of procedures.

Administration of epidural morphine can result in urine retention. The incidence of urinary retention following epidural opioid administration in humans ranges between 30% and 60% (Liang et al. 2010; O'Neill et al. 2012). Campoy et al. (2012) reported that approximately half of their dogs developed urine retention following epidural morphine. In addition, a case report of urinary retention in a dog has been described (Herperger 1998). Other opioids such as tramadol and buprenorphine have been used with success via the epidural route in animals (Pypendop et al. 2008; Almeida et al. 2010).

Although opioids are primarily used for neuraxial block, some have also been used as adjuncts for peripheral nerve blockade. Buprenorphine has been used as an adjunct to local anesthetics for peripheral nerve block and may enhance the quality of the nerve block through a local anesthetic-like mechanism of action involving Na^+ channel block, a property that other μ agonists do not share (Leffler et al. 2012). Addition of buprenorphine to bupivacaine has been reported to enhance analgesia following sciatic nerve block in people (Candido et al. 2010). Its use in animals has not yet been reported.

Toxicity of local anesthetics

As with the other agents that are used during anesthesia, administration of local anesthetics is not without risk. Techniques used for the provision of regional anesthesia may impose risks that are inherent to the technique (i.e. causing damage to a nerve during performance of a peripheral nerve block), but they also carry risks as a result of the toxicity of the agents themselves. It is imperative that the anesthetist understands why these complications occur, how they manifest, and what to do if and when they happen.

As already discussed, local anesthetic agents exert their principal actions by interrupting the generation and propagation of action potentials through Na^+ blockade. Unfortunately, this effect is not limited to the target peripheral nerve tissues. Once a sufficient plasma concentration of the agent has been attained, this same mechanism of action is responsible for the systemic (whole-body) toxic effects of local anesthetics.

High plasma levels of local anesthetics can occur following administration of an overdose or by unintentional intravascular administration. In addition, unanticipated high plasma levels of local anesthetics can be attained if biotransformation and/or elimination of the drug are slower than usual, as may occur in individuals with hepatic or renal insufficiencies. In people, the clearance of lidocaine decreased from 10 to $6\,mL\,kg^{-1}\,min^{-1}$ in the presence of hepatic disease (Thomson et al. 1973). When the pharmacokinetic variables of lidocaine were calculated in dogs after partial hepatectomy and transplantation, the maximal plasma concentration and area under the curve increased by almost 100%, when compared with normal individuals (Perez-Guille et al. 2011). Decreased biotransformation of local anesthetics is potentially more problematic when amide local anesthetics are used for nerve blockade as they have longer and more involved metabolic pathways than do aminoesters. In addition to severe liver and renal disease, heart failure can compromise metabolism and excretion of local anesthetics and result in elevated plasma concentrations (Thomson et al. 1971).

Local anesthetic systemic toxicity typically manifests with central nervous system (CNS) and cardiovascular system (CVS) complications being the most relevant and commonly recognized (Table 4.4).

Table 4.4 Clinical signs of local anesthetic toxicity.

Nystagmus
Muscular twitching
Tonic-clonic convulsions
Tremors or seizures (increased levels of lactic acid and hypoxia may be observed after onset of seizures)
Generalized CNS depression (drowsiness, unconsciousness, coma)
Hypotension (depressed systolic function, vasodilation, bradycardia, other arrhythmias)
ECG changes: widening of the QRS complex, inversion, bradycardia, ventricular premature complexes, ventricular tachycardia, ventricular fibrillation
Death

Central nervous system toxicity

Toxic effects from local anesthetics can be observed in the CNS, the autonomic ganglia, and the neuromuscular junction. Central nervous system toxicity occurs after these lipid-soluble agents cross the blood brain barrier. With most local anesthetics, CNS signs generally manifest before CVS toxicity occurs. Local anesthetics can cause depression of cortical inhibitory pathways, thereby allowing unopposed activity of excitatory neuronal pathways. This transitional stage of unbalanced excitation (i.e. seizure activity) is typically followed by generalized CNS depression.

- All local anesthetics have the ability to produce sleepiness, light-headedness, visual and auditory disturbances, and restlessness when high plasma concentrations result from either rapid absorption or inadvertent intravascular administration of a high dose.
- Nystagmus and muscular twitching may occur, followed by tonic-clonic convulsions.
- Larger doses result in generalized CNS depression, including hypoventilation and respiratory arrest (Groban 2003).
- Increased levels of lactic acid and hypoxia may be observed after the onset of seizures.

There are exceptions, especially when there is an overdose of bupivacaine. With this particular drug, cardiac toxicity usually occurs concurrently with the "warning" signs that are typical of CNS intoxication, without the classic dose-dependent relationships seen with other drugs (Sage et al. 1985). Unlike lidocaine, bupivacaine can cause arrhythmias at the same doses that produce seizures, and even at subconvulsive doses (de Jong et al. 1982).

There have been several studies that have investigated the relative toxicity of local anesthetics in small animals (Feldman et al. 1989, 1991, 1996). When administered intravenously, lidocaine, bupivacaine, and ropivacaine can produce convulsions in dogs at $20\,mg\,kg^{-1}$, $4.3\,mg\,kg^{-1}$, and $4.9\,mg\,kg^{-1}$, respectively. When two times those doses were used, mortality resulted in 33%, 83%, and 17% of the dogs following lidocaine, bupivacaine, and ropivacaine. Plasma levels were reported to be $47\,\mu g\,mL^{-1}$, $18\,\mu g\,mL^{-1}$, and $11\,\mu g\,mL^{-1}$ for lidocaine, bupivacaine, and ropivacaine. Taken together, these data suggest that bupivacaine is the most dangerous local anesthetic in common use: the toxic dose of bupivacaine is lower than that of other drugs, the early warning signs of toxicity that are usually seen do not occur before cardiovascular collapse is induced, mortality rates are higher when there is an overdose, and mortality occurs with lower plasma concentrations of the drug. When bupivacaine is used, correct dosing must be ensured, and it should NEVER be used intravenously (i.e. for IVRA).

Cardiovascular system toxicity

With most local anesthetics (not bupivacaine), larger doses of local anesthetics are required to produce signs of cardiovascular system (CVS) toxicity than to produce signs of CNS toxicity.

Cardiovascular signs are characterized by depression of myocardial automaticity and a reduction in the duration of the refractory period. Therefore, both myocardial contractility and conduction velocity of impulses through the heart would be expected to be depressed. Coyle et al. (1994) reported the electrocardiographic (ECG) and echocardiographic effects of a bupivacaine overdose in dogs. They reported markedly impaired systolic function and severe right-sided dilation following a mean total intravenous bupivacaine dose of $14.0 \pm 3.3\,mg\,kg^{-1}$. ECG changes included widening of the QRS complex, inversion, bradycardia, ventricular premature complexes, or a combination of these. As the toxicity progressed, ventricular premature complexes, Wenckebach phenomenon, and ventricular tachycardia were also observed.

The cardiotoxic effects of local anesthetics differ from one agent to another. For example, an overdose of lidocaine will result in hypotension and bradycardia, whereas toxic doses of bupivacaine and ropivacaine produce sudden cardiovascular collapse or ventricular dysrhythmias that are resistant to treatment. For this reason, recent research into the cardiotoxicity of the different local anesthetics has focused on the more potent, lipid-soluble, and toxic agents such as bupivacaine, levobupivacaine, and ropivacaine (Table 4.5).

Table 4.5 Summary of the relative potencies for toxicity of the commonly used local anesthetic agents.

	Relative potency for CNS toxicity	CVS:CNS ratio for toxicity
Esters		
Procaine	0.3	3.7
Chlorprocaine	0.3	3.7
Tetracaine	2.0	–
Amides		
Lidocaine	1.0	7.1
Mepivacaine	1.4	7.1
Bupivacaine	4.0	2.0
Levobupivacaine	2.9	2.0
Ropivacaine	2.9	2.0

Arrhythmogenicity

Prolongation of cardiac conduction is seen in a dose-dependent fashion when local anesthetics are administered to animals. This is evidenced by increases in the PR interval as well as the QRS duration. Bradycardia and AV blocks result from the depression of SA and AV nodal function. Increasing doses of bupivacaine result in re-entrant arrhythmias such as ventricular tachycardia and fibrillation. When potent aminoamides are compared, the potential for toxicity is highest with bupivacaine, lowest with ropivacaine, and intermediate with levobupivacaine (Groban 2003).

Mechanical activity

Decreases in blood pressure and increases in left ventricular end-diastolic pressure reflect the myocardial depressant effects of local anesthetics. Bupivacaine and levobupivacaine cause decreased myocardial contractility at subconvulsive doses when they are administered to sheep (Huang et al. 1998). In that study, the frequency of arrhythmias was highest with bupivacaine. In a study with pentobarbital anesthetized dogs, both lidocaine 16 mg kg^{-1} and bupivacaine 4 mg kg^{-1} depressed hemodynamic function (Bruelle et al. 1996). The doses of lidocaine, bupivacaine, levobupivacaine, and ropivacaine that induced cardiovascular collapse in dogs were 127 mg kg^{-1}, 22 mg kg^{-1}, 27 mg kg^{-1}, and 42 mg kg^{-1}, respectively (Groban et al. 2001). The mortality rates at these doses were 0% for lidocaine, 10% for ropivacaine, 30% for levobupivacaine, and 50% for bupivacaine, despite cardiac massage and advanced life support (Groban et al. 2001).

Treatment of CNS and CVS toxicity

Treatment of local anesthetic systemic toxicities consists of supportive therapy and pharmacological treatment of the different clinical signs. More recently, specific agents have been developed that have the ability to chelate local anesthetics in plasma, reducing their circulating concentrations and minimizing their side effects.

Treatment for CNS toxicity

- Provide oxygen;
- intubate and ventilate if necessary with 100% O_2;
- seizure control:
  - benzodiazepines (diazepam 0.25–0.5 mg kg^{-1} IV);
  - propofol (increments of 1 mg kg^{-1} IV);
  - levetiracetam 20 mg kg^{-1} IV TID.

Treatment for CVS toxicity

- Intravenous fluids;
- vasopressors:
  - phenylephrine (bolus: 0.5–1 µg kg^{-1} IV, CRI: 0.2–3 µg kg^{-1} min^{-1} IV);
  - vasopressin (bolus: 0.003 ui kg^{-1}, CRI: 0.03 ui kg^{-1} h^{-1});
  - epinephrine (increments of 1 µg kg^{-1});
    - epinephrine is not recommended for treatment of bupivacaine toxicity. The use of epinephrine may be limited due to the high incidence of serious ventricular dysrhythmias and lack of effectiveness on cardiac index and cardiac relaxation. Amrinone may be used instead (Feldman et al. 1991; Groban et al. 2001);
- inotropes:
  - dobutamine (CRI 5–10 µg kg^{-1} min^{-1})
  - dopamine (CRI 5–10 µg kg^{-1} min^{-1})
- anticholinergics:
  - atropine (0.02–0.05 mg kg^{-1} IV);
  - glycopyrrolate (0.005–0.01 mg kg^{-1} IV).

If there is ventricular fibrillation or sustained ventricular tachycardia with severe hypotension (MAP <45 mmHg):

- cardiac massage;
- bretylium (5–20 mg kg^{-1} over 1–2 min);
- magnesium (0.3–0.6 mEq kg^{-1} IV over 5 min);
- defibrillation (0.5 J kg^{-1}) may be considered;
- "lipid rescue" (Intralipid®) 1 mg kg^{-1} IV, can be repeated every 5 min or administered as a CRI at 0.25 mL kg^{-1} min^{-1}.

Lipid rescue

Administration of a 20% intravenous lipid emulsion (Intralipid®) has been shown to decrease mortality from 100% to 0% in rats following bupivacaine toxicity (Weinberg et al. 1998). It is believed that a lipid emulsion creates a lipid plasma phase that extracts the lipid-soluble bupivacaine from the aqueous plasma phase, making it unavailable to tissues (Weinberg et al. 2003). Bupivacaine 10 mg kg^{-1} IV was used to induce cardiovascular collapse in dogs. Following 10 minutes of unsuccessful cardiac massage, a 20% lipid emulsion was administered (bolus of 4 mL kg^{-1} followed by 0.5 mL kg^{-1} min for 10 minutes). This treatment resulted in 100% survival in treated dogs, whereas administration of saline resulted in 100% mortality (Weinberg et al. 2003). Since their initial description in the literature, lipid emulsions have been the subject of multiple investigations and are now recommended for treatment of local anesthetic induced cardiovascular collapse (RCA guidelines, accessed at www.aagbi.org/sites/default/files/la_toxicity_2010_0.pdf).

Because propofol can be used to treat seizures and it is formulated in 10% lipid solution, many people assume that propofol can be used as a replacement for a 20% lipid emulsion. It should be noted that 2 mg kg^{-1} of propofol provides only 3% of the dose of lipid that would be administered based on the doses of Intralipid that were used in the aforementioned studies (Weinberg et al. 2003). Using propofol for this purpose is unlikely to have the desired effect.

Neural toxicity

Neurological deficits have been seen in humans following epidural and spinal anesthesia with chloroprocaine (Ravindran et al. 1980). It is not known whether those cases were the result of direct neural toxicity from the local anesthetic or from the preservatives that were present in the formulations used. Cauda equina syndrome has also been documented after repeated doses or infusions of epidurally administered lidocaine 5% (Schneider et al. 1993). It is speculated that this complication may have occurred due to pooling of the anesthetic around the cauda equina, with large concentrations causing direct neural damage.

Neurotoxicity in a rat spinal model has been shown for a variety of agents, including lidocaine, mepivacaine, and tetracaine (Takenami et al. 2000, 2005, 2009). In a recent investigation, ropivacaine proved to be less neurotoxic than levobupivacaine, procaine, and bupivacaine (Takenami et al. 2012). Although all of these agents showed varying degrees of histological changes (affecting mainly axons of the dorsal root entry zone), reports of neurological deficits following use of modern local anesthetic agents in clinical veterinary practice are extremely rare.

Other toxic effects of local anesthetics

Local anesthetic agents can be used by several routes, and some toxic effects may be related, at least in part, to their route of administration and close proximity to certain tissues. Lidocaine and bupivacaine are frequently used in veterinary medicine to provide analgesia at the site of surgical incision, whether by local infiltration of the surgical site or by intraperitoneal administration for abdominal surgery. The efficacy of these techniques is questionable; some reports indicate an analgesic effect, whereas others have failed to detect such an advantage. Furthermore, improved postoperative pain relief in people has been demonstrated for some surgeries but not for others (Moiniche et al. 1998, 1999; Ng et al. 2002). However, an analgesic effect from a combination of intraperitoneal and incisional local anesthetics has been shown in dogs (Carpenter et al. 2004). Whether the presence of local anesthetics on the incision could impair wound healing has also been the focus of research for decades. *In vitro* evidence has been found against the use of local anesthetics for incisional analgesia: proliferation and differentiation of mesenchymal stem cells, which are implicated in

wound healing, was impaired when exposed to increasing concentrations of lidocaine, bupivacaine, and ropivacaine (Lucchinetti et al. 2012). Early studies in rats demonstrated delayed healing five to seven days after lidocaine infiltration at the site of incision (Morris and Tracey 1977). Similar results were found when procaine was studied (Morris and Appbly 1980). Interestingly, infiltration with sterile water also caused delayed healing at five days when compared with rats not been infiltrated. When lidocaine and bupivacaine infiltration was evaluated in rabbits, no differences were found between treated animals and those that were infiltrated with saline (Vasseur et al. 1984). When studied in guinea pigs, infiltration with 1% lidocaine caused histopathological changes; however, no differences were seen when breaking strength was evaluated (Drucker et al. 1998). In a recent study, no differences in wound healing were found between lidocaine, bupivacaine, and saline when tested in rats (Waite et al. 2010).

There is some controversy regarding the use of intra-articular administration of local anesthetics in people. Although there are investigations that favor this route of administration because of improved analgesia following surgery, there is concern about potential toxic effects, especially in specific joints such as the shoulder. Intra-articular bupivacaine and ropivacaine has been shown to improve patient comfort and functionality after a variety of surgical procedures in both people and dogs (Sammarco et al. 1996; Hoelzler et al. 2005; Gomez-Cardero and Rodriguez-Merchan 2010; Dobrydnjov et al. 2011). Other investigators have found either weak evidence to support the use of intra-articular local anesthesia (Moiniche et al. 1999), or no advantages at all (Rosen et al. 2010). Several investigations have documented the potential for toxic effects of local anesthetics on chondrocytes and stem cells (Farkas et al. 2010; Haasters et al. 2011).

Hypersensitivity reactions

The incidence of serious anaphylactic and anaphylactoid reactions during anesthesia in people has been estimated to range between 1:3500 and 1:20 000. The majority of these reactions are attributed to the use of muscle relaxants (69%), latex (12%), and antibiotics (8%) (Hepner and Castells 2003). Local anesthetic agents were implicated in less than 3% of the reactions. Most commonly, the toxic effects that result from high plasma levels of a local anesthetic are misdiagnosed as being a hypersensitivity reaction. When hypersensitivity reactions do occur, they are often limited to causing minor clinical signs such as skin redness, edema of the skin, or injection of mucous membranes. It has been estimated that from all of the adverse reactions associated with the use of local anesthetics, allergic reactions represent less than 1% (Brown et al. 1981).

Aminoester local anesthetics are derivatives of paraminobenzoic acid (PABA). During metabolism, these drugs undergo hydrolysis and the PABA molecule is produced. For this reason, aminoesters are more likely to cause severe hypersensitivity reactions (Type I; IgE mediated) as a result of potential previous exposure of the patient to environmental products containing PABA, such as foodstuffs, creams, sulfonamide agents, and methylparaben (a preservative) (Finucane 2003). Type I reactions involve the release of large amounts of histamine, serotonin, and leukotrienes from mast cells, resulting in profound bronchospasm and vasodilatation, constituting a medical emergency.

Allergic reactions to aminoamide local anesthetic agents occur much less frequently, although reports of these do exist (Brown et al. 1981). In people, the most common type of hypersensitivity to local anesthetics is a type IV reaction. Type IV reactions commonly have a slower onset and are associated with histamine release that is not mediated by immunoglobulin. The severity of these reactions can range from a mild contact dermatitis to anaphylactoid shock.

The treatment of allergic reactions to local anesthetics is no different from that of any other type of allergic reaction and involves:

- oxygen administration;
- securing the airway;
- removal of the agent where possible;
- administration of epinephrine;
- administration of bronchodilators (i.e. albuterol);
- administration of H_1 (i.e. diphenhydramine) and H_2 (i.e. famotidine) blocking agents; and
- administration of corticosteroids.

There is no known cross-sensitivity between amide and ester local anesthetics; a patient who is known to be hypersensitive to an aminoester

can safely receive an aminoamide agent (and vice versa) as long as the alternative drug is preservative-free.

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Part 2

Equipment

5 Equipment for Loco-regional Anesthesia and Analgesia

Matt R. Read

Needles

There are many different types of needles and catheters available to veterinarians who plan to perform local or regional anesthesia in their practices. Each type has its own inherent advantages and disadvantages; however, certain characteristics have been shown to improve utility and potentially impact patient safety. Needles are generally selected based on tip design, length, gauge, absence or presence of insulation, and clinician preference depending on the size of the patient and the planned block.

Unless otherwise stated by the manufacturer, all needles used for local and regional anesthesia are designed for single use. Damaged or bent needles should be immediately discarded as further use can result in breakage, injury to the patient, or accidental needle-stick injury to personnel. No attempt should be made to straighten or repair a damaged needle. The size and length preferences of needles described for the different techniques in this book are those of the authors and should be considered to be recommendations.

Needle tip design

The shape of a needle's tip can affect the ability to appreciate the different tissue planes encountered as the needle is advanced during performance of a block.

Even though veterinarians commonly use hypodermic needles for local anesthetic techniques such as local infiltration or injection over a readily palpable superficial nerve (i.e. dental blocks), they are not a good choice for performing deeper regional anesthetic blocks such as epidurals or brachial plexus blocks. Hypodermic needles are specifically designed for penetration into tissues with minimal resistance so they have a 15° bevel and sharp edges, and frequently do not allow the operator to "feel" the penetration of different tissue planes as the needle is advanced (Figure 5.1). For this reason, it is often difficult to appreciate where the tip of the needle is located when deeper blocks are being performed using long hypodermic needles. This potentially increases the risk of injury to the patient and negatively affects the ability to place the

Small Animal Regional Anesthesia and Analgesia, First Edition. Edited by Luis Campoy and Matt R. Read.

needle tip adjacent to the target nerves. Generally speaking, only small gauge (22–30-gauge) hypodermic needles should be used for performing superficial nerve blocks as they are less likely to cause nerve injury than larger gauge needles (14–20-gauge).

Several recent studies have investigated the effects of nerve perforation with different types of needles (Steinfeldt et al. 2010a, 2010b, 2011). This research involved perforation of brachial plexus nerves under direct visualization in anesthetized pigs, followed by recovery of the animals and resection of the nerves 48 hours later. They examined the nerves histologically and the degree of nerve injury was scored using a range of 0 (no injury) to 4 (severe injury). Their results showed that there are considerable post-traumatic inflammation and structural changes within the damaged nerves following perforation by pencil-point, short beveled, and Tuohy needles (Figure 5.2). There were no differences between the individual needle types.

Figure 5.1 The tip of an 18-gauge hypodermic needle bevel viewed at 25×. Hypodermic needles have a long bevel and sharp edge and are specifically designed for puncturing skin and adjacent tissues. Note the long bevel (15°) and sharp cutting edge of this needle.

The use of blunt, short bevel, or Tuohy needles is preferred when multiple tissue planes are going to be penetrated during performance of a regional anesthesia technique, and can potentially lessen the risk of lacerating important anatomical structures such as vessels and nerves. The blunt design of the needle tip influences the subjective "feel" of tissue layers as the needle is advanced, giving the anesthetist more tactile information about needle location in the patient. Because blunt needles provide more resistance during needle advancement, the anesthetist is more likely to feel a loss of resistance (as a tactile "pop") as certain tissue planes are penetrated (e.g. during performance of epidural anesthesia as the ligamentum flavum is penetrated). When used to perform regional anesthetic blocks, blunt (30°–45° atraumatic) needle tips (Figure 5.3) are less likely to

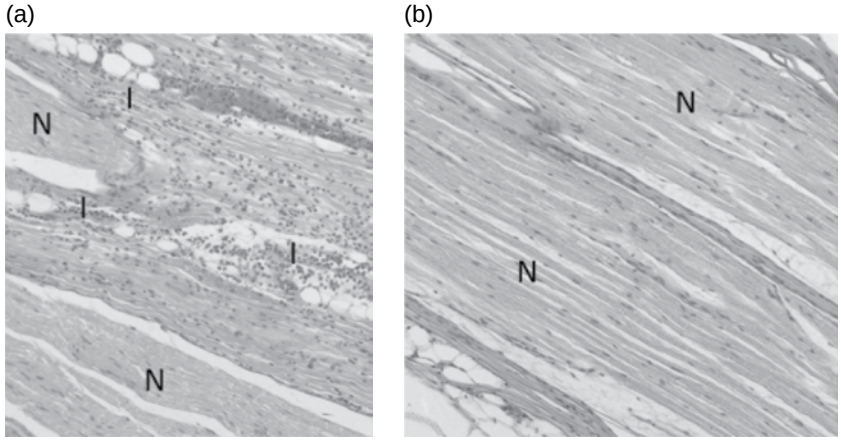


Figure 5.2 (a) Needle nerve perforation with a short beveled needle tip. Longitudinal microscopic view (200×, hematoxylin-eosin staining) of the musculocutaneous nerve. *N*, nerve fascicle; *I*, inflammatory cells. Score value 2.0. (b) No treatment control of the sciatic nerve. Longitudinal microscopic view (200×, hematoxylin-eosin staining) of the sciatic nerve, no treatment control. Score value 0.0. From Steinfeldt et al. 2010b. Used with permission.

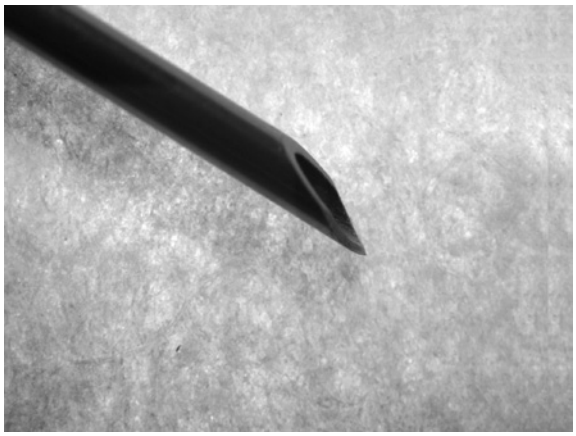


Figure 5.3 The tip of a 22-gauge insulated regional anesthesia needle bevel viewed at 25×. Note the short, blunt bevel (30°) of this needle compared with the needle tip in Figure 5.1.

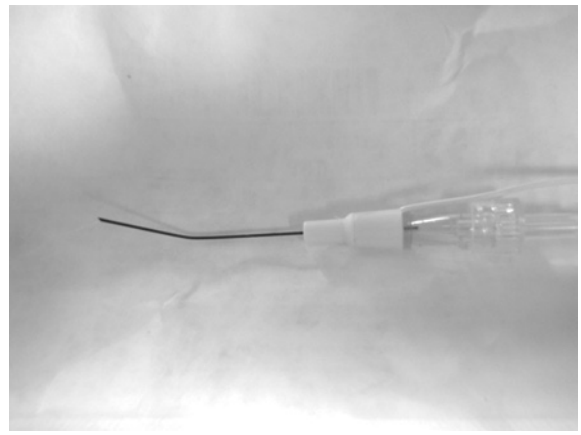


Figure 5.4 A 25-gauge insulated regional anesthesia needle that was bent during performance of a nerve block.

penetrate the perineurium, especially if the needle is advanced perpendicular to the long axis of the nerve. For these reasons, blunt needles are popular for use with single injection techniques as well as with methods that involve placement of indwelling perineural catheters.

Needle length and gauge

Desired needle length depends on the anticipated depth of the target nerves and the individual patient's characteristics. Although shorter needles are easier to manipulate during performance of the block, they may be too short to actually reach the targeted depth. Longer needles are more difficult to manipulate and to redirect once they are in the patient, especially if the needle is of a smaller gauge. It is also very easy to bend small gauge needles while they are being manipulated in the patient, necessitating their removal and initiating the block again with new equipment (Figure 5.4).

Excessive needle length may increase the risk of complications associated with the needle being inadvertently advanced too deeply. One case report documented the development of an epidural abscess and discospondylitis of the lumbosacral region following lumbar epidural anesthesia (Remedios et al. 1996). In that particular case, iatrogenic contamination of the epidural space and an intervertebral disk with colonic bacteria likely occurred during spinal needle placement. In that report, a 9 cm (3.5 inch) spinal needle was used to perform epidural anesthesia in a dog. The needle was thought to have been advanced through the lumbosacral disk space into the colon prior to being withdrawn. That case report serves to emphasize that, regardless of the type or length of the needle used, it is up to the anesthetist to be familiar with the relevant anatomy for the block, and to be cognizant of the risks and limitations associated with the particular regional anesthetic procedure.

Smaller gauge needles tend to cause less pain in awake patients and potentially carry less risk of tissue trauma, but they are more prone to bending than larger gauge needles. Small needles may also be more difficult to aspirate and inject through, making it more difficult for the anesthetist to appreciate resistance to injection and high injection pressures. Usually, small gauge needles (25-gauge, 27-gauge) are used for infiltration anesthesia and superficial blocks, whereas large gauge needles (22-gauge, 21-gauge, 19-gauge) are used for deeper blocks. Larger gauge needles are less prone to bending, and their larger size allows for easier aspiration and injection, better appreciation of resistance to injection, and the potential to pass an indwelling (perineural) catheter through the needle at the target location.

A recent study explored the effect of needle size on nerve injury in pigs (Steinfeldt et al. 2010a). Small (24-gauge) and large (19-gauge) pencil-point

needles were used to perforate the nerves of the brachial plexus in anesthetized pigs. The nerves were harvested 48 hours later and alterations in physical appearance and histological injury (detection of inflammatory cells, myelin damage, intraneural hematoma) were evaluated. Overall, the injury scores were significantly lower in the small diameter needle group (24-gauge). Myelin damage and intraneural hematoma occurred predominantly in the large-diameter needle group (19-gauge). Histological signs of inflammation were similar between groups. The severity of gross nerve injury after needle nerve perforation was related to the diameter of the needle, but inflammation was not. The authors emphasized that the functional consequences of these findings remain to be determined in actual patients. They concluded that when given the choice, and until more information is available, smaller gauge needles are advisable for peripheral nerve blocks to minimize the risk of nerve injury in the case of inadvertent nerve perforation.

The needle sizes and lengths presented in this textbook represent the preferences of the individual authors, and should be regarded as guidelines only. The choice of needle often comes down to the personal preference of the anesthetists based on their own experiences and the availability of equipment.

Specialized regional anesthesia needles

Spinal needles

Spinal needles with varying lengths (1.5, 2.5, 3.5 inch; 3.8, 6.35, 8.9 cm) and diameters (22-gauge, 20-gauge) are readily available to veterinarians. Spinal needles are manufactured with close-fitting,

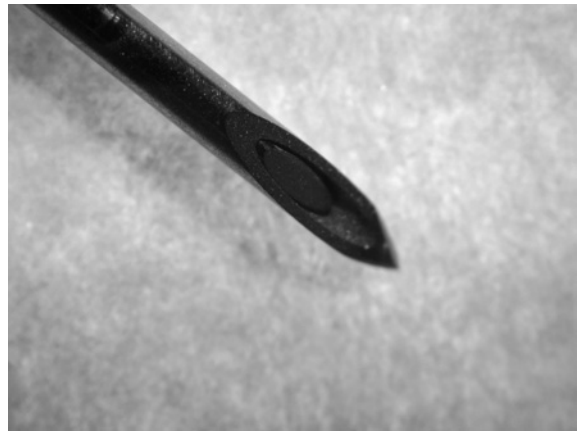


Figure 5.5 The tip of a 22-gauge spinal needle viewed at 25×. Note the close-fitting removable stylet that is positioned inside the needle to prevent tissue from entering the lumen of the needle as it is being advanced.

(a)

(b)

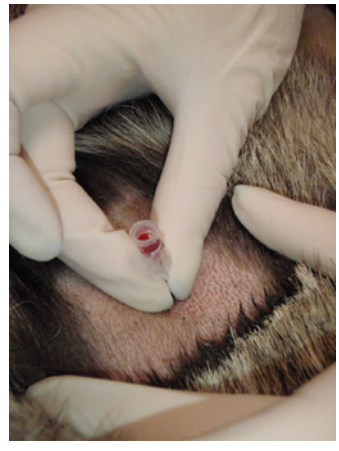


Figure 5.6 (a) A 20-gauge spinal needle is used to perform lumbosacral epidural anesthesia in a dog. The needle stylet has been removed and the clear needle hub allows the anesthetist to inspect the hub for the presence of blood or cerebrospinal fluid prior to drug administration. (b) A 20-gauge spinal needle in position for performance of lumbosacral epidural anesthesia in a dog. The stylet has been removed, and the clear needle hub allows the anesthetist to readily detect the presence of blood prior to drug administration. In this case, the tip of the spinal needle likely entered a venous sinus on the ventral aspect of the vertebral canal. No injection was made and the needle was withdrawn and replaced with a new needle.

removable stylets that prevent tissue or fluid from entering the needle as it are advanced during performance of a block (Figure 5.5).

Most spinal needles have short-blunt or medium-blunt tips that allow the anesthetist to more easily appreciate when different tissue planes are penetrated. Although they are more blunt than hypodermic needles, spinal needles still penetrate tissues easily, so for certain blocks Tuohy needles are preferred. Many spinal needles have clear needle hubs that allow the anesthetist to visually inspect the hub for the presence of blood or cerebrospinal fluid prior to drug administration (Figure 5.6).

Spinal needles used in veterinary medicine are usually of the Quincke cutting-type (Figure 5.7). They have a sharp cutting point that is useful for penetrating skin, adipose tissue, and intervertebral ligaments, while being blunt enough for the operator to appreciate the sequential penetration of different tissues as the needle is being advanced.

In people, "pencil-point" needles are commonly used for spinal and combined spinal/epidural procedures (Figure 5.8). There are several different types, including Sprotte ("rounder" end) and Whitacre (more "pointed" end) needles. Post-dural puncture headache is common in people following spinal anesthesia using Quincke-type needles. Pencil-point spinal needles were subsequently designed to prevent leakage of cerebrospinal fluid following dural puncture, as, unlike a Quincke-type tip, the pencil-point design does not leave a large hole in the dura once the needle is withdrawn. However, because of their "non-cutting" point geometry, these needles do not puncture skin as freely as do conventional Quincke needles. As pencil-point needles have a blunt tip, they need to be used together with an introducer or another needle that can easily penetrate skin and other tissues to minimize discomfort to awake patients. For this reason, Sprotte and Whitacre spinal needles are used in combined epidural/spinal kits in people. In this scenario, a Tuohy needle is used to enter the epidural space and a Sprotte or Whitacre needle is then used to puncture the dura and complete the block.

Sprotte-tip needles are also used for performing peripheral nerve blocks in people. They reduce tissue trauma during needle thrust, and can minimize potential for perineural hematomas. A recent study compared the degree of histological injury when brachial plexus nerves of anesthetized pigs were perforated with either short bevel or pencil-point needles under direct visualization (Steinfeldt et al. 2010b). That study found that the

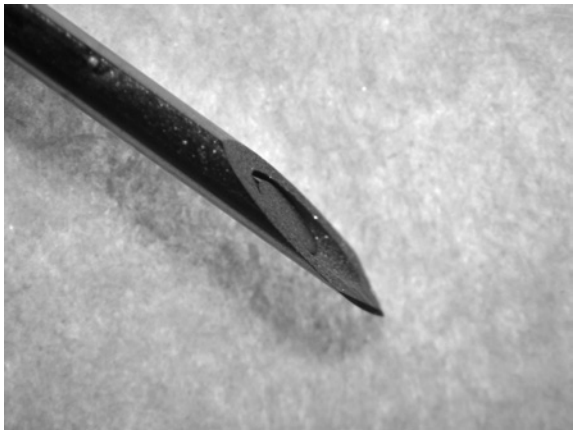


Figure 5.7 The tip of a Quincke-type 22-gauge spinal needle viewed at 25×. Note the presence of a stylet, as well as the sharp cutting point that is useful for penetrating skin, adipose tissue, and intervertebral ligaments during performance of an epidural block.

Figure 5.8 Close-up of the tip of a pencil-point (Sprotte) needle. Note that this needle also has ultrasound reflectors that are used to increase its visibility when used during an ultrasound-guided nerve block. Image used with permission of Pajunk GmbH.

magnitude of nerve injury following needle perforation was not related to the type of needle. The authors also found that post-traumatic inflammation rather than structural damage of nerves was the only detectable sign of nerve injury after needle perforation with either type of needle (Figure 5.2). They concluded that neither type of needle (pencil-point or short beveled) could be designated as being less traumatic in the case of needle nerve perforation. At this time, these specialized human spinal products are not commonly used in animals for epidural or peripheral nerve blocks.

Tuohy needles

Tuohy needles can be insulated or non-insulated, and are characterized by the presence of a curve at the distal tip of the needle (Figure 5.9).

Tuohy needles are commonly used to perform single injection techniques, or alternatively, are used to facilitate placement of indwelling epidural or perineural catheters. The curve at the distal tip of the needle helps to direct and "steer" the catheter in one particular direction along a peripheral nerve or into the epidural space (Figure 5.10).

Tuohy needles often have 1 cm gradation markings along their shafts to allow the anesthetist to estimate the insertion depth of the needle once it is placed in the patient (Figures 5.10 and 5.11). Better awareness of depth potentially reduces the risk of complications.

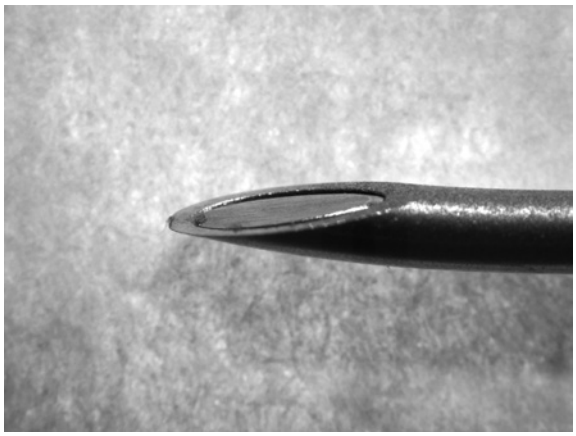


Figure 5.9 The tip of a 19-gauge Tuohy needle viewed at 25×. The edges of the needle are polished and rounded to prevent shearing of a catheter when it is advanced through the needle. Note the gentle curve at the distal tip of the needle that is used to "direct" a catheter into position.

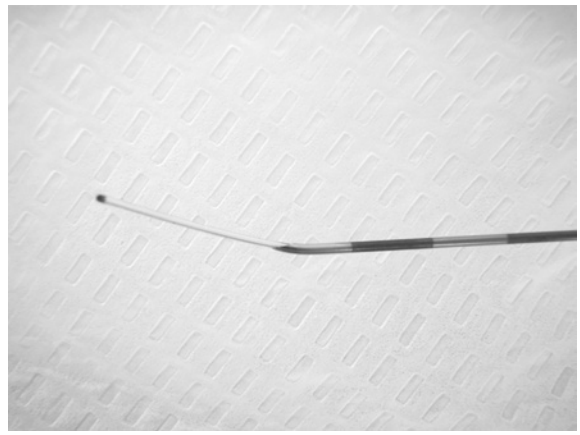


Figure 5.10 Demonstration of a Tuohy needle being used to advance an epidural catheter. Note how the end of the needle is curved and directs the catheter away from the long axis of the needle. This is useful when the catheter is being advanced into epidural or perineural spaces.

When used in conjunction with epidural or perineural catheters (see further discussion on catheters below), Tuohy needles should have polished and rounded inner bevels to minimize the risk of shearing as the catheter is being advanced into the patient. Tuohy needles are not as sharp as hypodermic or Quincke-type spinal needles, and as a result, the anesthetist receives more tactile feedback and is able to better appreciate the penetration of different tissue planes as the needle is being advanced.

Insulated

Tuohy needles have a pin-point electrode exposed at the leading edge of the atraumatic bevel. These needles are often used to aid with the placement of peripheral perineural catheters. Tuohy needles designed specifically for perineural catheter placement are typically manufactured with a pre-attached hemostasis valve assembly that allows for pre-mounting of the stimulating catheter before the needle is introduced into the patient. Once the target nerve is located using the stimulating needle, while the anesthetist holds the needle in position, an assistant can aspirate and/or

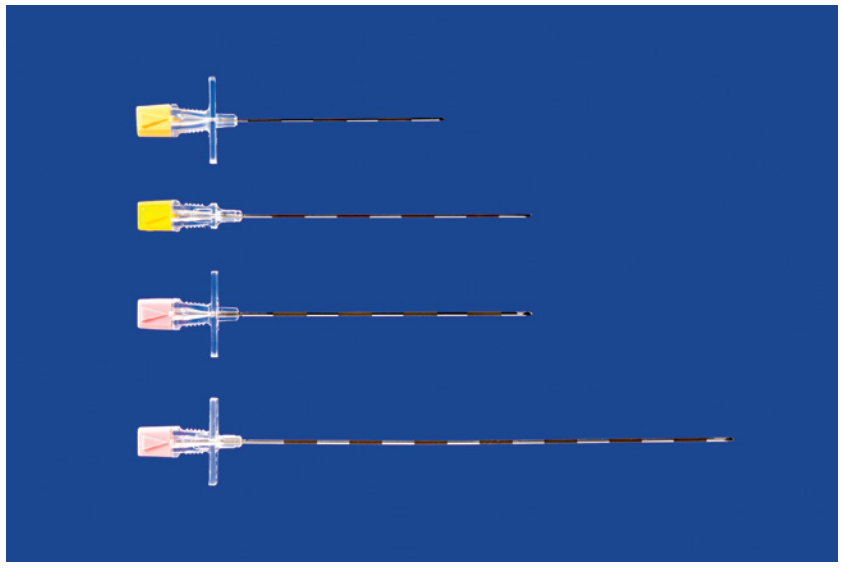


Figure 5.11 Gradations along spinal needles are used to indicate the depth of needle penetration when *in situ*. Image used with permission of MILA International Inc.

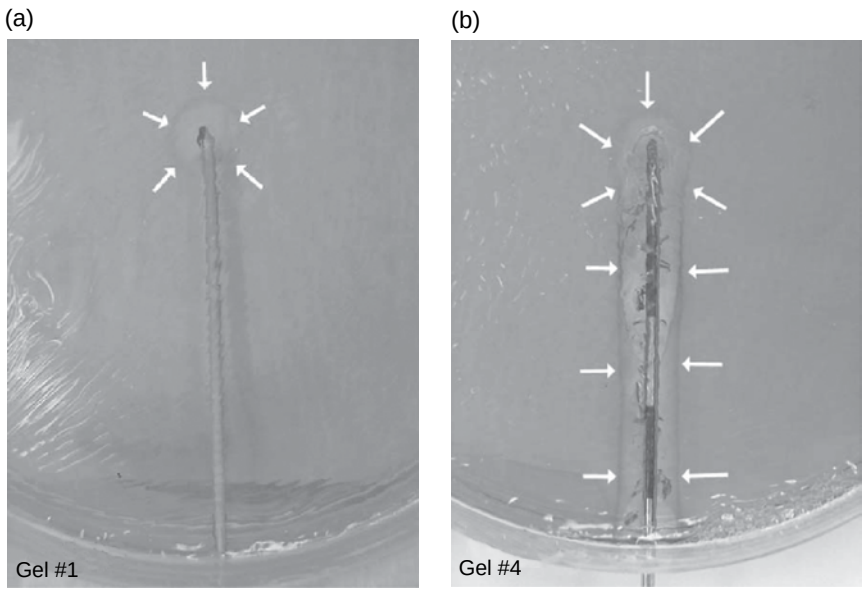


Figure 5.12 (a) and (b) Gel electrophoresis with insulated (Gel #1) and uninsulated (Gel #4) needles without any injectate present. Note the small conductive area in Gel #1 that would be used to stimulate a nerve compared to the large conductive zone along the entire uninsulated needle shaft in Gel #4. From Tsui et al. 2004. Used with permission.

inject the local anesthetic solution through pre-attached extension tubing that is connected to the valve assembly. As this arrangement allows the assistant to sterilely advance the catheter without first needing to disconnect the extension tubing or stimulating leads, there is almost no risk of moving the needle while it is in the patient.

Insulated needles

Uninsulated needles (e.g. hypodermic and spinal needles) are bare metallic needles. When connected to a peripheral nerve stimulator, the stimulating current is released along the entire length of the needle shaft (Figure 5.12).

As a result, uninsulated needles have a much larger conducting area and the current density at the extreme tip of the needle is much lower than when a comparably sized insulated needle is used. As current intensity is subsequently dispersed along a larger distance, a higher threshold current is required to stimulate a peripheral nerve when an uninsulated needle is used for a peripheral nerve block (Ford et al. 1984). More important, as current is released along the entire shaft of an uninsulated needle, if the tip of the

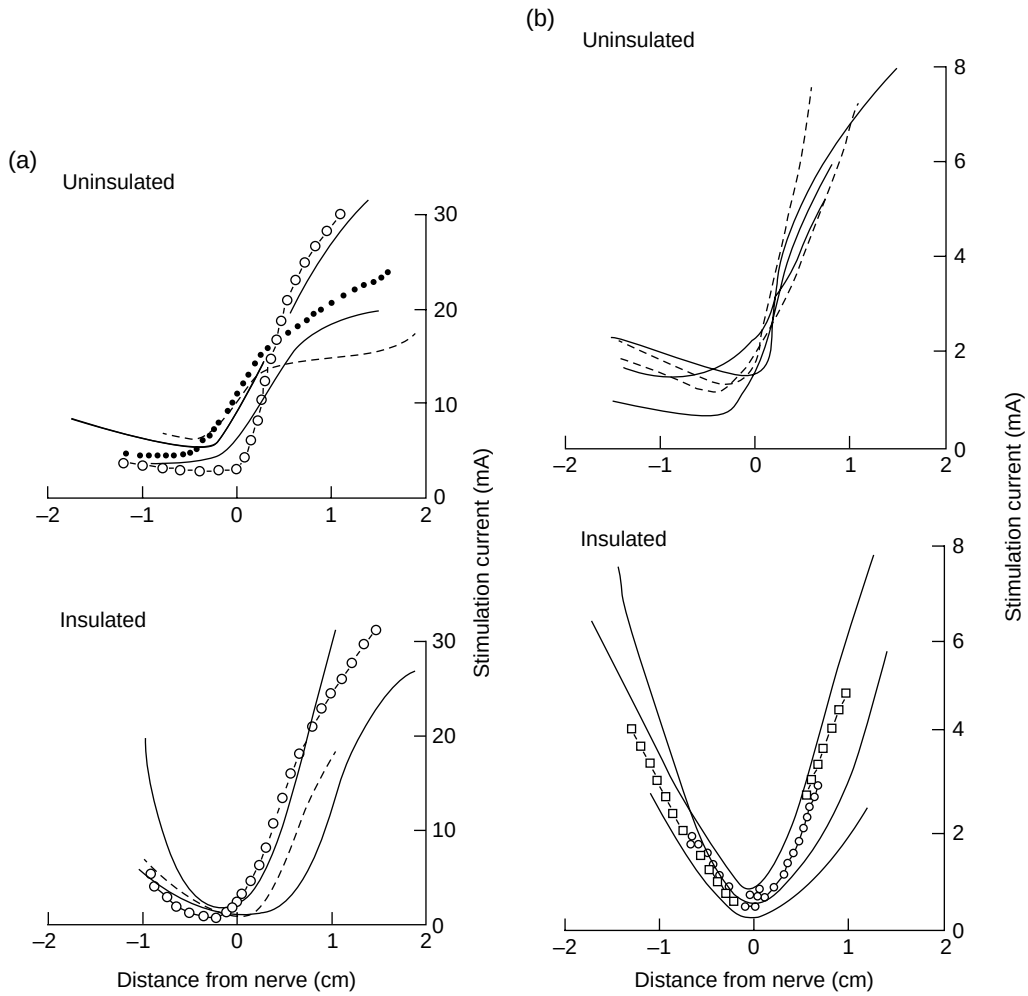


Figure 5.13 (a) The needle-to-sciatic nerve distance-stimulation current relationship for an uninsulated needle (top) and insulated needle (bottom). The lines are individual trials. The Y-axis is the current required to produce a small muscle twitch. The X-axis is the distance from the tip of the needle to the sciatic nerve. Negative values signify that the tip of the needle is past the nerve. (From Ford et al. 1984. Used with permission.) (b) The needle-to-saphenous nerve distance-stimulation current relationship for an uninsulated needle (top) and insulated needle (bottom). The lines are individual trials. The Y-axis is the current required to produce a small muscle twitch. The X-axis is the distance from the tip of the needle to the saphenous nerve. Negative values signify that the tip of the needle is past the nerve. From Ford et al. 1984. Used with permission.

needle passes the target nerve during needle advancement, it is still possible to stimulate the nerve if it is still in close proximity to the needle. One study that investigated the use of insulated versus uninsulated needles for performance of nerve blocks in cats showed that when uninsulated needles were used, the greatest degree of nerve stimulation occurred when the needle was 0.5–1 cm past the target nerves. Obviously, if a local anesthetic solution were injected through the needle at this location, it would be administered away from the nerve and result in a failed nerve block. For this reason, success rates are generally lower when uninsulated needles are used, as it is easy to inadvertently deliver local anesthetic drugs away from the target nerve while still getting motor responses to electrical stimulation (Figure 5.13).

Insulated needles are readily available to veterinarians. These special needles are coated with a thin layer of non-conducting material (most often Teflon) over the entire length of the needle, except for a small exposed area at the extreme needle tip. Some insulated needles are only coated on the outside of the needle shaft down to the level of the bevel, whereas others are coated on both the inside and outside of the needle shaft, except for a small point at the extreme tip of the needle. When connected to a peripheral nerve stimulator, the current is conducted down the shaft of the metal needle without being released into tissues and is therefore concentrated only at the needle tip. Current density is proportional to both the delivered current and the area of exposed needle. As the current is released only from the tip of an insulated needle, lower current intensities are required to stimulate the target nerves and it is less painful for the patient. Insulated needles have been shown to augment the accuracy of needle placement (Ford et al. 1984). When insulated needles are used for peripheral nerve blocks, low intensity currents (0.2–0.5 mA) can be used to successfully identify target nerves.

Insulated needles come in different configurations, including both 30° short bevels. Like Tuohy needles (as discussed above), they often have 1 cm laser-etched depth gradation markings along the shaft of the needle to allow for estimation of insertion depth once the needles are placed into the patient (Figure 5.14).

Better depth awareness reduces the risk of complications and helps to provide quick and accurate needle placement. Personal preference of puncture force and anticipated ease of passage through tissues dictates the specific choice of needle (gauge, needle tip, length) for different blocks.

Echogenic needles

With the growing use of ultrasound to guide needle placement during performance of loco-regional blocks in people, there have been many recent developments in needle design. An early goal was to increase the echogenicity of the needle to allow for easier visualization of the needle when it is *in situ*, allowing for accurate placement of the needle tip adjacent to the target nerve. Initially, different coatings were tested for their reflective properties but it was found that the surface material did not have a substantial effect on improving needle echogenicity. Needles with roughened tips were also investigated but this alteration affected the gliding properties of the needle and did not significantly improve needle visibility. The most successful alteration was the addition of "reflectors" to the needles. Several companies now produce needles and cannulae that have patterns embedded along the distal end of the needle shaft (Figures 5.8, 5.14, and 5.15).

These circumferential reflectors convey excellent visibility of the needle during ultrasound monitoring, as ultrasound waves are reflected off the needle regardless of its puncture angle and position relative to the ultrasound beam. Research is ongoing and to date, use of these specialized needles in animals has not been reported.

Injection accessories

It is often helpful to have extension tubing pre-attached to the nerve block needle prior to use. This way, anesthetists can rely on their assistants to attach and detach drug-filled syringes, and to aspirate and inject the local anesthetic solution without the anesthetists risking movement of the needles as would be the case if they were responsible for these manipulations themselves (Figure 5.16).

Many commercially available regional anesthesia needles have pre-attached extension tubing

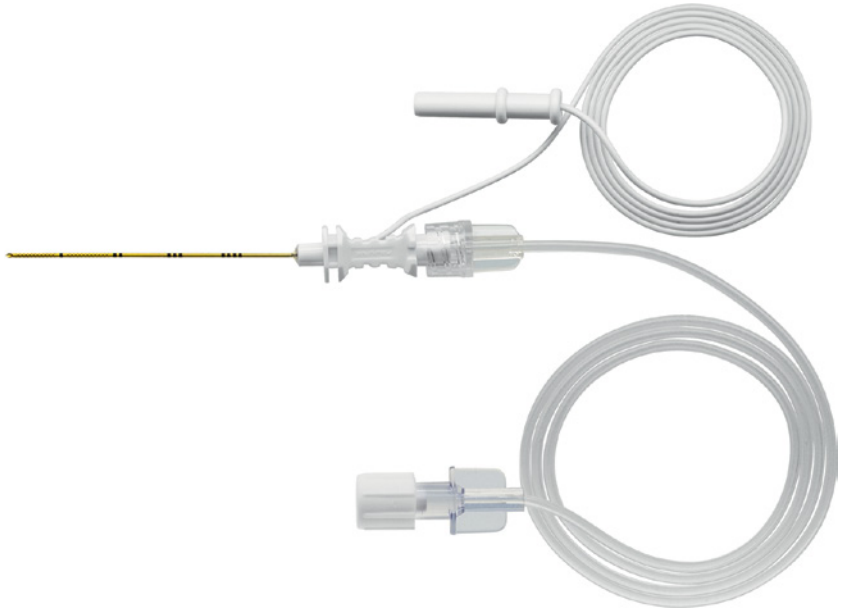


Figure 5.14 Laser etching along an insulated nerve block needle. Note that the number of lines indicates the distance (cm) from the needle tip. Image used with permission of Pajunk GmbH.

Figure 5.15 Ultrasound reflectors on a Tuohy needle. Image used with permission of Pajunk GmbH.

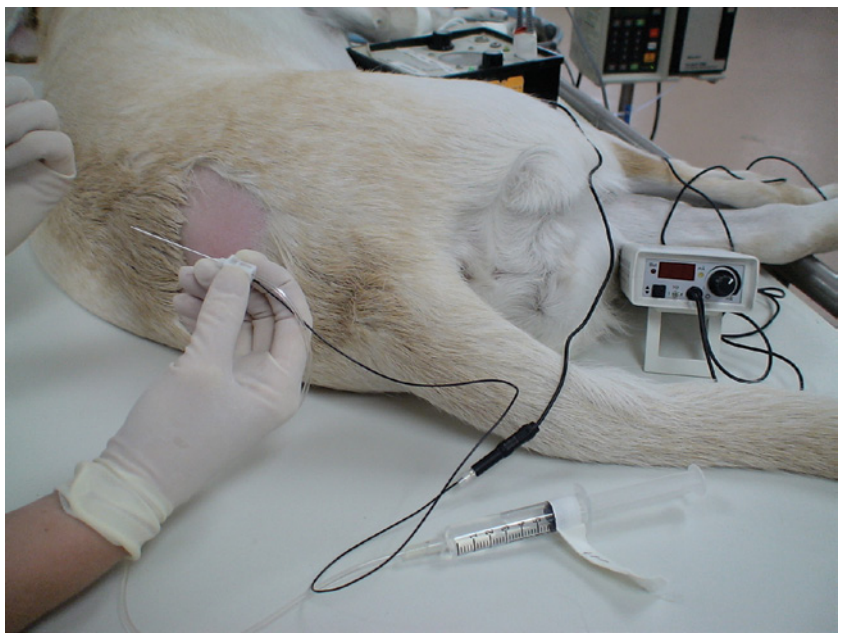


Figure 5.16 An insulated regional nerve block needle is being used to perform a nerve stimulator-guided epidural in a dog. Note that the drug-filled syringe is connected to pre-attached extension tubing. The dead space of the tubing and needle have already been "preloaded" with the injectate solution in order to displace air that might otherwise be injected into the epidural space on injection.

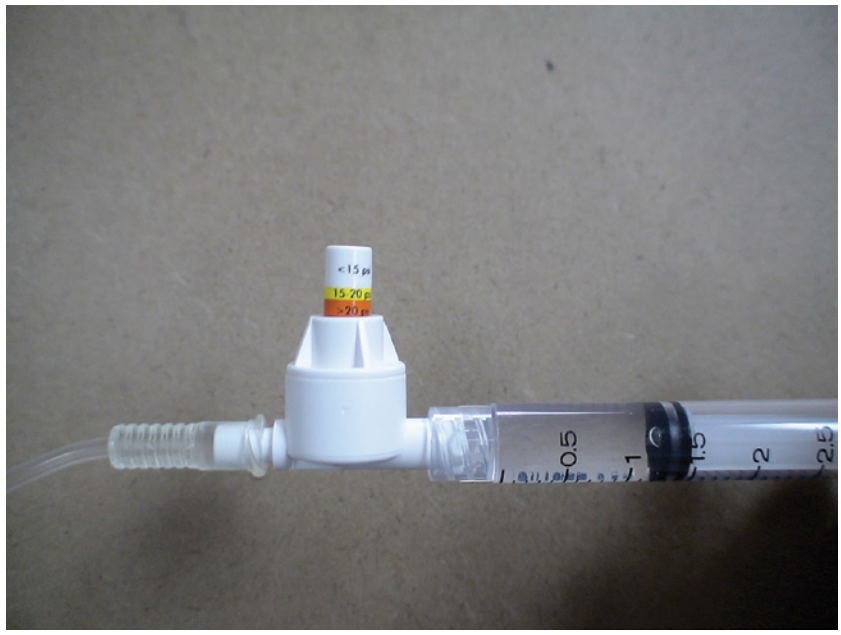


Figure 5.17 An inline pressure gauge (BSmart™, Concert Medical) can be used to monitor injection pressure during performance of regional anesthetic nerve blocks. Note the color-coded piston that relays objective information about the pressure being applied to the patient's tissues during injection of the local anesthetic solution.

for this reason, allowing for more efficient working conditions and helping to maintain a sterile environment during performance of the blocks.

Disposable inline pressure gauges can play an important role during performance of regional nerve blockade. These inexpensive pressure monitors (BSmart™, Concert Medical) are connected between the syringe and the extension tubing and provide a continuous measurement of the pressure being applied to the local tissues during injection of the drugs (Figure 5.17).

Kapur et al. (2007) studied neurological outcomes after intraneural injections of lidocaine into the sciatic nerves of dogs. They found that the worst neurological outcomes were associated with high injection pressures (20–38 psi, ~138–262 kPa), whereas intraneural injections associated with moderate pressures (<12 psi, ~82.7 kPa) resulted in blocks with longer than expected durations but no other adverse effects to the dogs (Figures 5.18 and 5.19).

All perineural injections were associated with low injection pressures (<5 psi, ~34.5 KPa) (Figure 5.20). Being able to continuously and objectively measure injection pressure during drug administration is very useful in minimizing and potentially eliminating this risk factor for patient injury (Hadzic et al. 2004). When an unexpectedly high pressure is detected during drug administration, the anesthetist should immediately stop injecting the drug and reposition the needle tip as necessary to decrease injection pressure. This has been theorized to minimize the potential for performing an intraneural injection and causing subsequent nerve injury to the patient.

Catheters for continuous regional anesthesia

Catheters

Continuous delivery of local anesthetic drugs can be achieved by use of perineural and epidural catheter placement. Using these catheters, local anesthetics and adjunct medication (e.g. opioids and α_2 agonists) can be delivered continuously by slow infusion or by intermittent boluses to provide analgesia for extended periods of time to patients with acute and chronic pain. In the past, nerves were first

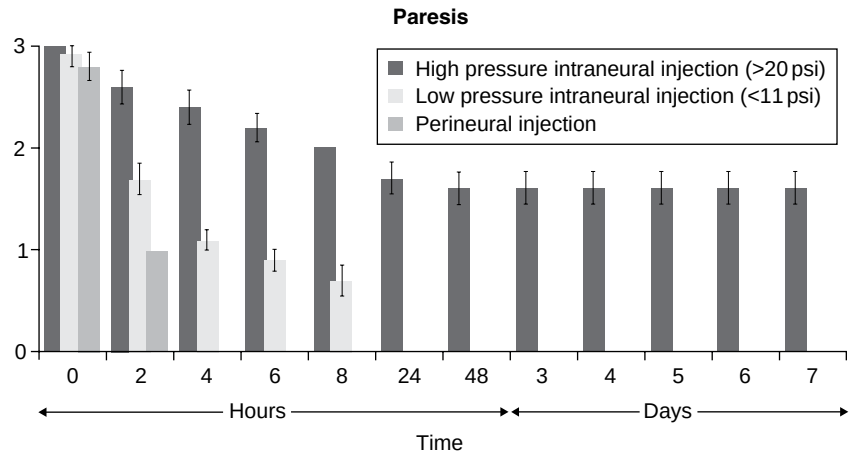


Figure 5.18 Duration of leg paresis after sciatic nerve injection in dogs with lidocaine 20 mg mL^{-1}. 0, no paresis; 1, slight paresis; 2, moderate paresis; 4, flaccid extremity. Data represent mean ± standard deviation. From Kapur et al. 2007. Used with permission.

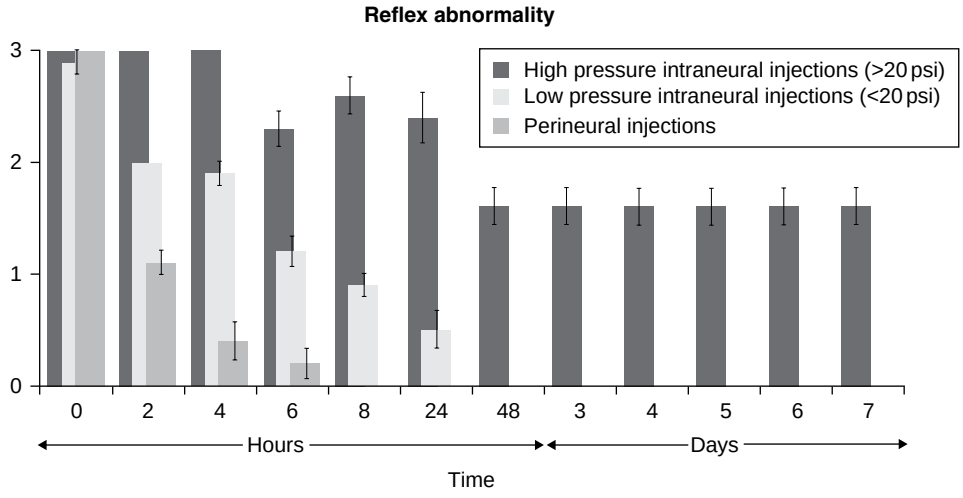


Figure 5.19 Duration of reflex abnormality after sciatic nerve injection in dogs with lidocaine 20 mg mL^{-1}. 0, no withdrawal to forceps pinch; 4, brisk withdrawal. Data represent mean ± standard deviation. From Kapur et al. 2007. Used with permission.

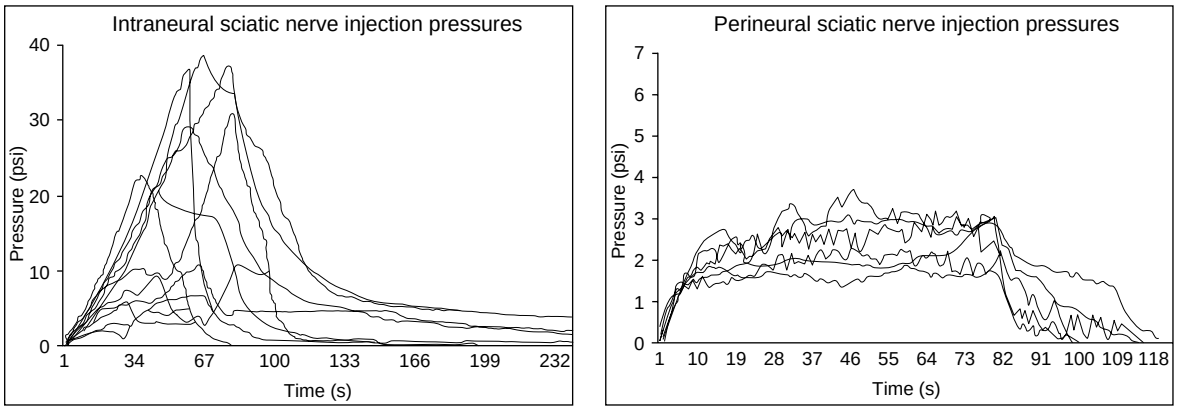


Figure 5.20 Pressure recordings during intraneural (sub-perineural) and perineural (sub-epineural) sciatic nerve injections in dogs. From Kapur et al. 2007. Used with permission.

electrolocated using a stimulating needle, and a catheter would then be advanced "blindly" through the needle and secured in place for later use. Although the technique was simple to perform, it often resulted in good success from the "primary block" (from the local anesthetic that was initially injected through the stimulating needle itself) but low success when subsequent doses of the local anesthetic were administered through the indwelling catheter (referred to as the "secondary block"). This commonly observed issue was described by Mahler and Reece (2007) in a case report involving the use of an indwelling brachial plexus catheter to provide analgesia to a dog. In people, the high failure rates associated with secondary blocks using simple catheters led to the development of stimulating catheters.

Similar to insulated needles, stimulating catheters are coated with a non-conducting material along their entire length except for the extreme distal tip. In this way, stimulating catheters can be used as soft, flexible insulated needles. Stimulating catheters are useful as they allow delivery of a low-level current (<0.5 mA) to target nerves through the catheter, even after it has been *in situ* for an extended period of time. Being able to stimulate the nerve through the catheter is useful for confirming that the catheter is still adjacent to the desired nerves/plexus prior to drug administration. Although placement of a stimulating catheter is still considered to be "blind," with good anatomical knowledge and the use of continuous nerve stimulation to allow for real-time observation of motor responses as the catheter is advanced, successful positioning of the catheter near the target nerves can often be achieved. Recently, some authors have employed ultrasound to assist with visualization of the catheter during its placement. In people, it has been reported that the use of ultrasound increases success rates of obtaining successful blocks (Dhir and Ganapathy 2008). Studies are needed in veterinary medicine to confirm or refute these findings in other species.

Catheters (for both epidural and perineural use) are often made from Teflon or polyamide nylon to resist kinking and stretching. As a result, most do not require a stylet for advancement during placement. Others are manufactured with an inner springwire coil covered by soft polyamide nylon. These catheters are softer, and, as a result, are less likely to result in vessel puncture. Catheters can be closed-tip with multiple side ports (fenestrations) or can be of the open-end, uni-port style (Figure 5.21). Fenestrated catheters will disperse local anesthetic solutions over a larger area and are therefore more widely used for perineural placement. Open-end, uni-port style catheters are commonly used for epidural placement.

Catheters typically have a mark at their distal tip so that once they are removed from the patient the anesthetist can verify the catheter's overall integrity to be sure that the catheter did not break off during removal, leaving a segment in the patient (Figure 5.10).

Epidural catheters are usually made of soft polyamide nylon, are usually 24–19-gauge, and are designed to be advanced through larger gauge Tuohy needles. They may have a removable metal stylet to provide rigidity, or they may have an inner springwire coil. In the latter case, the coil is often less tightly wound near the tip, making the distal tip softer and atraumatic when it encounters resistance in the target location. This feature is useful if the catheter is to be positioned in an awake or lightly sedated patient as it causes minimal discomfort during catheter advancement and can reduce the risk of inadvertently pushing the catheter into a venous sinus as it is advanced into the epidural space.

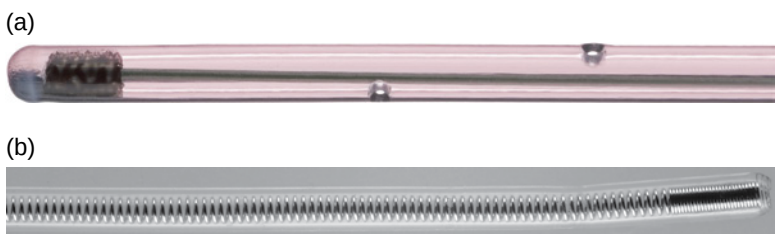


Figure 5.21 Examples of epidural catheter tips. Note the closed-end, stylet, and sideports in (a), and the open-end, coiled guide wire, and absence of side ports in the lower image (b). Images used with permission of Pajunk GmbH.

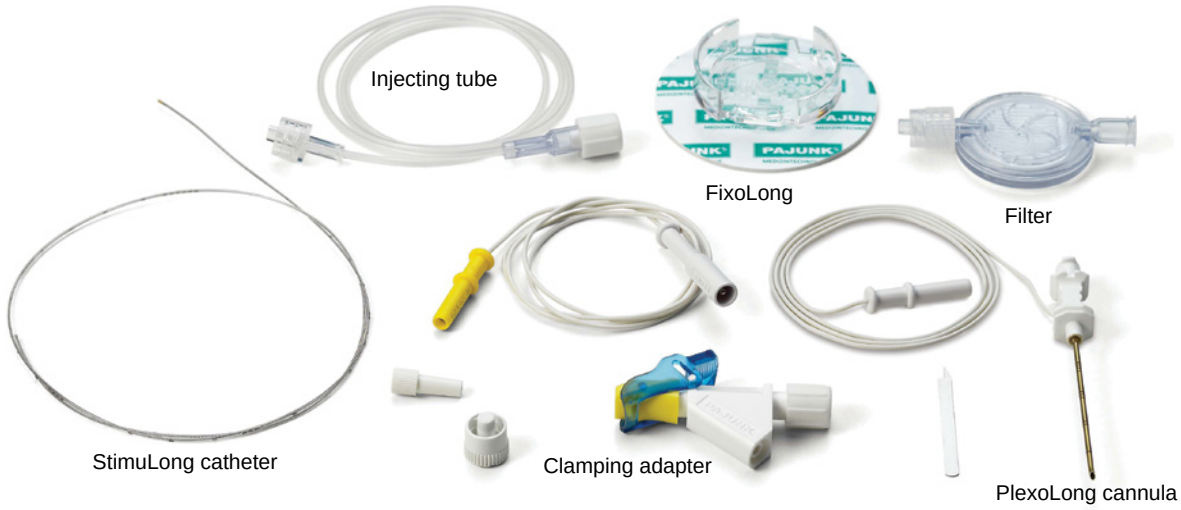


Figure 5.22 Contents of a stimulating catheter tray. Image used with permission of Pajunk GmbH.

Continuous peripheral nerve blocking techniques have been shown to be useful in people and animals to provide excellent analgesia, to reduce the incidence of analgesic side effects, and to improve quality of life. There are several different stimulating catheters available on the market, and, although the author has used many of them in a clinical setting, no controlled studies have been performed or reported to date that critically evaluate their use in veterinary patients. An example of the contents of a stimulating catheter tray is shown in Figure 5.22.

Catheter connectors and anchoring devices

Catheter connectors and fixation devices are vital components of the drug delivery system. These components are responsible for securing the catheter to the administration equipment (e.g. PRN adapter) and for securing the catheter to the patient. A common complication with the use of indwelling catheters is the development of an occlusion at the end of the catheter where it is connected to the injection device. As a result, different types of connectors have been developed for use in people and animals in an attempt to ensure catheter sterility and security while at the same time preventing occlusion of the catheter, which would necessitate its removal. Typically, catheters are attached securely to some sort of connector (Figure 5.23), which is then attached to an antibacterial, low volume filter (Figure 5.24). The antibacterial filter is usually flat to optimize patient comfort when it is bandaged against the skin. The filter is then attached to an injection port or directly to an administration set for drug delivery.

As the adhesives that come with most human products are designed to adhere to a person's bare skin, many of these materials are ineffective for use in animals, even when their hair is clipped. Modifications are often required when human fixation devices are adapted for use with veterinary patients. In addition to securing the connector, filter, and injection port, the catheter itself needs to be secured to the patient. Subcutaneous tunneling, tape, sutures, skin staples, and transparent, sterile, adhesive dressings can all be used in some form to secure the catheter at the point that it exits the patient's skin, and to maintain aseptic conditions when the catheter is to be left in position for an extended period of time (Figure 5.25).

Fixation devices are available from most equipment suppliers (and may be included in many peripheral nerve block/epidural catheter kits), but vary in their ability to secure the catheter to the clipped skin of veterinary patients. Ideally, the anchoring system should manage the catheter and its components (connector, filter, etc.) in a well-organized, comfortable way, while also allowing the veterinary staff to inspect the puncture site through a clear dressing for signs of inflammation

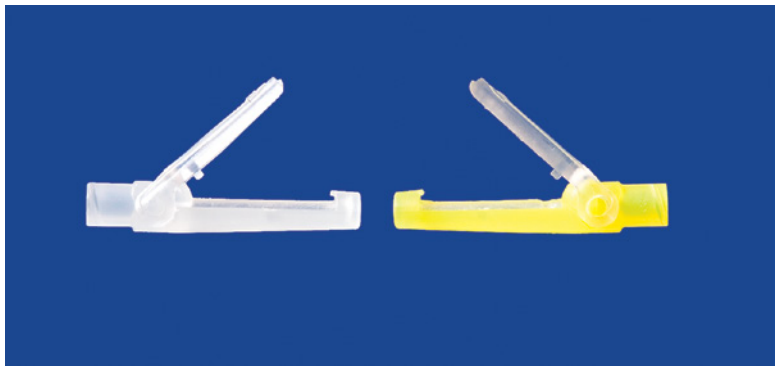


Figure 5.23 Example of catheter connectors used to securely attach an epidural or perineural catheter to other components of the injection system (e.g. filter, PRN adapter). Image used with permission of MILA International Inc.

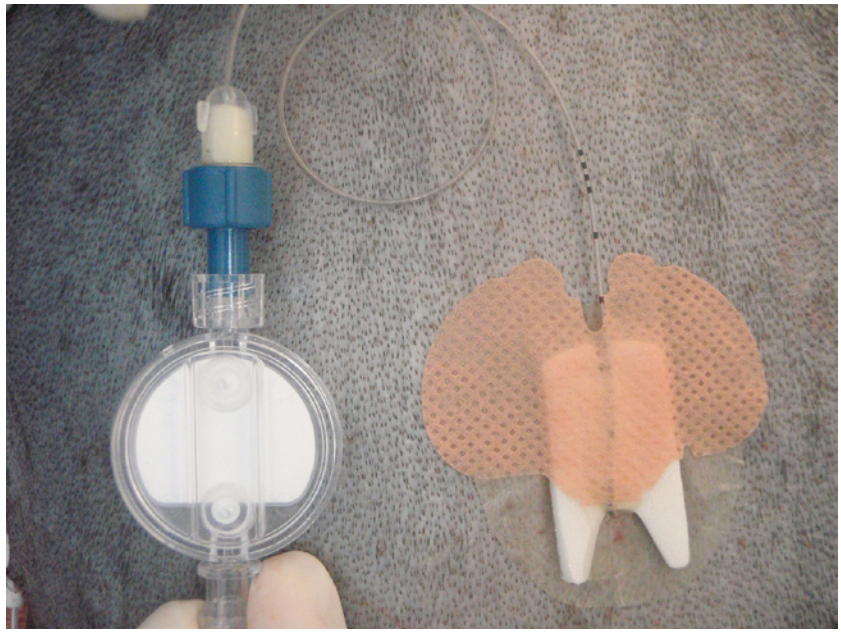


Figure 5.24 An epidural catheter has been placed in a dog. The catheter is attached securely to a connector (blue and white piece) that is attached to an anti-bacterial low volume filter (white disk).

or infection (Figure 5.25c). The ideal fixation device should prevent contamination of the puncture site from the environment, minimize risk of skin irritation, and prevent kinking of the catheter.

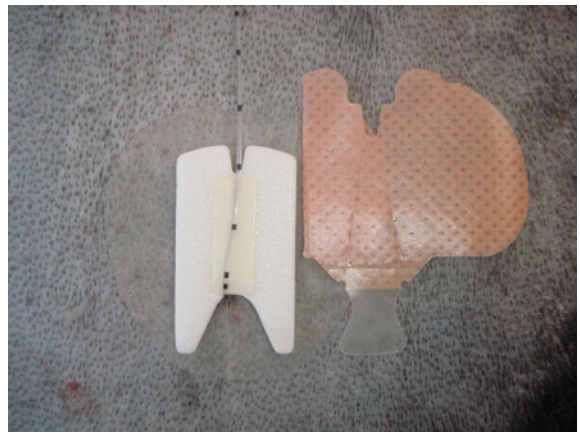
Wound soaker catheters

Several different names, including soaker catheters, wound catheters, fenestrated catheters, and diffusion catheters refer to these specialized polyurethane catheters. These catheters have closed tips and numerous fenestrations (small holes/microports) have been cut at regular intervals along their distal segments to allow injected solutions to leave the catheter (Figure 5.26).

This special design allows injected solutions to be deposited directly into surgical sites or wounds via the length of the catheter that is fenestrated, without preferential flow out of any of the

(a)

(b)



(c)

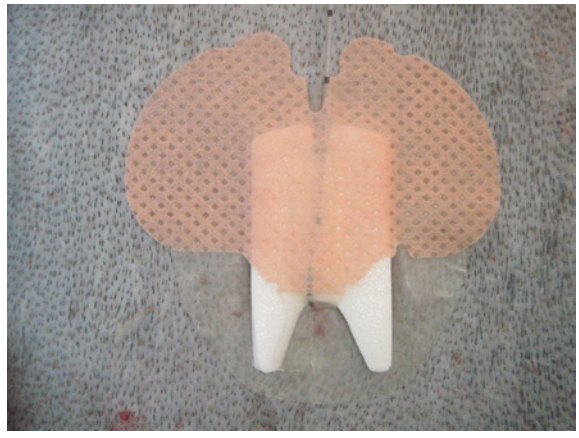


Figure 5.25 (a), (b), and (c) An example of a fixation device (Epi-Gard) that can be used to secure an epidural catheter to the skin of a dog.

(a)

(b)

Figure 5.26 (a) A polyurethane soaker catheter demonstrating injection of a local anesthetic solution via the different fenestrations. (b) The same type of catheter viewed at 25×. Note the lateral fenestration (small hole or microport) that has been cut in the side of the catheter to allow injected local anesthetic to leave the catheter at intervals along its length when it is positioned into a tissue bed. (a) used with permission of MILA International Inc.

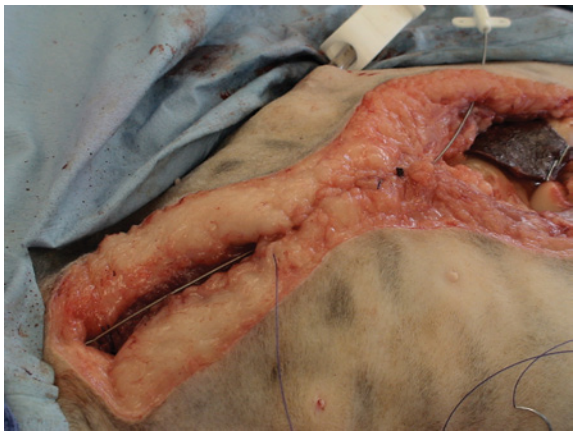


Figure 5.27 A wound diffusion/soaker catheter is placed subcutaneously along the sternum of a cat prior to incisional closure following median sternotomy. Note the "suture wings" (seen in the upper right corner of the image) that can be moved along the catheter to a location adjacent to the point of entry in the skin. At that location, the wings are sutured/stapled to the patient for added security.

individual holes. These catheters are useful for providing continuous or intermittent delivery of local anesthetics directly into large wounds or potentially painful areas that cannot be blocked through other methods of local or regional anesthesia (Figure 5.27). They are used commonly in people, and their use in veterinary medicine is increasing (Abelson et al. 2009).

Wound soaker catheters are sterile and should be placed at the time of surgery. Catheters should be placed in the deepest part of the surgical field, adjacent to exposed nerves if possible. Additionally, they should be tunneled subcutaneously from the surgical site and exit the wound dorsally (through a separate skin incision) to prevent pooling of the drug ventrally once the patient returns to a normal body position in recovery. All of the fenestrations should be positioned under the skin to prevent leakage of fluid outside of the incision. If needed, a simple interrupted suture pattern can be used to loosely anchor the catheter within the surgical field itself prior to skin closure. Many wound soaker catheters come with freely moveable "suture wings" that can be positioned anywhere along the catheter (Figure 5.27). The wings should be moved to the part of catheter that leaves the skin. At this location, the wings can be anchored to the skin to prevent movement and dislodgment of the catheter when the patient moves. Additional sutures can be used to further secure the injection-end of the catheter to the skin. An antibacterial filter can also be attached if desired. Finally, the catheter should be capped with an injection port or connected to an infusion line to allow for delivery of local anesthetic drugs. A sterile dressing may also be used to cover the site where the catheter enters the patient.

New techniques for placing wound soaker catheters without the need for surgical exploration involve the use of "peel-away" introducers. In this scenario, a peel-away over-the-needle introducer is placed into a tissue bed while the patient is deeply sedated or anesthetized. Next, the needle stylet is removed and the wound soaker catheter is advanced out of the distal end of the peel-away introducer into the patient. The catheter is held in place as the peel-away introducer is then removed from the patient. Finally, the wound soaker catheter is secured to the patient and can be used for local anesthetic delivery as described above.

Catheters can be purchased with a range of fenestrated lengths 5–25 cm (2–10 inches) as well as different sizes (gauges), allowing them to be useful for a variety of procedures. They are useful for intermittent bolus delivery of local anesthesia, or they can be attached to a continuous delivery system (see Pumps below).

Wound soaker catheters can be maintained in the patient and local anesthetics administered for several days, allowing for prolonged analgesic administration postoperatively into the recovery period (Abelson et al. 2009). The site of entry should be routinely inspected for abnormal signs of inflammation or infection, and it is recommended that the patient be monitored for 12–24 hours following discontinuation of local anesthetic use to ensure that analgesia is adequate from the other methods being employed before the catheter itself is removed. Although wound soaker catheters are highly effective for providing postoperative analgesia to a variety of patients, they should not be relied on as the only means of analgesia for many procedures. Preoperative and intraoperative analgesia must still be provided to the patient as soaker catheters are typically placed at the end of the surgical procedure. Balanced analgesia using these catheters in combination with other types of analgesic techniques should be considered for optimal patient care.

Figure 5.28 Three examples of elastomeric infusion pumps that can be used to deliver local anesthetic solutions slowly over time to a catheter (e.g. wound soaker catheter, epidural catheter). Note the delivery tubing and flow restrictor (blue) in (a) (Surefuser A, Nipro). The 2 ml/h pumps in (b) (Singleday Infusor, Baxter) have been prepared with different volumes of local anesthetic solution in their reservoirs to demonstrate reservoir capacity. The pump in (c) (Elastomeric Pump, MILA International Inc.) is soft-sided and has a four-layer balloon to maintain its integrity when used in a clinical setting. (c) used with permission of MILA International Inc.

For more information about the use of wound soaker catheters, see Chapter 8.

Devices for continuous drug administration

Elastomeric pumps

Elastomeric pumps are lightweight, portable, disposable pumps that are designed to deliver a continuous flow of medication over the infusion period at the nominal flow rate indicated on the device (Figure 5.28). These pumps are typically designed for single use only, but there are exceptions. There are many sizes and configurations available (e.g. 50 mL, 100 mL, 250 mL), and several have been found to be useful for delivering drugs to veterinary patients. Different types of elastomeric infusion pumps are available, with differing reservoir volume and delivery rates that allow the pumps to infuse at a steady rate over the course of five hours up to seven days. These pumps are very convenient to use with veterinary patients as they do not require a power source (like an electric pump), and they are often small enough to be comfortably attached to the patient. Most ambulatory pumps are maintained while the patient is still hospitalized, but as the pumps are designed for at-home use in people, they can potentially be sent home with small animal patients under certain conditions.

Elastomeric pumps use a balloon as a reservoir to store a volume of fluid. The multilayer balloon is frequently housed in a rigid plastic container that both protects the balloon from damage and prevents leakage of the drug out of the protective housing if the balloon does break. The balloon reservoir is connected to a special infusion line or flow control tube (flow restrictor) that limits the flow of the drug to a predetermined, nonadjustable rate (Figure 5.29).

Most elastomeric pumps have a built-in membrane filter in the administration line to eliminate air, bacteria, and particulate matter from the line (Figure 5.29). When filled, the pump operates with a sustained internal pressure, and, although it is the pressure in the balloon that drives the fluid into the administration line, it is the flow restrictor downstream that controls the flow. In this way, it is not the size of the balloon that determines and maintains a steady flow, but a separate restrictor that acts independently from the pressure in the balloon. Different configurations allow for different set flow rates, and some newer pumps allow the practitioner to alter the flow rates across a predetermined range using an adjustable dial. The housing usually has some sort of volume indicator to show roughly how much of the fluid has been infused.

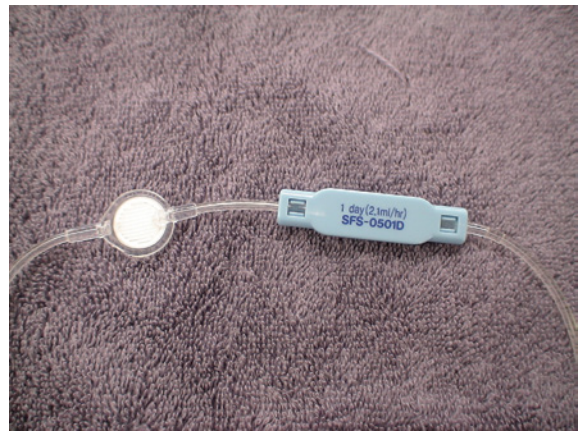


Figure 5.29 A typical flow restrictor component (blue) and inline membrane filter (white) of an elastomeric infusion pump (Surefuser A, Nipro) manufactured to deliver 2.1 ml of solution per hour over 24 hours. It is the flow restrictor that limits the actual delivery of solution through the tubing and this component needs to be maintained at the manufacturer's recommended temperature for optimal performance of the pump.

The recoil of the balloon creates pressure that is used as driving pressure to force the fluid in the reservoir out of the pump and down the extension tubing. These pumps are specifically designed to deliver fluids within 10–15% of the expected nominal flow rate for the duration of the infusion, which is comparable to the accuracy of many electronic delivery pumps (Capdevila et al. 2003; Dadure et al. 2003; Ilfeld et al. 2003) (Figure 5.30).

Several factors can affect the rate of infusion:

- ambient temperature;
- positioning of the pump relative to the catheter;
- degree of initial filling of the reservoir;
- number of uses of the pump (they are less accurate if a single-use pump is refilled for repeated use); and

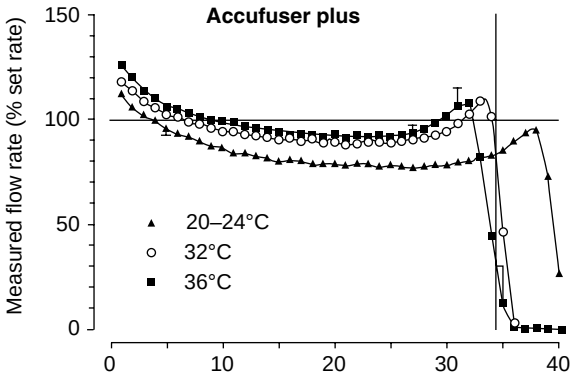


Figure 5.30 Performance over time for a portable elastomeric infusion pump (Accufuser Plus, McKinley Medical). Shown is the actual infusion rate as a fraction of the set infusion rate. The constant horizontal line represents the expected pump rate at 100% of set flow rate. The constant vertical line represents the expected infusion duration as calculated from the set rate and reservoir volume. Data are expressed as mean ± standard deviation. From Ilfeld et al. 2003. Used with permission.

- decreasing the viscosity of the injectate with dilution of the fluid may also alter the delivery compared to the rate that is expected.

These pumps are calibrated to deliver fluids at the advertised rate when maintained at 32–34°C. When used in people, the flow restrictor is usually secured to the patient's skin to maintain a stable temperature near 32°C. At higher temperatures (37°C), the infusion rate can increase (up to 10%) due to changes in the viscosity of the liquid medication and the internal calibration of the flow restrictor (Ilfeld et al. 2003). At lower temperatures (25°C), infusion rates can decrease by as much as 28% from the expected rates. A pilot study using two commonly available pumps in dogs showed that accuracy is reliable despite the flow restrictors of the pumps being maintained against the dogs' hair coats at intermediate temperatures between room temperature and 33°C (Read et al. 2010a). In that study, delivery rates increased with increases in temperature, and overall delivery was acceptable with expected infusion rates being achieved over a 24-hour period. In another pilot study that compared the infusion accuracy of two commonly available pumps filled with 1% and 2% lidocaine, there were no clinically significant differences attributable to the viscosity of the drugs at room temperature and at 33°C (Read et al. 2010b). Further studies need to be performed in animals to determine the optimal method of attachment to the patient to maintain temperature within this working range.

The reservoir balloon should ideally be maintained at a level approximating the tip of the catheter to which the pump is attached. If the reservoir is maintained significantly above the distal end of the catheter, delivery of the drug can potentially be increased due to increased hydrostatic pressure (Ilfeld et al. 2003).

The volume of local anesthetic used should match the particular pump's maximum volume. When lower volumes are used to load the pump, there is a tendency for the pump to infuse at a higher than expected rate. This is due to the fact that when the balloon is less expanded, pressure increases and infusion rates are subsequently increased (based on Laplace's Law). As an example, if only 30 mL of a maximum 50 mL are loaded into a balloon reservoir, the overall infusion rate can be increased by up to 8% over the duration of the infusion, compared to a 0% change when the balloon is loaded with the expected 50 mL.

Although certain new pumps can reportedly be refilled several times, the majority of elastomeric balloon pumps are designed for single use only and are disposable. This is because there is a reduction in the internal pressure that the balloon can generate after it has been filled and emptied several times. With repeated use, infusion rates become unreliable and progressively decrease, with some pumps showing up to an 18% decrease in expected delivery after the fifth use. Check the manufacturer's recommendations before considering using an elastomeric pump more than once.

The drug-binding properties of the balloon reservoir of the specific elastomeric pump should be reviewed before use. In one study, it was found that when 17 commonly infused drugs (including lidocaine and morphine) were diluted in either 0.9% saline or 5% dextrose, clinically insignificant levels of the drugs were bound to the material of which the reservoir was made (Jenke 1994). The authors concluded that the reservoirs were essentially inert with respect to the binding of the particular drugs used in the study. In another report, local anesthetics were taken up by the balloon materials and their

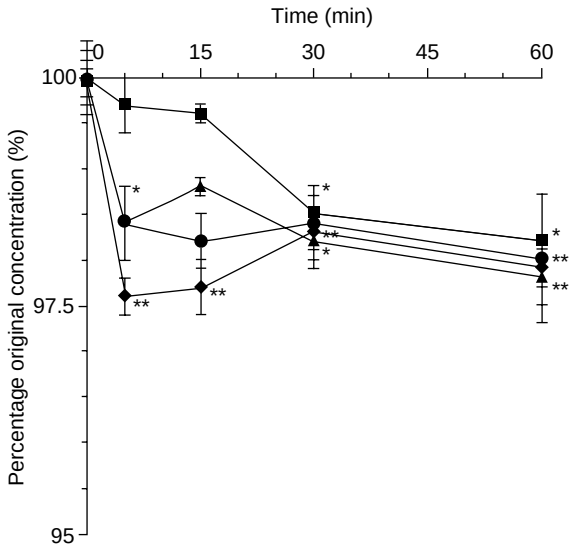


Figure 5.31 Concentration changes of local anesthetics flowing out of infusion balloons injected with their solutions of pH 6.0. The effluents were analyzed over time by high-performance liquid chromatography: lidocaine (●), bupivacaine (♦), ropivacaine (▲), mepivacaine (■). Data are expressed as mean ± standard error (n = 4). *$P < 0.05$ and **$P < 0.01$; significantly different from initial concentration (0 min). From Mizogami et al. 2004. Used with permission.

concentrations in the delivered solutions were deceased between 6% and 14% (Mizogami et al. 2004). Bupivacaine was most strongly adsorbed, followed by lidocaine, ropivacaine, and mepivacaine (Figure 5.31). Binding increased at a more alkaline pH (7.4 vs. 6.0), suggesting that local anesthetics should not be alkalinized prior to use with an infusion pump. When infusion balloons are used to continuously deliver local anesthetics, the anesthetist should be aware of the possibility that the actual concentration of local anesthetic being delivered by the pump may be lower than that which is anticipated. The clinical relevance of these findings appears to be minimal in people when these pumps are used for postoperative analgesia, but no studies have been performed in animals to date.

Battery-powered pumps

Other portable pumps include battery-powered, gas-driven delivery pumps (Infu-Disk™) (Figure 5.32). These are low cost, single-use, continuous flow pumps with small reservoir capacities

Figure 5.32 Example of a single-use battery-operated infusion pump (Infu-Disk™) that is designed to deliver 0.21 ml/hr of a solution. Image used with permission of MILA International Inc.

(5 or 10 mL). They have nonadjustable flow rates; fluids are delivered continuously with accuracy within 10% of the described label rate. Instead of using a balloon to pump the fluids, once activated, these pumps use battery cells to produce a continuous flow of gas that expands against a diaphragm, displacing the fluid volume from the pump. Variable flow rates are available, ranging from 0.03 $mL h^{-1}$ up to 4 $mL h^{-1}$. Accuracy is better than ± 10%, and up to 98% of the loaded volume is delivered. They are compact in size (4–5 cm diameter, weigh less than 20 g), making them very useful for many veterinary patients.

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6 Peripheral Nerve Stimulators

Robert M. Raw, Matt R. Read, and Luis Campoy

Introduction

Portable peripheral nerve stimulators were first introduced into human regional anesthesia in the late 1970s. Nerve stimulators have different designs depending on the specific purpose for which they are to be used. In anesthesia, nerve stimulators are used primarily for neurophysiologic studies, monitoring the depth of blockade at the neuromuscular junction following use of non-depolarizing muscle relaxants, and for locating nerves of interest during loco-regional anesthesia.

In simple terms, a nerve stimulator is a piece of equipment that is used to generate an electric field in the tissues immediately surrounding a target nerve. If the nerve carries motor fibers, the electric current that is induced by the nerve stimulator will result in depolarization of these nerves, and consequently, the muscles that are served by that nerve will contract. The visible contractions (also known as "twitches") are used to confirm the electrophysiologic end point associated with correct needle placement. The use of these instruments for performing nerve blocks in veterinary patients is increasing in popularity, as can be noted by increased use in the published literature.

Electrophysiology

Electricity is the physical phenomenon of sub-atomic particles (electrons and protons) that either (1) gather at a point with the potential to flow to another point, or (2) that flow between two points.

- Gathering of electrons represents energy called *electrical potential* and it is measured in volts (V).
- Flow of electrons can be either (a) unidirectional (direct current, DC), or back-and-forth (alternating current, AC) and is measured in amperes (A).

The flow of electrons between two points ("electrodes") occurs from the *anode* (positive) towards the *cathode* (negative). Electron movement generates an associated magnetic field. Conductors within a magnetic field have electron movement induced in the conductor; this is known as "inductive coupling." Therefore, a conductor-carrying current can induce current in a second conductor if the latter is located within the first conductor's magnetic field. This induced electron movement only occurs while the magnetic field changes; that is, inductive coupling can only occur with

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alternating or pulsed currents. The ease, or lack thereof, with which a conductor allows movement of electrons to occur is known as resistance (or impedance) and is measured in ohms (Ω).

Ohm's Law relates current, potential, and resistance as R=V/I, where R=resistance, V=potential, and I=current. This formula can be manipulated such that I=V/R, which explains why a constant resistance, current, and voltage are directly proportional to one another (A~V).

Mechanism of nerve activation

The concentration of sodium ions (Na^+) is approximately 10 times higher outside the cell membrane than inside the cell, whereas the concentration of potassium (K^+) ions is approximately 30 times higher inside the cell than outside. This creates a potential difference across the cell membrane. At rest, this potential in nerve cells ranges from approximately –60 to –70 mV.

With appropriate stimulation, sodium rapidly flows into the cell, reducing the voltage difference across the membrane. Once the potential difference reaches a threshold voltage (approximately –55 mV), it causes hundreds of sodium gates in that region of the membrane to open briefly. When this occurs, sodium ions flow into the cell, resulting in complete depolarization of the cell membrane. This phenomenon further opens more voltage-gated ion channels in the adjacent membrane, and so a wave of depolarization (also called an "action potential") courses along the cell.

The sodium ion permeability increases very rapidly at first, allowing sodium ions to flow from outside to inside, making the inside more positive. After that, the more slowly increasing potassium ion permeability allows potassium ions to flow from inside to outside, thus returning the intracellular potential to its resting value. While at rest following activation, the Na^+-K^+ pump restores the ion concentrations on either side of the cell membrane to their original values (Figure 6.1). All neuronal voltage-activated sodium channels inactivate within several milliseconds during depolarization, thus another depolarization will be impossible until a substantial fraction of sodium

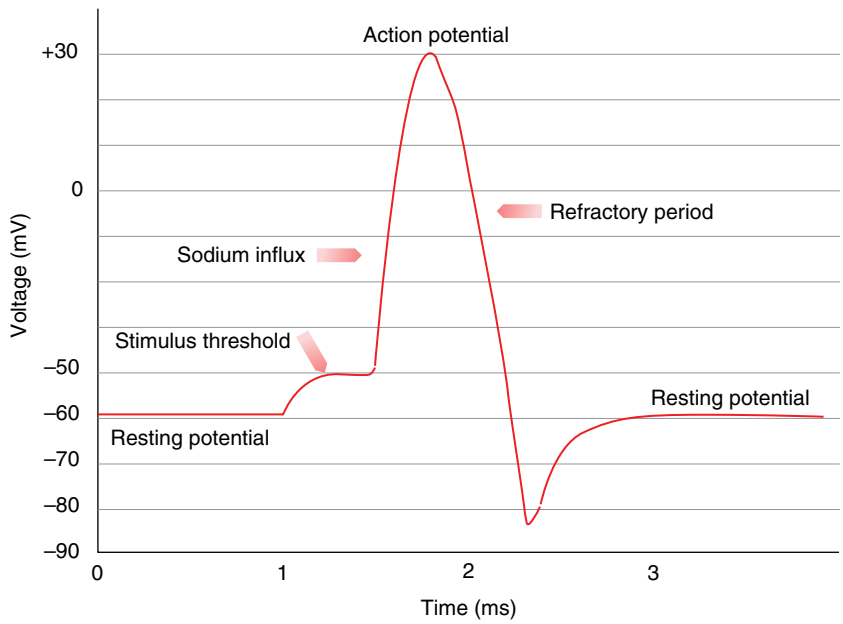


Figure 6.1 When the change in voltage is large enough (at least 15 mV) to open the Na^+ channels on the axon at –60 mV, an action potential is produced. When the Na^+ channels open, Na+ rushes INTO the cell. At the same time, K^+ rushes OUT of the cell. After the action potential is generated, the ions are pumped back to their original concentrations and the resting potential of the membrane is restored.

channels is returned to their closed state. This is referred to as the "refractory period" of the nerve.

The opposite phenomenon to depolarization is called hyperpolarization. Hyperpolarization is often caused by efflux of K^+ through the K^+ channels, or influx of Cl^- through the Cl^- channels. This potential can be in the order of –80 mV.

Electrostimulation

Nerve stimulators are used in conjunction with special stimulating needles (see Chapter 5 for more information about insulated needles). When a stimulating needle approaches a nerve carrying motor fibers, depolarization of the nerve occurs, resulting in synchronous contractions in the effector muscles that are innervated by that nerve.

There are several factors that determine the stimulus threshold of a nerve:

- polarity of the electrodes;
- rheobase of the nerve fiber;
- chronaxy of the nerve fiber;
- distance of the electrode (needle tip) from the nerve fiber; and
- current density at the electrode-needle tip.

Polarity of stimulating and returning electrodes

The potential field has a different influence on the electrical potential inside and outside the cell membrane, thus affecting the nerve cell's transmembrane potential.

- The cathode ("negative" or Black electrode) causes the closest part of the axon to depolarize. If the trans-membrane potential is reduced to a certain threshold, depolarization will occur and an action potential will result (Rosenberg and Greenhow 1978). An action potential will propagate in both directions away from the point of stimulus. When the axon segment closest to the electrode depolarizes, the two adjacent areas of the axon undergo mild hyperpolarization (called virtual anodes).
- The anode ("positive" or Red electrode) causes the closest part of the axon to hyperpolarize with two adjacent areas of mild depolarization, called virtual cathodes. In this case, the trans-membrane potential will be increased and will make the cell wall resistant to conducting an action potential.

This explains why the negative (Black) electrode is used as the "searching" electrode and is connected to the stimulating needle. It is more likely to cause stimulation of the nerve, rather than hyperpolarization. Nerves need twice the current to respond to an electrical stimulus when the adjacent electrode is the anode (positive Red lead), than when it is the cathode (negative Black electrode).

One theory about how stimulating electrical currents induce action potentials hypothesizes that axons act as electrical conductors within a magnetic field that is induced by the electrical current from the stimulating needle electrode. The axons thus experience induced-flow of electric charges due to pulsed electric charge flow from the stimulating needles inducing changing magnetic fields. It is this axonal induced flow of electric charges that induces depolarization (or hyperpolarization).

Nerves are also selectively stimulated depending on their size/thickness. Sensitivity to stimulation is predicted by electrical laws that state that large diameter axons are more easily excited than smaller diameter fibers (Basser and Roth 2000). This explains why motor nerves can be stimulated at lower currents than sensory nerves. When a potential is high enough, all axons will be stimulated.

Rheobase (mA)

Rheobase is a natural phenomenon and is the minimal electric CURRENT of an infinitely long duration that is required to stimulate a nerve. Further lengthening of duration of this electrical stimulus does not further reduce the current required (Figure 6.2).

Chronaxy (ms)

Chronaxy is an arbitrary definition and is the minimal DURATION of a stimulus required to stimulate a nerve fiber at a current of twice the rheobase (Figure 6.2).

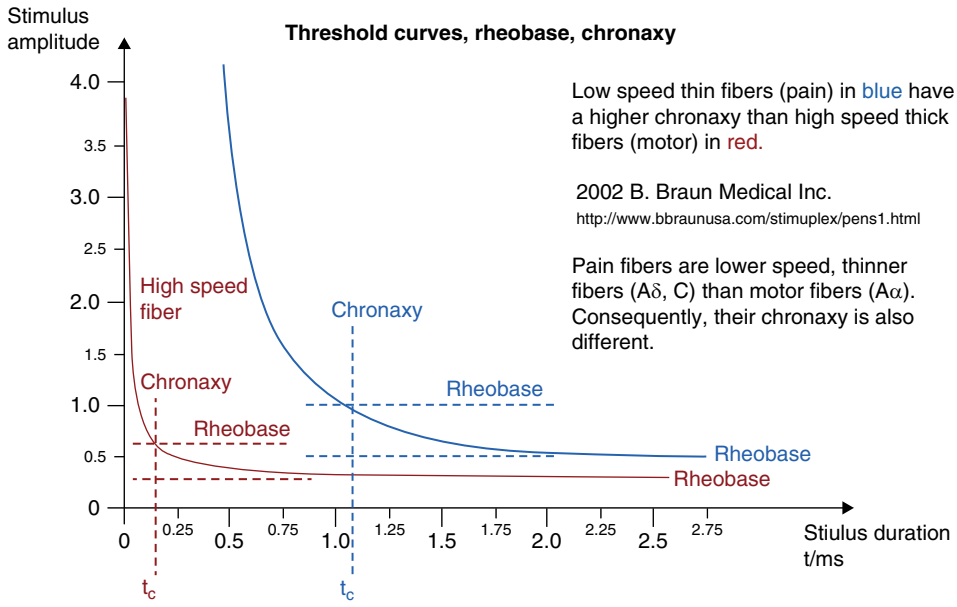


Figure 6.2 Chronaxy and rheobase are related in the formula I = Ir (1 + C/t), where I = current required to trigger an action potential, Ir = rheobase, C = chronaxy, and t = duration of the stimulus. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

Distance of the electrode (needle tip) from the nerve fiber

Coulomb's Law relates to the distance at which an electrode will stimulate a nerve. Coulomb's Law states that $E = k\ (Q/r^2)$, where E = current required, K = a constant, Q = minimal current, and r = distance. Using an insulated stimulating needle with a conductive tip (unipolar needles), the electrical current required to trigger a muscle contraction correlates with the distance of the tip of the needle to the nerve. Said another way, the closer the needle is to the nerve, the lower the electrical current that is required to elicit a response.

Current density in the biological tissues

Current density is also known as "potential gradient," and is a measure of the flow of an electric charge. Two factors influence this: distance of the electrode from the nerve, and surface area (cross section area) of the electrode transmitting the current. Larger electrodes have less potential gradient or current density. The current density is thus the electric current per unit area of cross section, measured in amperes per square meter ($A\ m^{-2}$).

Nerve stimulation is best discussed in terms of tissue potential fields. According to Ohm's Law, for a constant resistance, the potential fields will be proportional to the current density. The electrical stimulus delivered to tissue by a peripheral nerve stimulator is typically a voltage (potential) change in the form of a square-shaped impulse (Figure 6.3).

Additional concepts associated with the axon activation process

- Accommodation and habituation denote the adaptation of the cell to a continuing or repetitive stimulus. This is characterized by a rise in the excitation threshold. Facilitation denotes an increase in the excitability of the cell; correspondingly, there is a decrease in the threshold.
- Latency denotes the time between application of a stimulus pulse and the beginning of the activation.

Nerve stimulator components

The main components of a schematic peripheral nerve stimulator are (Figure 6.4):

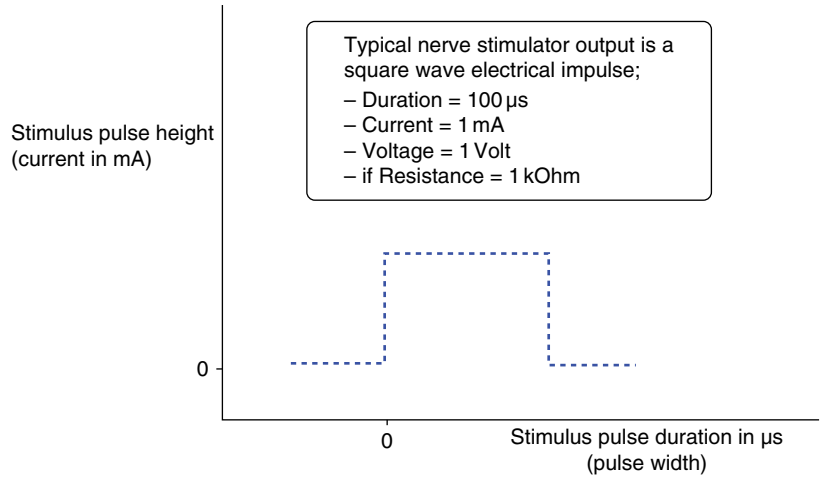


Figure 6.3 Square wave delivered by a peripheral nerve stimulator. The Y-axis represents current (mA) and the X-axis time (µs). This waveform contains a current increase (upstroke), a plateau (current maintained), and a current decrease (down stroke) back to baseline (zero). The duration of the plateau is the pulse width.

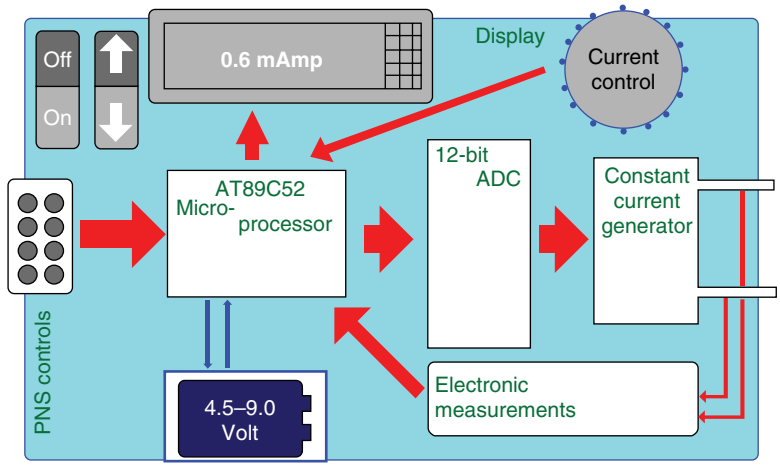


Figure 6.4 Conceptual diagram of a generic nerve stimulator.

- power source (batteries);
- on–off switch;
- current regulator (current control dial);
- microprocessor unit. This component produces an electric pulse with a specific voltage (height) and duration (width) with a square-shaped waveform. The oscillator is controlled by internal timers within the micro-controller;
- micro-controller. Each unit has two separate controllers for frequency and duration of the electric pulse. Each (frequency and pulse width) has certain value loaded into the timers from a table in the program memory;
- display. This is usually a liquid crystal display (LCD) to display important information to the user;

- analogue-digital-converter (ADC). For every pulse, the micro-controller outputs a 12-bit number corresponding to a selected current value. An ADC translates the 12-bit number to an analogue voltage. That analogue voltage is used as a reference value for the constant current generator;
- constant current generator. This component receives the reference value from the ADC outputs an electrical impulse of a set duration and voltage. The actual delivered current depends on resistance of the tissues in the patient and resistance within the stimulator leads; and
- electrical measurement unit. This component continuously measures the actual current that is being delivered by the nerve stimulator. This information is used to determine whether the circuit (nerve stimulator, needle, patient) is intact, to calculate the resistance within the circuit, and to send instructions to the microprocessor that will result in constant adjustments in the output voltage to match the set-current that has been determined by the operator.

Constant current output

Modern nerve stimulators used for performing regional anesthesia blocks in animals and people are designed to deliver a constant current, regardless of the variations in electrical impedance encountered as the needle tip is advanced through the various tissues. The units use built-in compensatory mechanisms to continuously correct for changes in tissue impedance and therefore adjust voltage output in order to accurately deliver a constant electrical current. As a result of this capability, the well-established relationship between the current and the needle-to-nerve distance is maintained and thus, accuracy of needle placement can be maximized.

Display

Displays can be digital or LCD, and should have an easily readable display to show the actual current delivered to the patient (not just the selected current) to safely and successfully deliver the nerve block (Figure 6.5). Additionally, it is desirable to have the capability to warn the operator if the dialed current is not being delivered to the patient (e.g. if the return electrode/cathode becomes disconnected from the patient) (Figure 6.6).

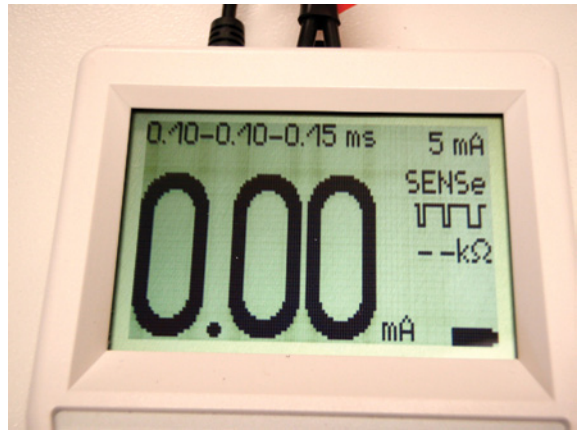


Figure 6.5 An example of a nerve stimulator (Stimuplex® HNS12, B.Braun Medical Inc.) with LCD display and useful indicators including: stimulus duration over three impulses (0.1-0.1-0.15 mA), the set current (5 mA), load impedance (kOhm), the actual current that is delivered to the patient (large digits: 0.00 mA), and battery strength (lower right).

Figure 6.6 Example of a nerve stimulator (Stimuplex® HNS12, B.Braun Medical Inc.) with LCD display that presents a warning message when the delivered current is not the same as the set current.

Other useful indicators on the screen include (Figures 6.5–6.7):

- stimulus frequency (Hz);
- pulse duration (ms); and
- load impedance (kOhm).

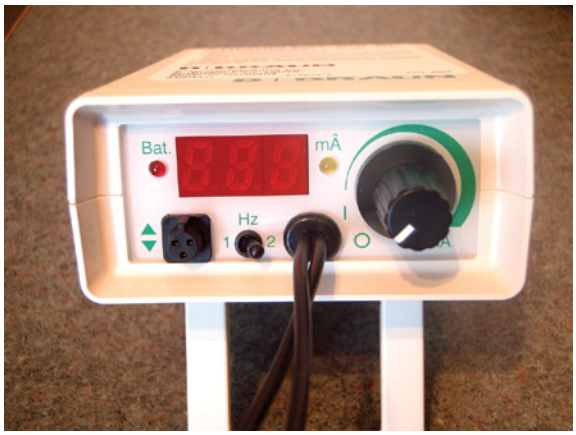


Figure 6.7 Example of a nerve stimulator (Stimuplex® Dig RC, B.Braun Medical Inc.) with a digital display, adjustable impulse frequency (1–2 Hz), and adjustable current (mA).

Controls

Most nerve stimulators have adjustable:

- current (mA);
- impulse frequency (Hz); and
- pulse width/duration (ms).

The settings need to be able to be adjusted quickly and easily by the operator, and the equipment should be designed in such a way as to allow for adjustment of the necessary settings without breaking sterile technique.

Current adjustment

A nerve stimulator unit should have an easily adjustable control for current intensity, as this is the parameter that is adjusted during the course of performing a nerve block. Current can be adjusted using several different methods that include digital or analog dials and remote controllers (e.g. foot pedals, or "under-the-glove" hand-held remote controllers) (Figure 6.8).

Additionally, the nerve stimulator should permit adjustment of threshold current intensity in small increments of 0.01 mA across the clinically useful range of 0.01 mA to 0.5 mA (Hadzic and Vloka 2004), allowing for close approximation of the needle-to-nerve distance.

Pulse width and frequency

Different types of nerves (motor, pain) are stimulated at different pulse widths, so nerve stimulators must be capable of delivering short pulse widths in the range of 0.05–0.2 ms. Across this range of pulse duration, only large motor fibers (Aα) are stimulated. This means that the operator can visualize the motor responses associated with nerve stimulation without causing significant discomfort in awake or lightly sedated patients. Sensory/pain fibers (Aδ, C) are typically stimulated at longer pulse durations (>0.2 ms); therefore, as long as the duration of each burst is below 0.2 ms, pain from the act of nerve stimulation itself should not be experienced by the patient. However, pain and discomfort from needle manipulation must still be a consideration in awake or lightly sedated patients.

A pulse frequency of 2 Hz has been found to be most optimal for peripheral nerve location during nerve blocks. At this pulse frequency, the operator can obtain more information about the needle-to-nerve distance and is less likely to pass by the target nerve between consecutive impulses as the needle is advanced. When using nerve stimulators that are only capable of delivering 1 Hz, the needle must be advanced very slowly to avoid missing the nerve between consecutive pulses.

Technology continues to evolve, and a new stimulating pattern has recently been developed. SENSe (Sequential Electrical Nerve Stimulation, "BBraun") technology reportedly increases the sensitivity and specificity of using nerve stimulation to identify target nerves by adding a longer pulse. This technique utilizes a series of three stimulations per second: two short pulses of 0.1 ms, followed by a third pulse that is 0.15 ms in duration. As the current is maintained constant, more energy is released with the longer pulse. As a result, the longer pulse has the ability to elicit a motor response, even when the needle is not located immediately adjacent to the nerve. As a result, the operator will observe one twitch per second during the initial approach. When the needle advances closer to the nerve, the smaller pulses have enough energy to stimulate the target nerve. When this occurs, the operator will see three consecutive muscle twitches every second. This new technology is claimed to shorten

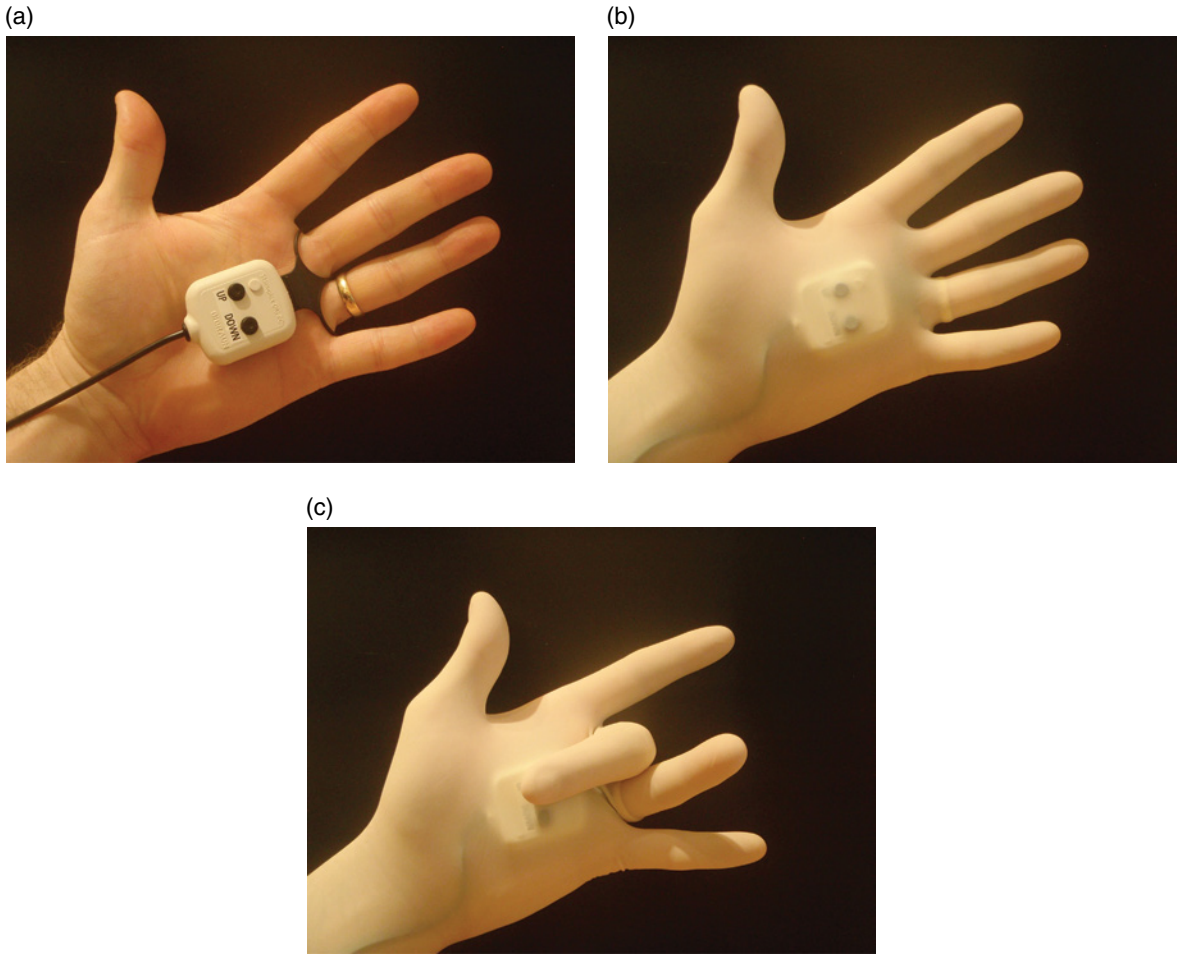


Figure 6.8 (a), (b), (c) Example of a remote control device for adjusting current delivery during performance of peripheral nerve blocks (Stimuplex® Dig RC, B.Braun Medical Inc.). The ability to control current delivery while remaining sterile is useful when there is limited assistance for the anesthetist.

the time it takes to identify the target nerves, without the need for constant adjustment of current during needle placement. If during needle manipulation the twitches are lost altogether, the longer pulse duration can again be used to help find the nerve without having to first increase the current.

Disconnection and malfunction indicators

An essential feature of any nerve stimulator is the ability to indicate when the desired current is not being delivered to the patient (Figure 6.6). This may occur with disconnection of the electrodes (anode (–) Black from the needle, cathode (+) Red from the patient), poor electrical connections (usually between the cathode electrode and patient), or battery failure.

Practical approach to peripheral nerve blocks using electrostimulation

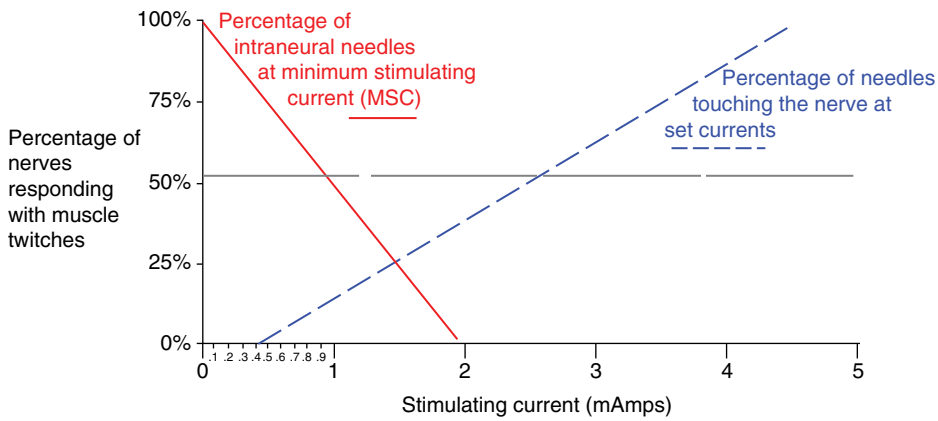
Even though new ultrasound-based research has caused us to challenge some of our long-standing

beliefs about nerve blocks, using electrostimulation guidance alone for nerve blocks is still acceptable practice.

Minimum stimulating current

Minimum stimulating current (MSC) is the lowest current that will induce any degree of muscle contraction when the needle is located in its final position. Once a muscle twitch is found, the current should be slowly dialed down to zero. Then, the current on the nerve stimulator is incrementally increased until a twitch is again observed. That current should be recorded as the MSC. In the past, the needle tip was considered to be located intraneurally when the MSC was 0.3 mA or less. Based on new research that uses ultrasound to visualize nerve blocks, this is no longer considered to be the case. Moreover, use of a nerve stimulator alone cannot determine whether a needle tip is located extra- or intraneurally. Perlas et al. (2006) studied the sensitivity of either electrical stimulation (≤0.5 mA) or paresthesia for nerve localization that was assessed concurrently by real-time ultrasonography. Those investigators found that using electrolocation and paresthesia to detect intraneural needle placement were sensitive in only 38% and 75% of the cases, respectively. Furthermore, Chan et al. (2007) evaluated the MSC associated with intraneural needle location in pigs. The median current required to elicit a motor response in the roots of the brachial plexus was 0.43 mA (0.12–1.8 mA) (min–max). In 45% of cases a current of <0.5 mA elicited a positive motor contraction, whereas in another 5%, a current >1 mA was necessary. These results were similar to those obtained by Tsai et al. (2008). Sauter et al. (2007) conducted an ultrasound-guided human study in two different nerves (radial and ulnar) and assessed both the MSC at the point of needle-to-nerve contact, and the distances from the nerves at which needles with a preset current started to elicit a twitch. Threshold levels at needle-to-nerve contact ranged widely from 0.4 to 4.5 mA for the radial nerve and from 0.32 to 2.0 mA for the ulnar nerve. Clearly, the long-held belief of eliciting a twitch between 0.4 and 0.6 mA but not below 0.3 mA, does not mean that the needle tip is not intraneural.

The question is "what MSC corresponds to 100% prevention of block failure?" The answer from the studies cited above is ≤0.5 mA. However, that threshold current may still occur when the needle is located intraneurally. In people, extensive clinical experience and many recent studies report that intraneural injections are nearly always harmless.



Percentage of nerves responding with muscle twitches at different currents, for two stimulating needle positions (i) intraneural, and (ii) touching epineurium (extraneural)

Figure 6.9 The range of MSC currents that may correspond to the needle being in direct contact with a nerve (and not within it) is 0.3–4.5 mA. The range of MSC that may occur with intraneurally positioned nerve block needles is 0.12–1.9 mA. Note that these two ranges overlap considerably.

The incidence of intraneural injections in animals is unknown, but long-term sequelae appear to be relatively minor as it is only recently that investigators have started to use ultrasound to perform nerve blocks in animals. The vast majority of blocks in veterinary medicine are still performed blindly or with use of nerve stimulation, yet few, if any, complications that would be associated with intraneural injections are seen or have been reported. We simply do not know if they occur, but should be aware of any signs.

Interestingly, the very lowest MSCs (especially below 0.3 mA) are correlated with the fastest and densest nerve block setups (likely because the incidence of intraneural drug injection is the highest).

Clinical factors that influence the minimal current needed to stimulate a nerve

- Diseased neurons usually need higher currents to elicit a stimulus. In people, this commonly occurs with geriatric patients, patients with diabetic neuropathy, or those with end-stage renal failure. MSC may need to be increased 10 times in order to elicit the same responses that would be seen in a normal patient. Distal muscle disease due to nonuse or other reasons may conceal nerve stimulation. The effects of these diseases in animals are unknown.
- Coincident use of neuromuscular blocking drugs will preclude nerve electrolocation until the relaxant effect has worn off.

Practical use of peripheral nerve locators for local anesthesia

An insulated stimulating needle is advanced towards the expected anatomic position of the relevant nerve. When the nerve is exposed to sufficient current, depolarization of the nerve will occur, resulting in a distal muscle twitch (Jalinous 1991; Hadzic and Vloka 2004).

Step-by-step procedure

- Start with a current of 1.0–1.5 mA at a pulse duration of 100–150 µs to survey/scan the area where the nerve is anatomically most likely to be encountered.
- If the nerve is not immediately encountered, carefully and methodically withdraw the needle to the level of the skin and redirect the needle until the nerve is identified by a muscle twitch.
- Once a twitch is elicited, in stepwise fashion, reduce the current and make needle adjustments until a twitch is elicited at a current of 0.5 mA or less.
- Determine the MSC before injection of local anesthetic. It is possible, once the final position is found at 0.5 mA, that the nerve may continue to elicit a muscle response at even lower currents without a needle tip repositioning.
- Ensure negative blood aspiration to rule out intravascular needle location.
- Slowly inject the local anesthetic solution.
- Ensure absence of resistance on injection to rule out intraneural needle location.
- The twitches will cease once local anesthetic solution has been injected. This was long believed to be the result of the injectate displacing the nerve away from the needle tip (referred to as a "Raj test"). More recently, this has been shown to be the result of the local anesthetic acting as an electrolyte solution that expands the conductive area around the stimulating needle, making the low-level current less effective for stimulating the nerve (Tsui et al. 2004).
- Once the injection has been made, the patient must be monitored to ensure the absence of signs that might suggest development of a local anesthetic systemic toxicity (see Chapter 4 for more information).

Practice tips: needle navigation rules

- Don't inject after a lateralizing movement. This is a common cause of block failures. Only inject if the last movement was a penetrative movement. A lateralizing movement is one where the needle tip was pushed sideways to elicit the biggest twitch. Lateralization compresses the tissues between the needle tip and the closest motor fascicle. The shortened electrical distance is sufficient to elicit a muscle twitch, but the compressed tissues would represent a barrier to drug flow. A lateralizing movement may create a false sense of needle

proximity and therefore a "false positive." It is therefore recommended to use lateralizing movement only to indicate the direction needed for needle adjustment. Then the needle should be withdrawn a small distance (1–4 mm) in the same direction as it was previously advanced, re-oriented towards the new direction, and then re-advanced until the twitch is again elicited. The previously compressed tissues will spring back and the twitch can be found again, making the block more likely to be successful.

- Avoid unsteady needles with "unforgiving" nerves. Unforgiving blocks are the ones where the nerve has a closely apposed, firm fascial compartment sheath, or where it lies tightly between two muscles with no loose tissue or fat. Small needle displacement while injecting the drug can displace the needle outside of the fascial compartment in which the nerve lies. The operator should ensure that the needle holding hand is totally stabilized by touching a firm immobile surface, like part of the bed, a bone or any relatively firm patient body part area not involved with respiration or movement of the limb being blocked. Additionally, the threshold current for unforgiving blocks should be the very lowest current possible (e.g. under 0.45 mA).
  - Forgiving nerves lie in wide, capacious fascial envelopes where inaccurate drug injection or even blind speculative injection of sufficient drug will always produce complete analgesia by the end of the case, if not a fast onset surgical grade block.
- Don't "bracket" the nerve when searching for it. This means do not make corrections that are too large for the current and nerve size so that redirecting the needle can let it pass on opposite sides of the nerve. When there is total uncertainty of the nerve's location, use higher currents to increase the electrical width of the needle, and only make wider needle direction correction in proportion to the higher current and anticipated nerve width. This mistake is easy to make with deeper nerves since small angle changes in needle direction will result in bigger needle tip position changes.
- Always reverse (withdraw) needles in exactly the same direction that they were placed. Changing the direction before reversing makes it impossible to accurately redirect the needle when advancing it again. Typically, when it is readvanced, it simply ends up in the exact same spot or else it overcorrects and brackets the nerve. Use careful movements and go slowly.
- Systematically create zones of exclusion that do not contain the target nerve. That is, when the nerve is not found, reinsert the needle in straight lines that are closer together than the nerve's expected width.
- Don't "torque" the needle. This is done by placing a finger on the needle shaft to force it sideways as it bends. Avoid touching the needle shaft entirely as this will break the sterility of the procedure. If it is desired to move the needle sideways, simply withdraw the needle and redirect it. This also avoids accidentally lateralizing and injecting the drug.
- Watch for "wrong" muscle twitches. For example, if you know that a more superficial muscle has a separate nerve supply, observing a slight twitch in it may suggest that the needle is still within the superficial muscle and that you still have to advance the needle deeper to reach the target nerve.
- "Investigate" an arc at right angles to the nerve: approach nerves with needles perpendicular to the long axis of the nerve. Then make serial probing insertions to the left and to the right of the nerve axis, until the nerve is identified by muscle twitches. Make each adjustment of needle direction so small that it is impossible to "step over" the large nerve as you adjust the needle's direction.

Nerve stimulation is very useful for performing regional anesthesia in animals, and its use will continue to be documented with careful practice and considerate research.

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7 Ultrasound-guided Peripheral Nerve Blocks

Olga Seco, Laura Zarucco, and Luis Campoy

The combination of ultrasound technology and electrolocation is gaining popularity among clinicians for performance of regional anesthesia. Ultrasound is useful for real-time visualization of the stimulating needle, peripheral nerves, and other important anatomic structures such as vessels, muscles, and fascial planes.

Basic ultrasound physics and technology

Diagnostic ultrasound uses high frequency sound waves (in the MHz range) to provide real-time imaging of the different tissues in the body. When an electrical current is applied to an array of piezoelectric crystals within the ultrasound transducer, mechanical energy in the form of vibration is generated resulting in ultrasound waves. As the ultrasound waves move through tissues of different acoustic impedances, they are attenuated, reflected, or scattered. Waves reflected back to the transducer are then transformed into an electrical signal that is processed by the ultrasound machine to generate an image (Figure 7.1). Depending on the amount of waves returned, different structures will be displayed with different degrees of echogenicity (brightness) and therefore, once processed, in different shades of grey. Structures with higher water content appear hypoechoic ("blacker") because the sound waves are transmitted through them easily, with little reflection. Bone blocks the wave transmission, as the velocity of the sound through bone is markedly different than in soft tissues, so the strong signal returned to the transducer provides a hyperechoic ("whiter") appearance on the screen.

The wavelength is the distance that the ultrasound wave travels during one cycle, and the shorter it is (high frequency), the higher the resolution of the image. However, high frequency sound waves are attenuated more than low frequency ones, limiting the depth they can travel into the tissue. This means that high frequency transducers can generate higher resolution images of more superficial structures. Therefore, increasing resolution of the image by increasing the frequency of the transducer decreases the penetration of the ultrasound beam. The quality of the ultrasonographic image depends on the quality of the ultrasound machine and software, the quality of the transducer, and the skill of the clinician in imaging the region.

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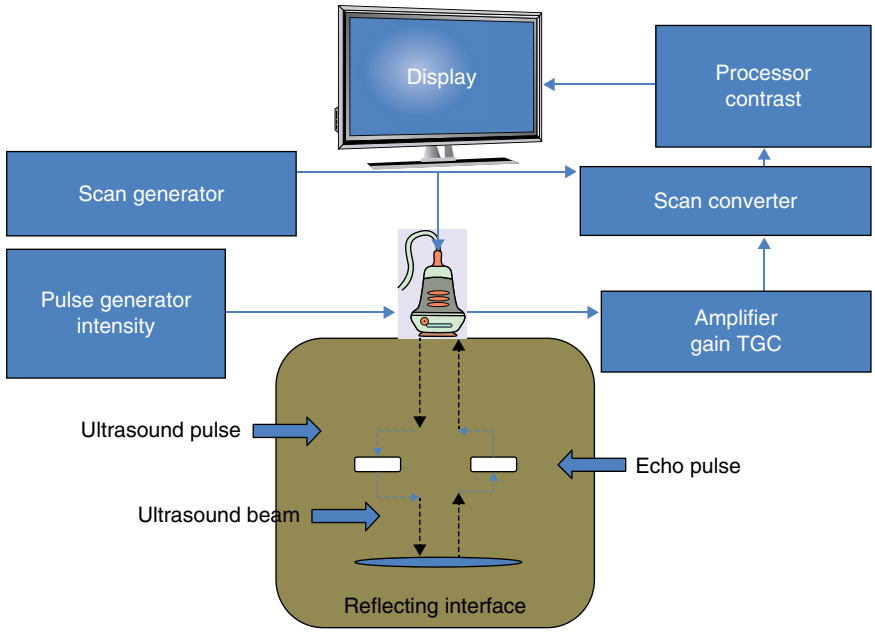

Figure 7.1 Schematic of a basic ultrasound machine. TGC, Time Gain Compensation.

Resolution

Resolution describes the amount of detail in the image. It quantifies how close two different lines can be to each other and still be visibly resolved as being two separate structures. The resolution of nerve images is significantly enhanced with a feature called "compound imaging." Compound imaging is an advanced feature offered by some ultrasound units. Multiple lines of crystals on the transducer (as opposed to a single line) emit and receive ultrasound in multiple planes. The enhanced data are then electronically reconstructed and displayed on the screen.

"Spectrum imaging" is designed for imaging by using the entire frequency territory supported by the transducer; this will produce better penetration and resolution.

The three types of resolution in ultrasound imaging are:

- detail;
- contrast; and
- temporal.

Detail resolution

Detail resolution is the ability to image two separate reflectors as two different echoes. This is determined by the axial and lateral resolution of the ultrasound pulses as they travel through tissue, as well as the closeness of the two reflectors. Focusing the beam is the best way to improve lateral resolution. The focus of the ultrasound image should be adjusted so that the level of the target structures is optimally visible. Most machines allow for the use of one or several focal zones. The zone of optimal resolution becomes smaller as the focal zones decrease. The quality of the images relates to the frequency of the sound wave, with the higher frequencies giving the best resolution, as the axial resolution improves, but with a limited depth penetration.

Contrast resolution

Contrast resolution (shades of gray) is the ability to distinguish between differences in the intensity of an image. It can also influence the detail resolution.

Temporal resolution

Temporal resolution is the ability to distinguish events that are closely spaced in time. It improves with a high frame rate.

Doppler effect

The Doppler effect is used to estimate the velocity of moving reflectors by measuring the frequency shift of sound waves. Color Doppler velocity imaging maps the mean velocity to a color scale. Color Doppler imaging is dependent on the angle between the blood flow and the ultrasound beam.

A newer color Doppler technology known as "power Doppler" estimates the integrated Doppler power spectrum. This modality is more sensitive for detecting blood flow than velocity imaging and is almost independent of the angle between the vessel and the ultrasound beam. Power Doppler is not subjected to aliasing artifacts. However, it has very high motion sensitivity and cannot provide directional information.

Color Doppler is a useful feature that helps to differentiate vascular from non-vascular structures. It may be useful to distinguish a nerve from a blood vessel when navigating sensitive anatomy (Figure 7.2).

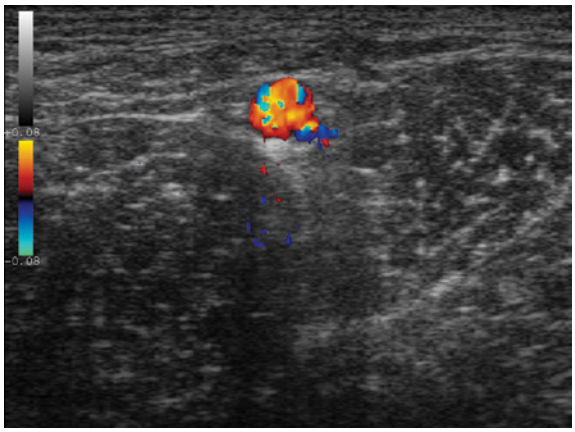

Figure 7.2 Use of color Doppler to image the femoral artery of a dog.

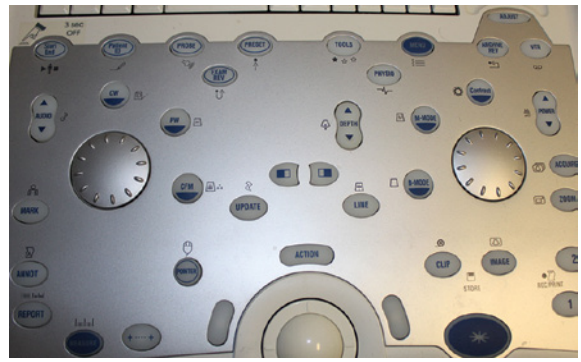

Figure 7.3 Controls on a portable ultrasound machine.

Knobology (Figure 7.3)

Ultrasound settings depend on the machine being used; however, there are some settings that may be general to all machines.

Persistence or temporal averaging

It takes the weighted average between successive image frames to reduce the ultrasound speckle noise. High levels of persistence are desired to optimize peripheral nerve imaging.

Frequency

Scanning is made possible by the piezoelectric effect, namely that if you apply voltage to a crystal, it will release sound. The higher the frequency of these emissions, the greater the resolution and the worse the penetration. For this reason, when performing nerve blocks, use the highest frequency transducer that allows for imaging of the intended structures (~9–12 MHz).

Depth

This magnifies and reduces workload for near images. Adjust depth so that the focal point lies in the centre of the image. It is also important to adjust the image depth to optimize the image of the structures of interest, finding a balance between

overview and detail, as the ultrasound image quality is reduced at large magnifications.

Focus and zoom

Focus adjustment allows maximum information to be obtained from the area of interest by altering crystal emission timing. Improved resolution is seen where the focal points are placed at the region of interest. Zoom takes a segment of an image and blows it up.

Power

The power regulates the intensity of the sound output from the transducer by changing the voltage applied to the piezoelectric crystal in the transducer. The power should be set as low as possible to obtain a good resolution and avoid artifacts. Excessive power decreases resolution; however, enough power is needed for the ultrasound to penetrate the tissues adequately. Therefore, it is important to choose a transducer frequency that will penetrate to the area of interest without requiring high power settings. The theory of ALARA states that one should use "As Low As Reasonably Achievable."

Gain

The gain is related to the amplification of the returning echoes. Gain amplifies all segments of the returning signals, but has no effect on transducer emission. Most ultrasound units have a general gain control that causes uniform amplification of all returning echoes and a surface and depth gain. Many units also have focal gain controls to amplify echoes differently at certain depths of the image. The optimal gain must be selected to optimize the image.

Time gain compensation (Figure 7.4)

The echoes returning from deeper structures are weaker than those returning from more superficial structures because of increased sound attenuation. The echo return time is directly related to the depth of the reflected surface. Increasing the gain in the deeper field will compensate for the weaker echoes returning from these structures. This function is called time gain compensation (TGC). It is available in most ultrasound units and enables control of the gain setting individually for a particular depth. The purpose of TGC is to increase the gain for echoes returning from faraway objects and to produce uniform image brightness throughout the depth of the display. Some equipment will only enable control of a near gain or far gain. It is very important to set this control properly to obtain good quality images.

Figure 7.4 Time gain compensation (TGC) controls on a portable ultrasound machine.

Artifacts

Many artifacts are generated during the use of diagnostic ultrasound. Some of these artifacts can be disruptive when attempting to obtain a diagnostic image, whereas others can be useful.

- Contact artifact is the most common artifact. It is defined as loss of acoustic coupling between transducer and skin. Firm and even pressure with the transducer, the use of ultrasound gel or alcohol between the transducer and the skin, and elimination of air bubbles between transducer and sterile cover or standoff pad are all necessary to avoid contact artifact.
- Anisotropy is the property of being directionally dependent. It describes a different resulting echogenicity of soft tissues, such as nerves, when the angle of the transducer is changed.

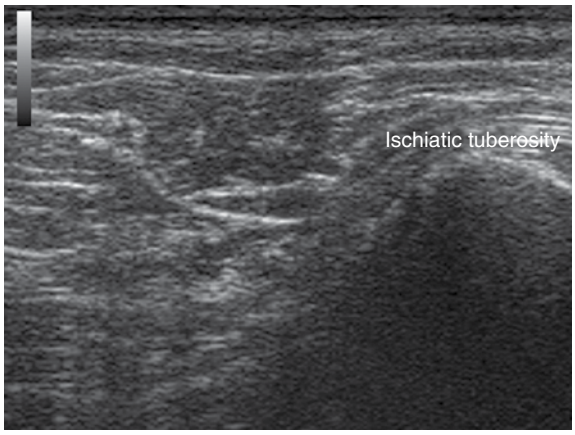

Figure 7.5 Ultrasound image from a dog. Note the acoustic shadowing caused by the ischiatic tuberosity (lower right of image). The transducer has been placed transversally in order to obtain a short axis view of the sciatic nerve between the greater trochanter and the ischiatic tuberosity.

Nerves may appear hyperechoic when the transducer is perpendicular to the nerve fiber, but can appear hypoechoic when the transducer is angled obliquely (see below).

- Acoustic shadowing. The sound waves are absorbed, reflected, or refracted as they cross different tissues, contributing to attenuation of the sound beam. The portion of the ultrasound beam that is reflected produces the ultrasound image. Acoustic shadowing (depicted as dark areas) is produced distal to highly attenuating structures, and acoustic enhancement (depicted as lighter areas) is seen distal to tissues with low sound attenuation. Acoustic shadowing occurs as a result of nearly complete reflection or absorption of the sound, and is more frequently produced by gas or bone (Figure 7.5). Acoustic shadowing is a useful artifact during performance of nerve blocks as it helps to visualize the reflective needles.

Ultrasonographic appearance of various tissues (Figure 7.6)

Different tissues will be displayed in the ultrasound image in different shades of gray depending on how much they reflect or absorb the ultrasound beam.

Fascial tissue

Fascial tissues appear as highly echogenic lines between the less echogenic adjacent tissues (i.e. muscles).

Muscles

Muscle has a heterogeneous striated appearance consistent with hypoechoic muscle fibers and echogenic fascia, connective tissue, and fat. In a short axis view, muscle presents a marbled appearance. In a longitudinal view, muscle appears as homogeneous fine parallel echoes, with the fine echoes produced by the septa between the more hypoechoic muscle bundles. The fascia and connective tissue surrounding the muscles appear highly echogenic. Muscle appears hypoechoic to tendons because of its higher water content.

Blood vessels

Vessels appear as fluid-filled circular structures in transverse view, and tubular structures in longitudinal view. Color Doppler is useful to confirm blood flow in the lumen. When the ultrasound transducer is pressed against a tissue, arteries tend to remain "open," whereas more compliant veins will be compressed and will disappear on the screen. This technique is useful when trying to differentiate structures.

Fat

Fat has an echoic speckly ultrasonographic appearance. Fat causes attenuation of the sound wave and makes imaging difficult.

Bone

The surface of the bone can be visualized with ultrasound as a very echogenic line casting acoustic shadowing due to total reflection of the ultrasound beam.

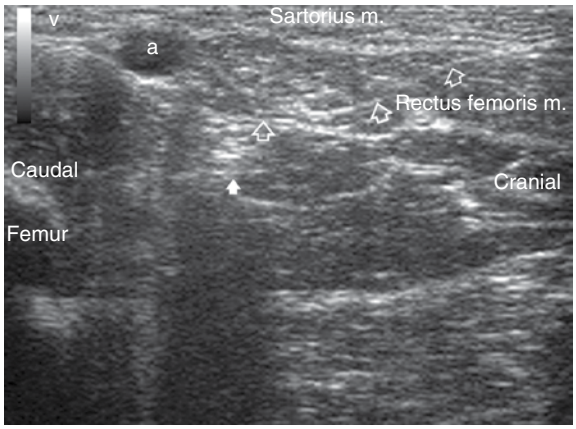

Figure 7.6 Ultrasound image at the level of the femoral triangle in a dog. Various tissue echogenicities are observed. The femoral nerve (solid white arrow) has a hyperechoic appearance compared with the surrounding tissues. (a: femoral artery; v: femoral vein; solid arrow: femoral nerve; hollow arrows: fascia iliaca).

Pleura and air

Air reflects most of the ultrasound beam due to the great difference in acoustic impedance between soft tissues and air. The normal visceral pleural surface of the lung appears as a hyperechoic line with distal reverberation artifacts. The visceral pleural surface can be seen moving against the parietal pleural with respiration.

Equipment selection

A large selection of ultrasound equipment is available, ranging from small, portable, relatively inexpensive units, to more sophisticated cart-based units. When selecting equipment for use in clinical anesthesia, it is important to be able to obtain good quality images of the nerves of interest. The quality of the nerve images obtained depends on the quality of the ultrasound machine, the proper transducer selection for each individual location, as well as the clinician's skills. Despite the equipment used, it is critical to be familiar with the anatomy of the area and to have a good understanding of the unit and the knowledge to change the image settings to optimize the image. In general, the peripheral nerve blocks performed in animals can be accomplished with portable ultrasound systems. High frequency transducers (10–15 MHz) are more suitable for imaging superficial nerves that are less than 5 cm in depth. Lower frequency transducers (4–7 MHz) are needed for imaging deeper structures. Peripheral nerves are usually visualized with linear array transducers. The highest frequency transducer that will penetrate to the depth needed for a particular examination should be selected, as it will provide the best image quality.

The resolution of nerve images is significantly enhanced with a feature called "compound imaging." Compound imaging is an advanced feature in some units. Multiple lines of crystals on the transducer (opposed to a single line) emit and receive ultrasound in multiple planes. The enhanced data are then electronically reconstructed and displayed on the screen. Color Doppler can also be a useful feature that permits the differentiation of vascular and non-vascular structures. There are many portable compact units currently available with many of these advanced features that are suitable for peripheral nerve imaging.

Practical approach to ultrasound-guided peripheral nerve blockade

Sound knowledge of the anatomy of the area of interest is critical in order to interpret the ultrasound image. When performing peripheral nerve blocks, it is also important to identify small arteries or veins that may be located in the vicinity. Nerves have a homogeneously echoic appearance, whereas arteries have a more anechoic appearance with thick walls. Power Doppler is a good tool to distinguish between them.

Before performing a block, it is important to purge all the air from the needle/syringe system as once the anesthetic solution is injected, even a small amount of air will cause artifacts in the ultrasound image.

Nerve visualization

Using transverse images (short axis) makes identification of nerves easier. Peripheral nerves have a round to oval shape with internal hypoechoic nerve fascicles surrounded by the hyperechoic epineurium when imaged in a short axis view (Figure 7.6).

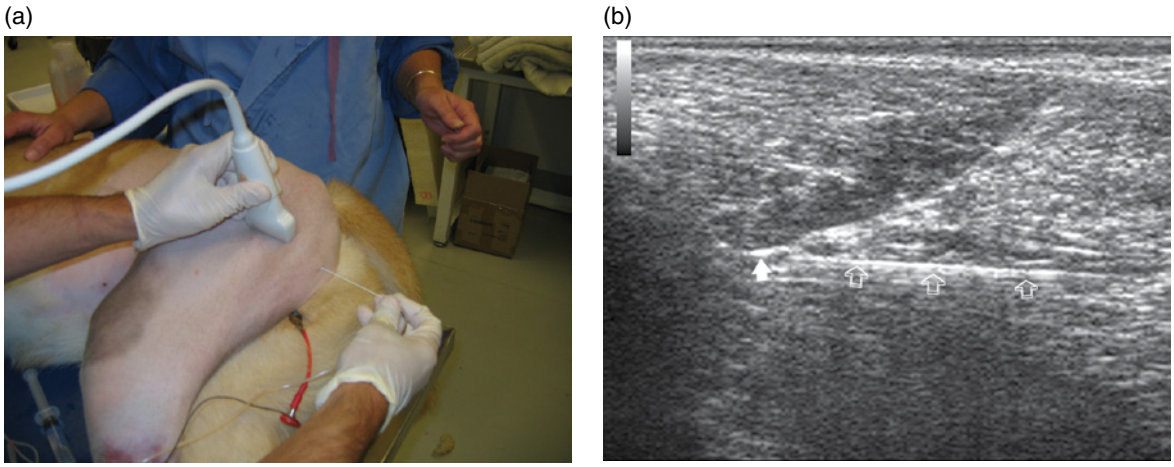

Figure 7.7 (a) Sciatic nerve block being performed in a dog. An "in-plane" needling technique is being used whereby the shaft of the needle is advanced along the long axis of the ultrasound beam. (b) Ultrasound image of the sciatic nerve in a dog (solid arrow). A needle is being guided towards the nerve using the "in-plane" technique. The hyperechoic linear echo of the full needle (arrows) is visualized as it is advanced towards the nerve.

It is useful to know the course and divisions of the target nerves for easier identification. Transducer manipulation is also important for nerve imaging, as nerve echogenicity will increase or decrease drastically depending on the angle of imaging; that is why nerves sometimes appear with a hyperechoic, hypoechoic, or "honeycomb" structure. A clear target image is displayed only when a strong signal is returned to the transducer. For this reason, image quality and structural echogenicity are highly dependent on the angle of incidence, which is best at 90° (i.e. beam is perpendicular to the target). Even with the most sophisticated equipment, a hyperechoic target may appear hypoechoic (a phenomenon called "anisotropy") and may even become invisible when the signal return is poor. Most peripheral nerves have an internal fascicular pattern characterized by hypoechoic (dark) fascicles surrounded by hyperechoic (bright) connective tissue. This fascicular echotexture results in the "honeycomb" appearance of nerves when imaged on their short axis. Although the genesis of this fascicular echotexture pattern is not completely understood, approximately one-third of the number of fascicles detectable under light microscopy are visible during ultrasound at 15 MHz (Silvestri et al. 1995).

Needle positioning using "inline" or "in-plane" technique (Figure 7.7a)

This approach aims to align and move the long axis of the needle along the long axis of the ultrasound beam. With this approach the full needle tip and shaft are within the field of view (Figure 7.7b). The target is positioned away from the side of the approaching needle.

Needle positioning using "out-of-plane" technique (Figure 7.8a)

With this approach the needle is positioned perpendicular to the long axis of the transducer, so it crosses the plane of imaging as an echogenic (bright) dot (Figure 7.8b). The target is usually placed in the center of the field of view. The needle tip must be identified (and distinguished from the needle shaft) when using this technique and can be followed by sliding and tilting of the transducer as the needle is advanced. If the tip of the needle is in the ultrasound window, the spread of local anesthetic can be visualized during injection.

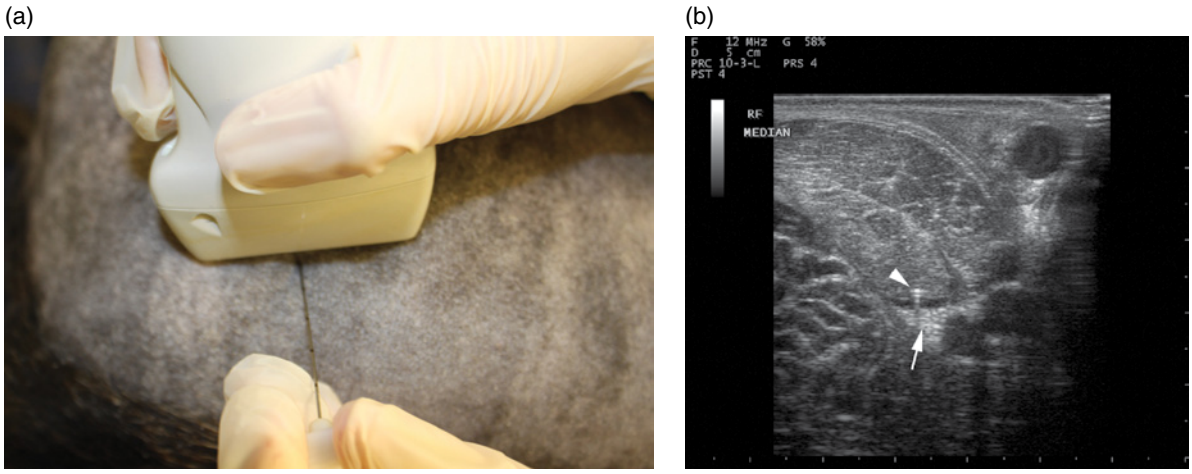

Figure 7.8 (a) An ultrasound-guided nerve block being performed in a dog. An "out-of-plane" needling technique is being used whereby the needle is advanced perpendicular to the transducer, crossing the plane of the ultrasound beam. (b) Transverse ultrasound image of the median nerve (arrow) in a horse. A needle is being guided to the median nerve using an "out-of-plane" needling technique. The needle tip is visualized in this image (solid arrowhead) as an echogenic dot abaxial to the median nerve. Note the local anesthetic solution surrounding the needle tip (anechoic shadow between the needle and the nerve).

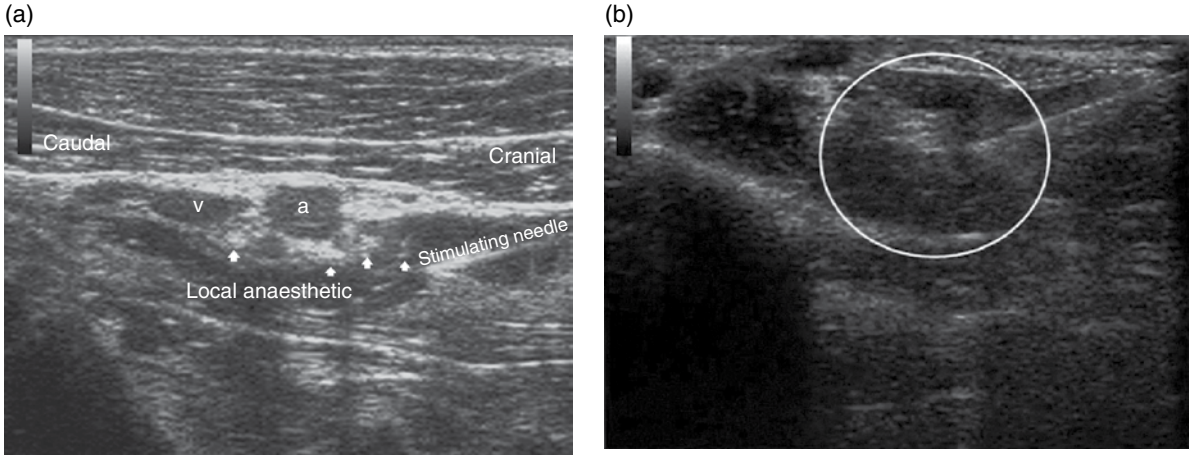

Figure 7.9 (a) Ultrasound image of the brachial plexus of a dog. Note the local anesthetic solution spreading around the nerve of the brachial plexus deep to the axillary vessels. (a: axillary artery; v: axillary vein; solid arrows: nerves of the brachial plexus). (b) Local anesthetic solution being injected around the femoral nerve of a dog.

Visualization of local anesthetic administration (Figure 7.9a)

The local anesthetic can be visualized around the nerve as it exits the tip of the needle and spreads as anechoic (black) shadow (Figure 7.9b). The fluid often forms a ring around the nerve, an observation referred to as the "doughnut sign." This sign is important to observe as it helps to rule out intravascular needle placement. Failure to observe the spread of the local anesthetic may also indicate an intravascular injection, even in the absence of blood aspiration, as the pressure applied by the transducer may occlude venous structures making aspiration negative (Robards et al. 2008). If this dispersion is not observed, the injection should be

stopped immediately and the needle repositioned. If the syringe has not been properly purged of air, hyperechoic echoes will be visualized within the fluid.

Advantages of ultrasound- versus nerve stimulator-guided peripheral nerve blocks

Used in conjunction with electrostimulation, ultrasound-guided techniques offer numerous advantages including:

- guiding the needle into the correct position with greater accuracy, thereby improving the success rate of the block when compared with conventional blind or electrolocation techniques (Sandhu et al. 2006; Casati et al. 2007; Oberndorfer et al. 2007);
- minimizing block performance time (Williams et al. 2003);
- reducing the need for multiple needle passes, helping to reduce tissue damage (Sites et al. 2006; Sites and Brull 2006);
- identifying flow when using color-flow Doppler, which is useful for confirming blood vessels;
- navigating away from sensitive anatomy, thereby reducing the risk of complications such as vascular laceration (Gray 2006); and
- monitoring the perineural spread of local anesthetic during the injection.

Ultrasound guidance for nerve localization holds the promise of improving block success and decreasing complications. However, current literature still fails to show a significant difference in block success rates for surgical anesthesia between electrolocation and ultrasound-guided techniques (Griffin and Nicholls 2010). Therefore, it seems that the use of ultrasound will not always necessarily prevent intraneural injection. As Allan et al. (2011) stated "If you consider the answer to the question 'is it prudent to avoid intraneural injection?' to be 'yes', then current evidence would support using ultrasound guidance over other techniques." However, in a recent study by Liu et al. (2011) that reported their experiences with 257 human patients, intraneural injections were detected in 17% of patients during ultrasound-guided blocks, but none of the patients developed postoperative neurological complications at follow-up (one week, four to six weeks and end of study).

How is electrolocation combined with ultrasound-guidance used?

Although ultrasound-guidance and electrostimulation-guidance are fully useable separately for performing nerve blocks, they are most useful when combined. With skillful application of anatomic knowledge, peripheral nerve blocks can be performed successfully using electrostimulation-guidance alone. If ultrasound-guidance is used to aid location of nerves, the stimulator still has a very useful role to exclude mistakenly injecting tissue artifacts instead of the nerve, and to also locate an invisible nerve within a visible compartment that is known to contain the nerve.

The primary tool used to guide the needle to the nerve is the ultrasound produced two-dimensional image. Tissue structures are identified as being either the actual nerve or as containing the unseen nerve.

The nerve stimulator is useful for confirming that the visualized structure is actually the nerve and not an artifact such as a tendon, a blood vessel, a lymph node, etc. Sometimes only a zone within fascial planes is seen, without an actual nerve being visualized. In this case, the nerve stimulator needle can be used to "explore" the zone of interest, as would be the case where ultrasound is not available.

The paradigm of how the nerve stimulator should be used in combination with ultrasound-guidance is different from when it is used as the primary tool for locating a nerve. When used together, the nerve stimulator is simply used to *confirm* that a structure is a nerve, rather than being used to search for the nerve.

When using a nerve stimulator together with ultrasound imaging, set the nerve stimulator's frequency as slow as possible (1 Hz). This will result in fewer twitches per second, and will result in less disturbance in the ultrasound image. Set the nerve stimulator current to the expected level that will result in a muscle twitch only if close contact is made between the needle and the nerve (i.e. 0.4 mA).

Therefore, any twitch that is elicited will be a positive response, without any further need to adjust the needle position or the nerve stimulator. At this point, injection of local anesthetic drug can be performed.

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Part 3

Loco-regional Anesthetic Blocks for Small Animal Patients

8 Incisional Infiltration of Local Anesthetics and Use of Wound Catheters

Matt R. Read

Overview

In people and animals, providing effective postoperative analgesia is important from the patient's perspective and has been shown to improve clinical outcomes. A significant number of human patients experience moderate to severe postoperative pain following surgical procedures (Liu et al. 2006), and animals would not be expected to be any different. Multimodal analgesic techniques are becoming increasingly popular for treating pain in animals. Local anesthetic drugs can be used in a variety of ways including topical administration into surgical wounds ("splash blocks"), infiltration into target tissues ("field blocks"), specific nerve blocks, epidural administration, and intra-articular injection. As has been described elsewhere, local anesthetics have their primary analgesic action by preventing the generation and transmission of nerve impulses by blocking the influx of sodium across the cell membrane of nerve axons and inhibiting conduction of action potentials. Although veterinarians and physicians have been using direct injection of local anesthetics into tissues as the simplest form of analgesia for surgery and other painful procedures for decades, over the last 10 years there has been a resurgence of interest in the use of local anesthetics at the surgical site. Also, there are many new reports of using tissue infiltration of local anesthesia via indwelling catheters as a method for providing prolonged pain relief in the postoperative period.

Incisional infiltration with local anesthetics

Wound infiltration involves the injection of a local anesthetic directly into the surgical field, and is popular in human and veterinary medicine due to its relative simplicity, safety, and low cost (Moiniche et al. 1998; Carpenter et al. 2004; Savvas et al. 2008). In people, this has been used to provide operative analgesia since the early 1900s, and, interestingly enough, the term "balanced anesthesia" was originally used in reference to local infiltration analgesia in combination with light general anesthesia (Brower and Johnson 2003). This technique is commonly used in people to provide analgesia to surgical patients, and includes infiltration,

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topical administration, or instillation of the local anesthetic into skin, subcutaneous tissue, fascia, muscle, and/or parietal peritoneum (Moiniche et al. 1998). Local anesthetics such as lidocaine and bupivacaine are used in this way to provide postoperative pain control, and have been shown to reduce pain scores and the need for supplementary analgesics, to extend the time to the patient's first request for analgesia, and to reduce the duration of hospital stays.

In a systematic review, Moiniche et al. (1998) reported the results of 26 randomized, controlled trials with data from more than 1200 patients. Studies included in their analysis were double-blinded, randomized comparisons of local anesthesia with either placebo (saline) or nonplacebo (no treatment). They only included reports that examined analgesia following abdominal incisions and only those that described administration of incisional local anesthesia. The authors of the review reported that the location of infiltration played an important role in the success of the intervention, and that there was a significant dose–response relationship observed in these studies, with larger doses (highest concentration) of local anesthetics resulting in the most pronounced pain relief. They also reported that the beneficial effects of most studies were short-lived (two to seven hours), and that up to the time of their publication in 1998, the human literature "provides no support for an analgesic effect outlasting the pharmacological effect" of incisional local anesthesia, meaning that the postoperative benefits that are seen relate to the expected duration of the particular drug that is used. Eight of the 26 articles reviewed were unequivocally negative, meaning that there was no documented benefit of the incisional use of local anesthetics. In their conclusions, the authors stressed the importance of where and how much local anesthetic is used for these types of local infiltration techniques. As one could presume, it matters what and how much you use, and where you put it. This is undoubtedly true for veterinary patients as well.

Recently, three studies have reported the results of using incisional infiltration of local anesthesia for provision of preemptive and postoperative analgesia for a variety of abdominal surgeries in dogs (Carpenter et al. 2004; Savvas et al. 2008; Fitzpatrick et al. 2010). In the first study, immediately prior to closure of the linea alba, Carpenter et al. (2004) randomly administered 0.88 mL kg^{-1} 0.9% saline, 8.8 mg kg^{-1} 2% lidocaine with epinephrine (1:200 000), and 4.4 mg kg^{-1} 0.75% bupivacaine into the intraperitoneal space. The lidocaine and bupivacaine were diluted with saline until an equivalent final volume of 0.88 mL kg^{-1} was used. They also administered a "splash" block using 2 mL of either saline, 2% lidocaine with epinephrine, or 0.75% bupivacaine immediately prior to closure of the skin of each dog. The blinded investigators found that intraperitoneal and incisional bupivacaine provided effective analgesia following ovariohysterectomy in their dogs. More dogs in the control group were given supplemental analgesia than in the bupivacaine group, and bupivacaine dogs had lower pain scores (using visual analog and composite pain scores) and were less sedate than control dogs.

Savvas et al. (2008) compared saline and bupivacaine 0.25% (2 mg kg^{-1}) for preoperative or postoperative incisional use. They injected the respective solution in a fan-like fashion both subcutaneously and intramuscularly at the proposed incision site, either just before the start of the incision or at the end of surgery following subcutaneous tissue closure (Figure 8.1). They were careful to make sure that the entire length of the incision was infiltrated. The study was blinded, and showed that preoperative administration of bupivacaine to dogs resulted in significantly lower pain scores and less frequent use of additional postoperative analgesia compared to the other three groups. In that study, none of the preoperative bupivacaine dogs required

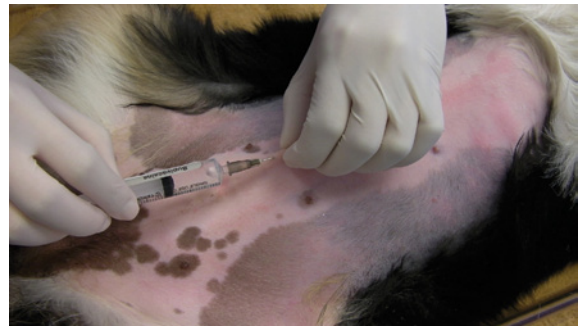


Figure 8.1 Photograph of local infiltration along a planned incision site using bupivacaine prior to exploratory laparotomy in a dog.

additional postoperative analgesics, and the authors concluded that this was a simple, attractive and effective technique to reduce postoperative pain for at last 24 hours after celiotomy in dogs.

Most recently, Fitzpatrick et al. (2010) reported the results of a study that used infiltration of local anesthetics as part of a multimodal approach to managing pain following ovariohysterectomy in dogs. They enrolled 92 dogs scheduled for elective ovariohysterectomy and randomly assigned these dogs to one of four different treatment groups: no perioperative incisional injections, preoperative infiltration with saline, preoperative infiltration using 2 mg kg^{-1} bupivacaine diluted with saline to a total volume of 0.8 mL kg^{-1}, or postoperative infiltration using 2 mg kg^{-1} bupivacaine diluted with saline to a total volume of 0.8 mL kg^{-1}. The respective solutions were infiltrated along the superficial and deep tissues of the incision site. The dogs received morphine in their premedication, hydromorphone at extubation, buprenorphine every six hours for 24 hours, and carprofen 2.2 mg kg^{-1} every 12 hours. A blinded observer used a composite pain scale and a quantitative tool (von Frey filaments) to test peri-incisional analgesia up to 24 hours following surgery. The authors found no significant differences in pain scores, doses of rescue analgesics, and responses to von Frey filaments between the different treatment groups, and were unable to demonstrate supplemental analgesia from the bupivacaine incisional block in their dogs that were receiving multimodal analgesia. None of the dogs in any of the groups required rescue analgesia, and there was no evidence that incisional bupivacaine increased the incidence of complications.

Lykkegaard et al. (2005) developed a model to assess surgical pain and stress in pigs. Using this model, they investigated the use of preoperative infiltration of a local anesthetic solution into the abdominal wall of pigs, and measured the effects of this preemptive analgesic intervention on spinal nociception and activation of the hypothalamic-pituitary (HPA) axis. In that study, 10 minutes prior to surgery the skin, muscle, and peritoneum of the flanks of pigs were either infiltrated with saline or a mixture of lidocaine and bupivacaine. A third group of pigs was anesthetized but did not undergo surgery (sham group). Two hours after surgery, half the pigs from each group were euthanized and c-fos gene expression was measured in the dorsal horn of the spinal cord. Expression of this gene is frequently used in laboratory studies as a marker of nociception and a measure of neuronal activity following various painful stimuli. The surviving pigs had blood collected at predetermined times postoperatively for determination of ACTH, cortisol, C-reactive protein, and interleukin-6 concentrations. Their results showed that when compared to the saline infiltration group, the sham and local anesthetic groups of pigs had no increases in the expression of c-fos, and the saline infiltration group had dramatic increases in plasma ACTH and cortisol compared to the other two groups (Figure 8.2). The authors concluded that preoperative incisional infiltration of a local anesthetic can have profound inhibitory effects on spinal nociception and HPA axis activation caused by surgery, and recommended the use of directly applied local anesthetics during surgery and other traumatic procedures.

To date, there have been no published reports of incisional infiltration of local anesthetics in cats. Based on the results from the canine studies reported above, more research is needed to establish the ideal anatomic location for infiltration, and the optimal drug choices, doses, and concentrations to be used for these types of blocks.

Continuous wound infusion with local anesthetics

Although other regional anesthetic techniques (epidural analgesia, regional nerve blocks) can provide excellent analgesia for surgery and the immediate postoperative period, these methods are sometimes contraindicated or require specialized equipment or extensive technical experience on the part of the anesthetist. As discussed above, the use of single-injection local anesthetic infiltration is limited by the duration of action of the particular agent used. A promising new modality is the relatively simple technique of placing a multifenestrated (multiholed) catheter into the surgical wound at the end of the procedure. This technique can be used to provide analgesia following a variety of surgical procedures, is technically very simple to perform, offers the potential for complete analgesia, and has the added benefit of permitting repeated or continuous infusion of local anesthetics

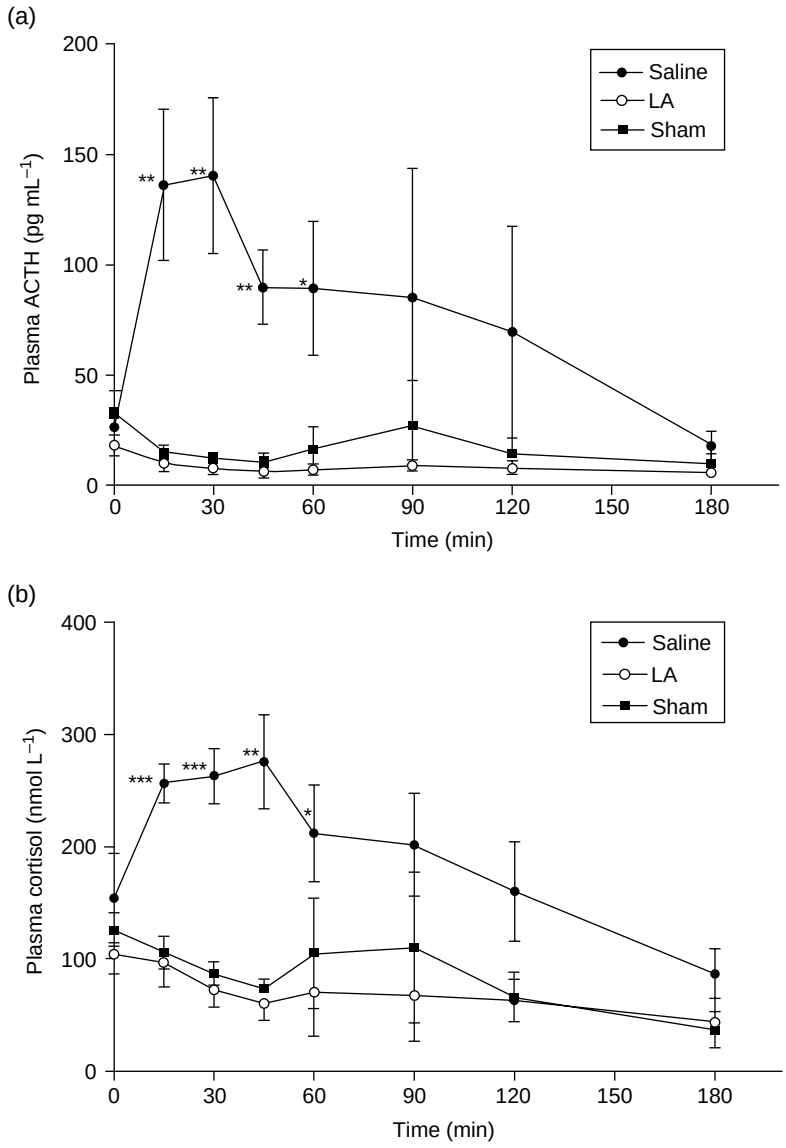


Figure 8.2 (a) Plasma ACTH concentration in pigs following unilateral laparotomy with (●, n = 5) and without (○, n = 6) infiltration with local anesthetic. The incision of the skin was started at Time = 0. The sham group (■, n = 4) was anesthetized but no surgery was performed. Values represent means ± SEM. * indicates significant differences between groups operated with and without local anesthetic (* $P<0.05$ and ** $P<0.01$). (b) Plasma cortisol concentration in pigs following unilateral laparotomy with (●, n = 5) and without (○, n = 6) infiltration with local anesthetic. The incision of the skin was started at Time = 0. The sham group (■, n = 4) was anesthetized but no surgery was performed. Values represent means ± SEM. * indicates significant differences between groups operated with and without local anesthetic (* $P<0.05$; ** $P<0.01$; *** $P<0.001$). From Lykkegaard et al. 2005. Used with permission.

into the wound for a prolonged period of time postoperatively. Also, there is the perceived benefit of the operator not needing to be competent in all of the aspects of performing a 'typical' regional anesthetic block (e.g. knowledge of specific nerve anatomy, access to specialized equipment such as nerve stimulators, ultrasound, insulated needles, etc.). In people, the increasing use of portable

infusion pumps in combination with indwelling fenestrated wound soaker catheters has the added benefit of being an ambulatory "at-home" analgesic technique, thus potentially shortening the hospital stay.

Wound soaker catheters are small, flexible catheters that can be positioned in tissues at or near a surgical field to allow for prolonged administration of local anesthetic solutions for analgesia in the postoperative period. Clinical investigations of this technique in people following a variety of surgical procedures have demonstrated not only improved pain control, but also decreased postoperative opioid use and its associated side effects in people such as nausea, vomiting, and urine retention.

Indications and uses

Wound soaker catheters can be used for providing postoperative analgesia for a variety of surgical procedures. In people, they have been shown to be highly effective when used in combination with systemically administered analgesic agents as part of a balanced analgesia plan. In many cases, wound soaker catheters have been shown to be superior to other methods of postoperative analgesic techniques such as systemically administered opioids and nonsteroidal analgesic drugs.

Review of human studies

In people, wound soaker catheters are typically placed into surgical incisions at the end of surgery to provide postoperative analgesia for major procedures. Their use has been reported following general surgery (upper abdominal, vascular), sternotomy, mastectomy, gynecology and urology procedures, and orthopedic surgery (Liu et al. 2006; Sidiropoulou et al. 2008; Tirotta et al. 2009). In these instances, catheters are placed in a variety of locations: subcutaneous, subfascial, intra-articular, periosteal, and peripleural (Liu et al. 2006).

A large meta-analysis review of 44 clinical trials that enrolled a total of 2141 patients looked at the effects of wound catheters in clinical pain practice in people (Liu et al. 2006). Only prospective, randomized controlled trials were included, and only those that assessed either self-reported visual analog (VAS) scores or opioid consumption were included. Surgeons placed the wound catheters at the end of surgery, and all trials included control groups whereby either no catheters were used or catheters were placed and either saline or water were infused as placebos. All patients had catheters in place for >24 hours. Bupivacaine and ropivacaine (0.25% and 0.5% solutions) were the primary local anesthetics used for the wound infusions. Local anesthetics were administered an average of two days postoperatively. For all groups combined, VAS pain scores were reduced considerably both at rest and during activity. The need for opioid rescue analgesia was decreased in the wound catheter groups versus the control groups (44% vs. 66%, respectively). The percentage of patients reporting excellent analgesia was greater in the continuous local anesthetic groups (43% vs. 13%). In orthopedic patients, this difference was even more significant, with 92% vs. 27% reporting excellent analgesia in the local anesthetic versus control groups. Length of hospital stay was reduced by a day in the local anesthetic groups, which was also significant. In 12 of 14 trials involving thoracotomy, wound catheter patients reported lower pain scores and had lower postoperative opioid use. Ten of 12 general surgery studies (vascular, upper abdominal) reported lower pain scores and decreased opioid use in wound catheter patients. Patient satisfaction was reported to be better in patients receiving wound soaker catheters. Thirteen of 16 orthopedic studies reported substantial analgesic efficacy, either as reduced pain scores or as reduced opioid consumption. Pain scores were decreased in 11 of the 16 trials through postoperative days two to five.

Wound catheters have also been used in women undergoing mastectomy procedures (Sidiropoulou et al. 2008). Results showed low VAS pain scores and less disability later in the postoperative period (16–24 hours) in patients receiving wound catheters when compared to patients receiving preoperative single-shot thoracic paravertebral blocks. There were also less opioid-related side effects in the wound soaker catheter patients.

Continuous wound catheters have also been tested in pediatric patients undergoing sternotomy for cardiac procedures (Tirotta et al. 2009).

A prospective randomized double-blinded study documented lower opioid use over the first 24 hours following surgery in patients receiving wound catheters, and an earlier return to bowel function. There were no differences in pain scores over the study period, and plasma levels of local anesthetics remained below the toxic thresholds during the study.

Despite a high level of heterogeneity in terms of surgical procedures, location of wound soaker catheters, modes of delivery of the local anesthetic, and the doses and types of the administered local anesthetics, there are many data that document global reductions in pain scores and opioid use, fewer opioid-related side effects (nausea, vomiting), increased patient satisfaction, and a decreased duration of hospital stay in patients receiving local anesthetic infusions through wound catheters. There is growing evidence that locally applied local anesthetics can also inhibit inflammatory responses that can sensitize nociceptive receptors and contribute to pain and hyperalgesia (Liu et al. 2006; Lykkegaard et al. 2005). The incidences of technical failure (1%), infection (0.7%), and local anesthetic toxicity (0%) are extremely low, and the technique is relatively inexpensive and technically easy to perform.

Review of veterinary studies

In animals, use of wound catheters has been reported for procedures such as total ear canal ablation, amputation, oncologic surgery, and closure of large wounds (Radlinsky et al. 2005; Wolfe et al. 2006; Davis et al. 2007a, 2007b; Abelson et al. 2009).

Total ear canal ablation-bulla osteotomy in dogs

Two randomized, blinded, controlled studies have evaluated the postoperative analgesic efficacy, degree of sedation, and incidence of complications associated with the use of a continuous ambulatory infusion of either lidocaine or bupivacaine following major ear surgery in clinical patients (Radlinsky et al. 2005; Wolfe et al. 2006). In the study by Radlinsky et al., 16 dogs were enrolled. At the end of surgery, treated dogs had wound soaker catheters placed in the tissues lateral to the bulla and received either 0.5% or 0.75% bupivacaine from an elastomeric pump via the catheter. Control dogs received saline infusions via similarly placed catheters. All dogs received morphine at the time of extubation and at intervals up to four hours depending on their perceived need. Wound catheters were removed after 48 hours.

In the study by Wolfe et al., twenty dogs had wound catheters placed at the end of their surgeries (Figure 8.3). Ten treated dogs received 2% lidocaine infusions (25–50 $\mu g\,kg^{-1}\,min^{-1}$) administered by elastomeric pumps via the wound catheters and saline infusions administered intravenous by syringe pump. Ten control dogs received saline via the wound catheters and intravenous morphine (0.12 $mg\,kg^{-1}\,h^{-1}$) infusions by a syringe pump. In all dogs, catheters were placed prior to surgical wound closure, and the use of local anesthesia administered via wound catheters was subsequently compared to the use of systemically administered morphine that was administered by either boluses or infusions.

Both of these studies reported no significant differences between their two treatment groups. Analgesia was considered to be comparable between their treatments; however, both studies described low inter-observer agreement in terms

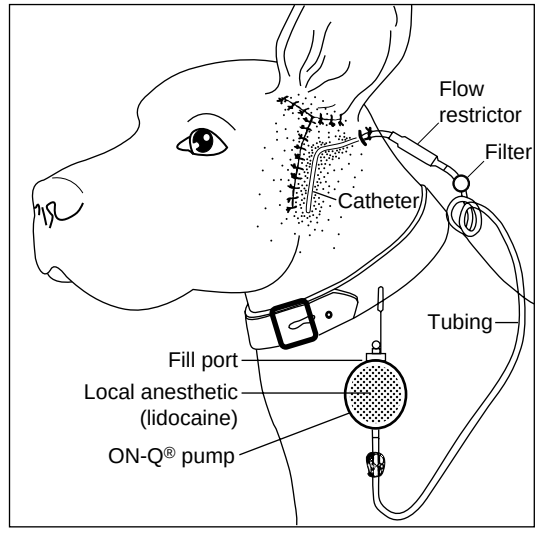


Figure 8.3 Application of a continuous infusion pump for local anesthetic wound infiltration following total ear canal ablation in a dog. From Wolfe et al. 2006. Used with permission.

of pain scoring (Wolfe et al. 2006) and low pain scores in general (Radlinsky et al. 2005), making statistical significance difficult to achieve with the number of dogs enrolled in each of the studies. Wolfe et al. (2006) reported similar overall pain scores, but dogs in the local anesthetic group showed lower levels of sedation than dogs in the intravenous morphine group and there were fewer drug-related complications in the lidocaine group than those in the morphine group (e.g. uncontrolled pain, dysphoria, respiratory distress, drug overdose). Wound soaker catheter dogs also received less rescue analgesia than dogs in the morphine group, although this finding was not statistically significant. In the study by Radlinsky et al. (2005), plasma

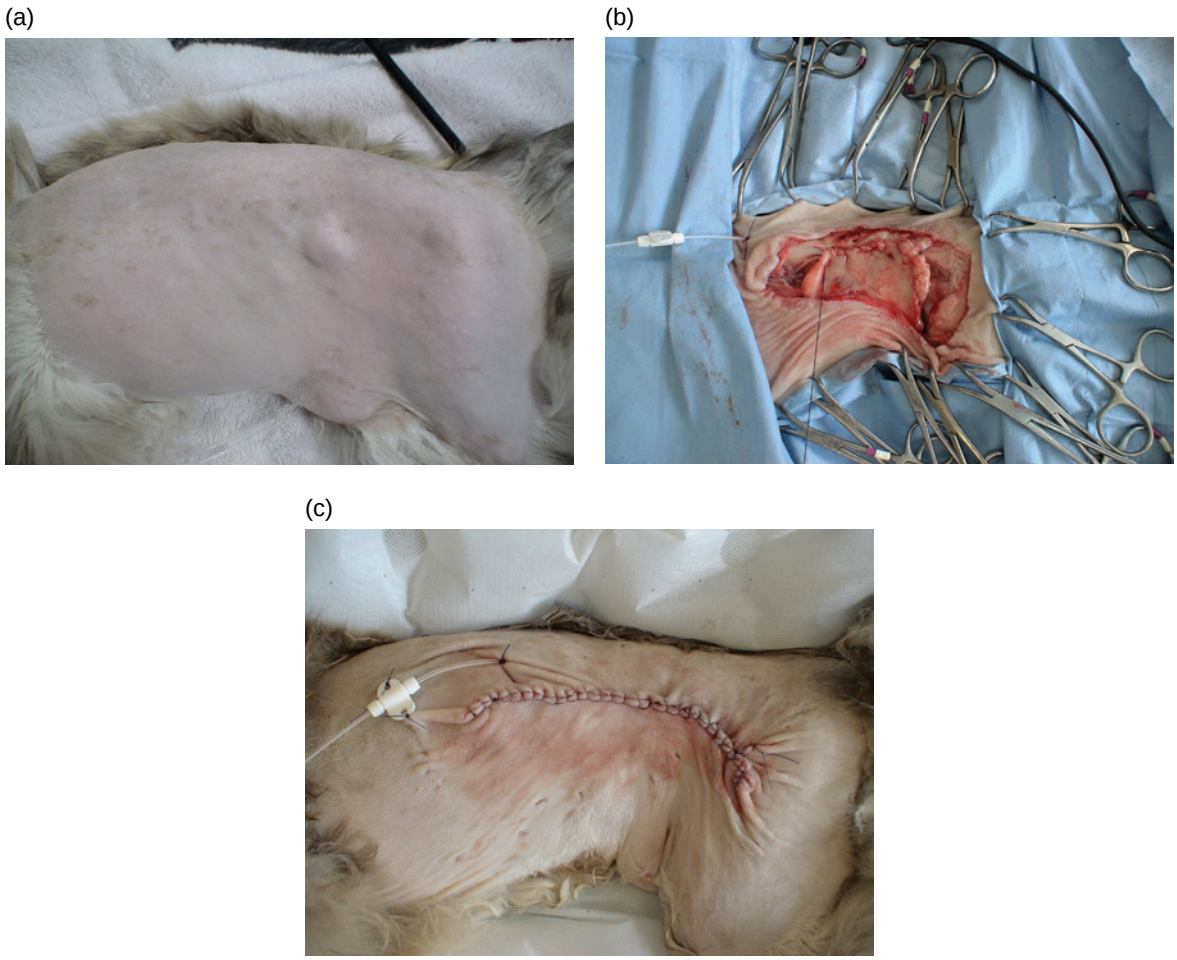


Figure 8.4 (a) An example of how a wound soaker catheter can be used for provision of pain management to a surgical patient. This photograph shows the clipped left side of a cat with a sarcoma located in its flank region (the left of the photograph is cranial, the bottom of the photograph is ventral). Surgical resection with wide margins was planned as part of this cat's treatment. (b) Photograph of the same cat in surgery. The mass has been excised with wide margins and a wound soaker catheter has been placed deep into the surgical wound. Superficial tissue layers are being sequentially closed over the catheter. (c) Photograph of the same cat following surgery. The incision has been closed and the wound soaker catheter has been secured in place by suturing the moveable wings (upper left) to the skin. The catheter was left in place for five days while the cat was hospitalized to allow local anesthetic solutions to be administered as part of this cat's multimodal approach to pain management. The cat recovered uneventfully.

bupivacaine levels were not detected in any patients, and the authors concluded that although their data suggest that the potential for local anesthetic systemic toxicity is low, their infusion rates (0.13–0.21 mg kg^{-1} h^{-1}) may have, in fact, been inadequate for providing additional analgesia beyond that provided by the concurrently administered doses of morphine. Despite questions still remaining after these studies, in clinical practice wound soaker catheters are used commonly for management of pain following these invasive surgical procedures.

Feline oncologic surgery

Davis et al. (2007a, 2007b) described the use of wound soaker catheters for providing analgesia to cats following major oncologic surgeries. Wound catheters were placed prior to wound closure, and were used as a component of multimodal analgesia in combination with systemically administered opioids, ketamine, nonsteroidal anti-inflammatories, and α_2 adrenoreceptor agonists. These authors reported that, compared with cats not receiving wound catheters, cats receiving local anesthetic infused through wound catheters spent significantly less time in hospital than those cats that did not receive a local anesthetic infusion (Davis et al. 2007b). These conclusions were based on these cats becoming mobile more quickly and showing a faster return to having normal appetite. No increases in postoperative wound infection rates were documented in these reports. See Figure 8.4 for an example of how wound soaker catheters can be used for provision of analgesia following oncologic surgery in cats.

Amputation

Abelson et al. (2009) reported their experiences of using wound soaker catheters for providing analgesia to a variety of surgical patients in a veterinary teaching hospital over a two-year period. The majority of the cases described in their report were dogs that underwent amputation of their thoracic or pelvic limbs (46 of 56 cases) (Figure 8.5). Catheters remained in place between 12 hours and three days (mean 1.6 days). Their patients received either bupivacaine administered as intermittent boluses or lidocaine administered as continuous infusions. The authors suggested that those patients that received local anesthetic through wound soaker catheters received less systemically administered opioids than dogs that did not have wound soaker catheters placed. This resulted in less sedation and a more rapid return to mobility, eating, and urination, and led to a shortened period of overall hospitalization for the wound catheter patients.

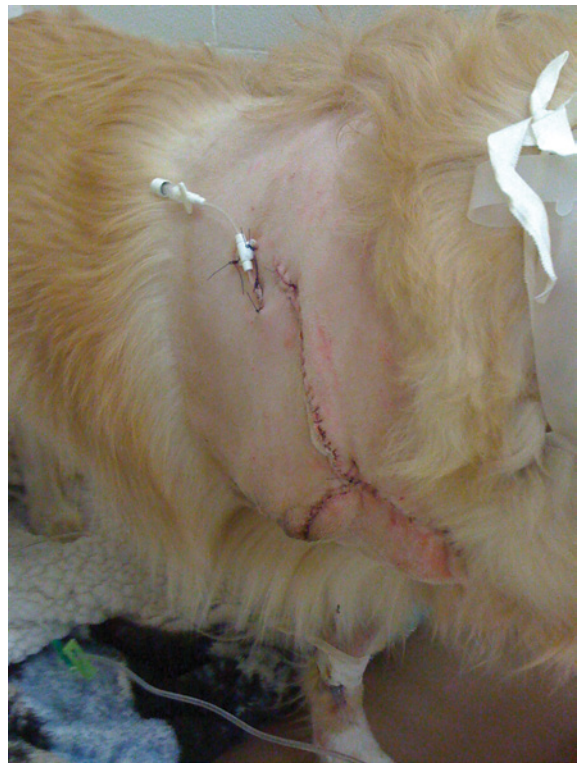


Figure 8.5 Photograph of a dog following right thoracic limb amputation. A wound soaker catheter was placed into the surgical incision during wound closure, and has been left in place to provide local analgesia postoperatively.

Distribution

No studies have been conducted in animals to describe the distribution of local anesthetics administered through wound soaker catheters. Distribution would be expected to depend on the volume of local anesthetic administered, the degree of blood flow to adjacent tissues (leading to

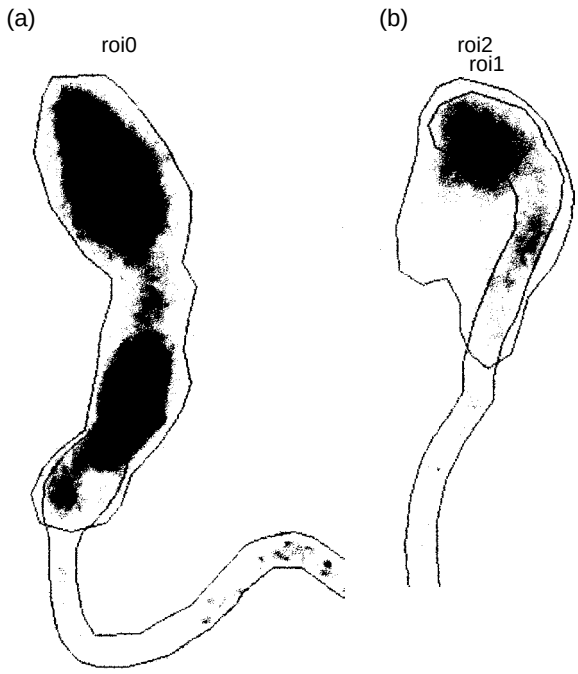


Figure 8.6 Catheter placement relative to wound spread area of ^{99m}Tc-DPTA administered through a triple-orifice epidural catheter (a) and a 15-cm multiholed catheter (b) placed in the subfascial layers of wounds in human total hip arthroplasty patients (lateral projections). From Andersen et al. 2010. Used with permission.

systemic absorption), and the degree of dead space associated with the surgical site following wound closure. In a prospective study performed in people, investigators compared the spread of solutions that were injected through either triple-orifice epidural catheters or 15-cm multiholed wound catheters (Andersen et al. 2010). Radioactive-labeled saline was administered postoperatively through catheters that were placed in subfascial layers of wounds following total hip arthroplasty, and wound spread of the saline was recorded with a double-head gamma camera. The results showed that both catheter systems resulted in acceptable spread of the injectate through the wounds, but no evaluation of analgesic efficacy was made as no local anesthetics were administered (Figure 8.6).

In the study by Wolfe et al. (2006), wound edema and drainage were common complications following total ear canal ablation-bulla osteotomy (TECA-BO) surgery, but were thought to be unrelated to the dose and volume of the administered local anesthetic and more related to the surgical procedure itself. In the study by Radlinsky et al. (2005), plasma levels of bupivacaine were not detected following local anesthetic administration into the surgical wound following TECA-BO surgery.

Further research is required to describe the distribution of local anesthetic drugs that are administered into different surgical wounds based on the volume of drug and the positioning of the wound soaker catheter at the site.

Choice of local anesthetics

Most veterinary references describe using either bupivacaine as intermittent boluses or lidocaine as a continuous infusion:

- bupivacaine 0.5%, administered at 1 mg kg^{-1} every six to eight hours (Davis et al. 2007a; Abelson et al. 2009).
- lidocaine 2%, administered as an infusion at 1.5–3 mg kg^{-1} h^{-1} (Wolfe et al. 2006; Abelson et al. 2009).

In people, continuous wound catheters most often infuse a single agent such as a local anesthetic, although adjunctive medications such as α_2 adrenoreceptor agonists have also been used (Johnson et al. 2008).

To date, definitive studies have not been performed on veterinary patients to document the effect of local anesthetic dose, volume, and drug concentration on analgesic efficacy and safety (plasma levels) when administered via wound soaker catheters.

Equipment

The catheters discussed in this chapter are referred to by many different names including soaker catheters, wound catheters, fenestrated catheters, and diffusion catheters. They are typically made of polyurethane and have a closed tip with several lateral fenestrations (small holes/microports) along a predetermined length of the distal catheter. Their special design allows local anesthetic solution to be distributed evenly over the entire length of

fenestrations directly into the surgical site, without preferential leakage out of the more proximally-located side ports (Figure 8.7).

If the catheter is to be placed at the end of surgery, the following items are required:

- wound catheter (sterile, without peel-away introducer);
- appropriate-sized suture;
- PRN injection port;
- local anesthetic solution; and
- infusion system (pump) if continuous delivery of the local anesthetic is desired.

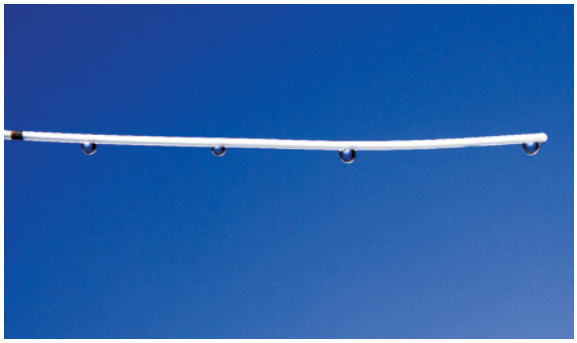


Figure 8.7 Close-up view of the distal end of a wound soaker catheter. Note the consistent distribution of local anesthetic solution through the multiple fenestrations in the distal end of the catheter. The black mark on the left side of the catheter indicates to the user where the fenestrations stop. Photograph provided courtesy of MILA International.

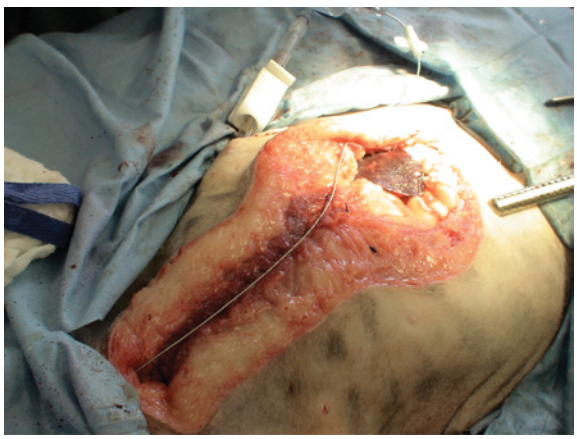
If the catheter is to be placed percutaneously without surgery, the following are required:

- clippers;
- skin preparation solutions;
- sterile gloves;
- wound catheter (sterile, with peel-away introducer);
- appropriate-sized suture;
- PRN injection port;
- local anesthetic solution; and
- infusion system (pump) if continuous delivery of the local anesthetic is desired.

Technique

Wound soaker catheters can be placed using an "open-technique" by the veterinarian at the time of surgery prior to closure of the surgical site. These catheters are frequently placed into the surgical field after a body cavity is closed (Figure 8.8).

(a)



(b)

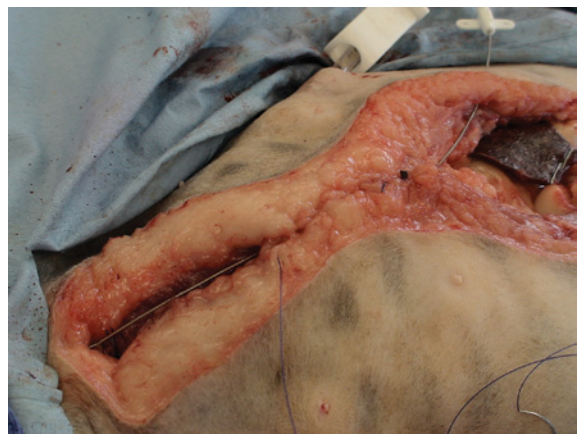


Figure 8.8 (a) Photograph of a wound soaker catheter being positioned into a surgical wound following median sternotomy in a cat (the cat is in dorsal recumbency with its head to the left of the photograph). Note that the thorax has already been closed and a chest tube has been placed to evacuate air from the pleural space. (b) Photograph of a wound soaker catheter being secured along the sternum during incisional closure. The catheter has been positioned along the sternum and is being secured in place by apposition of the more superficial subcutaneous tissues. Note that the catheter exits the skin through a separate incision and the wings of the catheter (upper right of photograph) will be used to secure the catheter to the skin to prevent its dislodgement.

If transected nerves are able to be visualized (e.g. following limb amputation), the catheter can be positioned in close proximity to the nerves, otherwise the catheter is simply placed into the wound (Abelson et al. 2009). This placement maximizes the effects of the local anesthetic and facilitates blocking somatic sensation of the incision and the surrounding muscles that were manipulated during surgery. If needed, simple interrupted sutures can be placed around portions of the catheter in the wound itself in order to maintain its position in the wound and prevent inadvertent dislocation during closure of the surgical site. These sutures should only be tightened enough to maintain catheter position during closure of the surgical field, and should not be so tight as to prevent easy withdrawal of the catheter from the wound when its postoperative use is no longer necessary.

Alternatively, the wound catheter can be placed into a tissue bed by using a peel-away introducer. This technique involves placing a needle with a peel-away covering into a tissue, withdrawing the needle stylet, and advancing the wound catheter through the introducer into the patient. The peel-away introducer is then removed from the patient and is separated from the wound catheter for its complete removal. The wound catheter is then secured to the skin and is left in place for delivery of local anesthesia to the patient.

Once the catheter is in position, a PRN injection port or infusion system is then attached to the catheter to facilitate local anesthetic administration while maintaining strict aseptic technique.

Clinical tips

Wound soaker catheters should be used when analgesia is to be provided for more than a single day. Most human research shows benefits to the patient when continuous infusion or intermittent doses of local anesthetics are used for an extended period of time (>24 hours), as opposed to only administering a single treatment. As described below, the most common complication with the use of wound soaker catheters is dislodgement of the catheter. As such, ensuring that the catheter is secured well to the patient is of paramount importance.

There are several different methods of securing the catheter. Most commercially available catheters have suture wings to allow the catheter to be secured to the patient with suture (Figure 8.4c). As the wings are typically made of a soft material, small gauge (3-0, 4-0) suture can cut through the wings when tightened, so larger sizes of suture (2-0, 0) are often more desirable, depending on the patient's size. Many catheters also have a movable suture wing that can be moved along the catheter to a position immediately adjacent to the percutaneous site of insertion, making the catheter even more secure than just suturing the permanent suture wings at the distal end of the catheter to the patient. Skin adhesives can also be used, as well as transparent wound dressings that allow the catheter and puncture site to be kept clean, while also allowing the practitioner to inspect the area for signs of infection or dislodgement. If intermittent boluses of local anesthetic are to be used, a PRN injection port should be attached to the end of the catheter to permit injection of the local anesthetic while maintaining aseptic technique.

Potential complications

Overall, the reported incidence of complications related to the use of wound soaker catheters is relatively low in both the veterinary and the human literature. There are very few reports of major complications that could potentially result in patient injury, and most complications following use of wound soaker catheters are considered to be minor (Wolfe et al. 2006; Liu et al. 2006; Davis et al. 2007a; Johnson et al. 2008; Kehlet and Kristensen 2009; Abelson et al. 2009). Although both are relatively uncommon, there are two main types of complications: equipment-related and drug-related.

Equipment-related complications include catheter dislodgement from the site of placement, catheter disconnection from the local anesthetic delivery system, catheter occlusion, and catheter breakage. These issues are generally considered to be minor and are more of an inconvenience to the veterinary staff than a danger to the patient.

Drug-related complications include local anesthetic systemic toxicities and are the result of rapid absorption of the delivered anesthetic or

inadvertent overdose of local anesthetic solution. These are also very rare, but are more serious in terms of potential risk to the patient. Calculating potentially toxic doses of the local anesthetics to be used, and using doses below these levels can minimize drug-related complications.

Although the use of wound soaker catheters to deliver analgesia in animals is a relatively new concept, the use of indwelling catheters in the epidural space for repeated administration of analgesics has been reported previously. In a study of indwelling epidural catheter use in dogs (Swalander et al. 2000), 64/81 dogs did not experience any complications during the study period. Seventeen dogs had complications that were considered to be minor, with catheter dislodgement being the most common (16% of all cases). This is similar to the incidence of catheter dislodgement that occurs with the use of epidural catheters in people (13%). Other complications reported in this study included serosanguinous discharge from the percutaneous puncture site, contamination of the bandage covering the epidural catheter, filter breakage, and localized dermatitis. All complications were treated with immediate removal of the catheter and close observation of the puncture site and provision of supportive care as needed. Comparable supportive methods would be indicated in cases of similar complications with wound soaker catheters in dogs and cats.

Radlinsky et al. (2005) and Wolfe et al. (2006) reported the use of wound catheters for delivery of local analgesia to dogs following total ear canal ablation procedures (Figure 8.3). In those reports, catheter-related complications were found to be uncommon and were considered to be minor. In the study by Wolfe et al., premature catheter removal occurred in two dogs, inadvertent catheter occlusion by clamping occurred in one dog, and delivery system disconnection from the catheter occurred in one dog. Overall, complications related to the method of analgesia were found to be less common in dogs receiving wound soaker catheters and local anesthetic infusion than dogs in the other treatment group that received systemic opioids administered by an intravenous infusion (25% vs. 60%). Serious complications such as wound infection and dehiscence of the surgical site did not occur in either study.

Recently, a retrospective study explored the clinical use of wound soaker catheters in dogs at a veterinary teaching hospital (Abelson et al. 2009). The authors found that the most common complication was disconnection of the catheter from the delivery system (7.7% of cases), and that this complication was more common in cases when "home-made" soaker catheters that were created from red rubber catheters were used as opposed to commercially available wound soaker catheters. The incidence of wound infections in their hospital was 5.3%, and was similar to the overall infection rate observed in comparable surgical cases that did not receive wound soaker catheters. One dog in their study developed signs of local anesthetic systemic toxicity. The dog manifested the typical signs of toxicity (tremors and ataxia) and the signs resolved quickly when the lidocaine infusion was discontinued.

Based on the available literature, in people, the rate of adverse effects and the potential for toxicity from continuous wound infiltration devices appears to be very low (Liu et al. 2006; Johnson et al. 2008; Kehlet and Kristensen 2009; Tirotta et al. 2009). More than 45 randomized clinical trials have been performed, with over 4000 patients reportedly enrolled in these studies. These reports have not demonstrated increased wound problems (infections, interference with healing) when wound soaker catheters are used to deliver local anesthetics into the surgical wounds postoperatively (Kehlet and Kristensen 2009; Tirotta et al. 2009). In a large meta-analysis that enrolled a total of 2141 patients, there were no cases of local anesthetic toxicity (Liu et al. 2006). The overall infection rates were comparable between patient receiving wound soaker catheters with local anesthetic (0.7%) and those in the control groups that received a catheter with placebo or no catheter at all (1.2%). The overall combined incidence of catheter or pump failure was 1.1%.

Wound healing

Local anesthetic infiltration into tissues has been reported to have variable effects on wound healing. Publications in the 1970s and 1980s reported tissue necrosis at the site of injection, diminished collagen synthesis, and delayed wound healing (Drucker et al. 1998). These studies suggest that there is variability in healing in response to doses and

concentrations of the local anesthetic agent, the concurrent use of epinephrine as a vasoconstrictor, and the general health of the patient. Disruption of wound healing is reportedly increased in human patients who are aged, diabetic, obese, and those with vascular diseases (Brower and Johnson 2003). These authors point out that, in contrast to other areas of medical investigation, there is no well-defined syndrome of poor wound healing associated with local anesthetic infiltration, and that most studies that report on the analgesic efficacy of this technique do not adequately address wound healing when they determine their observation periods or sample sizes.

A review by Brower and Johnson (2003) summarizes what is currently known about the effect of infiltration anesthesia on wound healing. They found that nine of 12 studies that used *in vivo* animal models showed a harmful effect of local anesthetics on wound healing when doses that mimic currently used concentrations were used. The drugs can cause inhibition of activation, migration, and metabolic activity of inflammatory cells, and may have myotoxic effects even if fibroblasts and other cells involved in wound healing are not affected. However, most of these *in vivo* animal studies only assessed the effects of the local anesthetics over a short period of time (less than six weeks), and all of the studies used rodents as research models, not domestic veterinary species. They point out that there are three stages of wound healing, and that the majority of mature wound strength is not achieved until remodeling occurs between six and 12 months after the procedure. If the third and final stage of wound healing is unaffected by the prior use of local anesthetics, final wound strength may not actually be affected in clinical patients. After reviewing the available literature, Brower and Johnson (2003) concluded that although the exact mechanism of toxicity has not yet been established, local anesthetics may have inhibitory effects on the first two stages of wound healing (inflammatory and granulation/proliferation stages). Further, even though inhibition of wound healing appears to be both time- and concentration-dependent in all of the cases where these effects were tested, until more data are obtained it would be premature to dismiss infiltration with local anesthetics as a potential analgesic technique.

Two studies that were conducted in rabbits and guinea pigs confirm that local anesthetics do affect wound healing at the histological level, but found that they do not affect the breaking strength of healing surgical wounds. Vasseur et al. (1984) looked at the influence of lidocaine and bupivacaine on the breaking strength and histopathologic appearance of surgical wounds on the ventral abdominal midline of rabbits. They investigated the effects of direct infiltration of the linea alba with saline, 0.5% lidocaine, 2% lidocaine, or 0.5% bupivacaine following surgical closure. They euthanized the rabbits at six, 12, and 18 days after surgery, and performed histopathology and mechanical testing of the harvested tissue samples. They found that tissues that were previously infiltrated with saline did not appear to be different from those that were infiltrated with the local anesthetics, and that there were no differences in breaking strengths between the different groups. Drucker et al. (1998) investigated the effects of lidocaine on wound healing in guinea pigs. This study reported similar results to those of Vasseur et al. (1984). Following tissue infiltration with 1% lidocaine or saline, tissue samples harvested eight days postoperatively had no differences in the degree of collagenization, edema, or acute and chronic inflammatory processes. The number of collagen fibers was higher in the control group, and there was less vascularization in the lidocaine group. However, the mean breaking strength was not different between groups, suggesting that although histological changes may be recognized, the clinically important end point of wound strength was not affected by the tissue infiltration of the local anesthetic.

The healing process is complex and involves several factors that are difficult to control including pathophysiologic disorders associated with diseased tissues and the presence of external influences such as the use of local anesthetics. Although the effects of local anesthetics on wound healing are not completely understood, the drugs and concentrations that are typically used in practice (and have been reported in this chapter) appear to carry minimal risk to the patient. Although the benefits of using local anesthetics for tissue infiltration or as wound infusions appear to outweigh the potential risks in the majority of

patients, special consideration should be made for certain patients that are at higher risk of wound complications.

Summary

The use of local anesthetics through local infiltration and wound soaker catheters appears to be a relatively safe method for providing analgesia to surgical wounds, and when appropriate precautions are taken by the practitioner (patient selection, monitoring the surgical and catheter sites for complications, accurate calculation of drug doses, etc.), this technique should not result in serious risks to the patient. Further research is ongoing and will undoubtedly provide veterinarians with information that can be used to further improve the utility and safety of using this promising and effective analgesic technique.

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9 The Eye

Elizabeth A. Giuliano and Karen P. Walsh

Overview

Local anesthesia, by way of regional eyelid blocks, is rarely used for small animal ophthalmic examinations compared with its routine use in horses. However, local anesthesia can be a useful adjunct to multimodal analgesic surgical planning and improve postoperative analgesia. Retrobulbar blocks are routinely used for enucleation or evisceration/prosthesis surgeries and may be used by some veterinary ophthalmologists for intraocular surgery (Accola et al. 2006; Myrna et al. 2010). Topical anesthesia is commonly used to facilitate ocular examination in the conscious small animal patient. Small animal patients typically require heavy sedation or general anesthesia to perform regional anesthesia safely for both the operator and the patient. Potential side effects should be considered prior to performing local anesthesia. The possible effects on intraocular pressure are of particular concern, as this may affect the overall outcome of surgery and treatment. Knowledge of regional anatomy and physiology is essential to perform these techniques safely and effectively. Equipment needs are minimal; needles and syringes routinely available in small animal practice are sufficient.

Functional regional nerve anatomy

The orbit is the conical cavity that contains the globe and ocular adnexa (Murphy and Pollock 1993). The axis of the orbit varies between different skull types. Mesocephalic dogs generally have orbits that form an angle of approximately 30° from the median and dorsal planes. This is in contrast to the skulls of brachycephalic breeds where the axis of the orbit can deviate as much as 50° from the median plane. The orbital rim is made up of bone for approximately four-fifths of its circumference, with the remaining portion completed by the orbital ligament. This ligament is located at the posteriolateral orbital margin and typically forms a larger proportion of the orbit's circumference in brachycephalic breeds. In dogs, the orbit is composed of bone (medial wall and part of the orbital roof) and soft tissue (lateral wall and floor). Within the orbit, various foramina and fissures provide an osseous pathway for blood vessels and nerves. The two of greatest importance with regards to regional analgesia are the optic foramen and the orbital fissure (Figure 9.1). The optic canal houses the optic nerve and the internal ophthalmic artery. The oculomotor (III),

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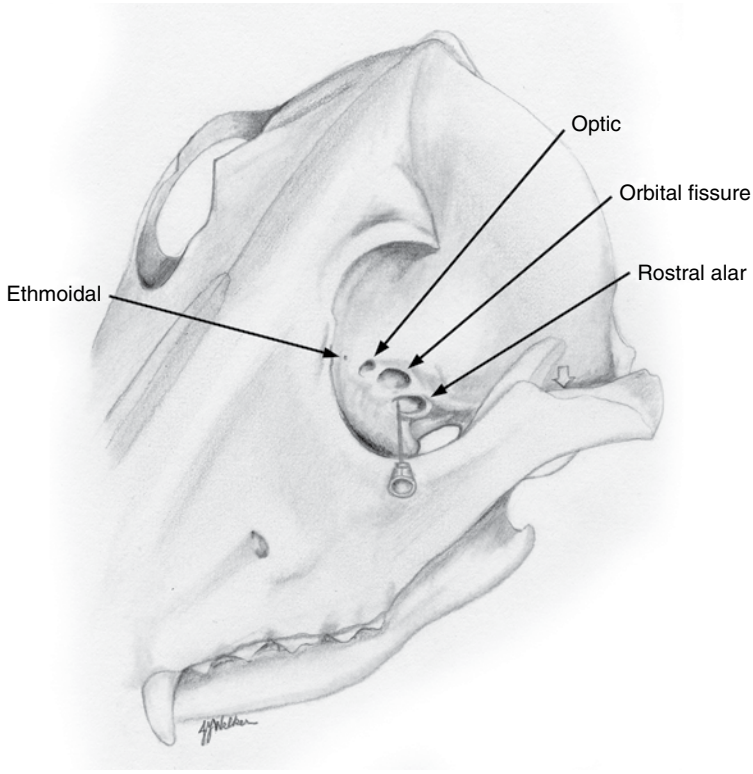

Figure 9.1 Diagram of the canine orbit and its foramina. Needle depicts the approximate location for retrobulbar local anesthetic injection. Small arrow over zygomatic arch denotes the approximate location for an auriculopalpebral block. Illustration by Jeanie Welker.

Table 9.1 Orbital foramina and their associated nerves and vessels of ophthalmic importance.

Foramina	Associated nerves and vessels
Rostral alar	Maxillary artery and nerve
Orbital fissure	Oculomotor, ophthalmic, abducens and trochlear nerves
Optic	Optic nerve

trochlear (IV), abducens (VI), and ophthalmic (V) cranial nerves, as well as the external ophthalmic artery, enter the orbit via the orbital fissure. In close proximity to these foramina is the rostral alar foramen carrying the zygomatic nerve, a branch of the maxillary nerve, and the maxillary artery (Table 9.1). The ethmoidal foramen allows passage for the external ethmoidal artery and ethmoidal nerve.

Optic nerve

The optic nerve (II) originates ventrolaterally from the posterior pole of the globe and resembles a central nervous system tract due to its formation by centripetal growth of retinal ganglion cells. Optic nerve myelin is formed by oligodendrogliocytes (central nervous system type). An outer sheath that is continuous with the dura mater and an inner sheath that is continuous with the pia mater surround the nerve. The space between these two layers contains cerebrospinal fluid as it is continuous with the subarachnoid space. Within the orbit, this nerve lies at the center of the orbital cone, separated from surrounding extraocular muscles by an intraperiorbital fat body. The optic nerve is slightly longer in length than the measured distance between its point of origin at the back of the eye and the optic canal to allow for globe movement.

Oculomotor nerve

The oculomotor nerve (III) enters the orbit via the orbital fissure. It supplies motor innervation to the majority of the ocular muscles (dorsal, medial, and ventral rectus muscles, the ventral oblique, and the levator palpebrae superioris muscles). The oculomotor nerve also contains pre-ganglionic parasympathetic fibers that synapse in the ciliary ganglion and post-ganglionic fibers that innervate the iris sphincter and ciliary muscles within the eye. Oculomotor nerve deficits are most commonly clinically appreciated in cavernous sinus and orbital fissure syndromes, in which the oculomotor, trochlear, and abducens nerves, as well as the maxillary and ophthalmic branches of the trigeminal nerve, are affected. Known as complete (i.e. both internal and external) ophthalmoplegia, this syndrome typically results in ventrolateral strabismus, inability to retract the globe, pupillary dilation, ptosis, and decreased corneal sensation.

Trochlear nerve

The trochlear nerve (IV) is unique in that it is the only cranial nerve to leave the dorsal surface of the brainstem and it is the only nerve in the body in which all fibers supply muscles on the contra-lateral side of the body. It enters the orbit via the orbital fissure lateral to the oculomotor nerve and the only structure it innervates is the dorsal oblique muscle.

Trigeminal nerve

The sensory innervation of the eye originates in the trigeminal nerve (V). It divides into three major branches at the trigeminal ganglion: ophthalmic (V_1), maxillary (V_2), and mandibular (V_3). Of these three branches, only the first two innervate ocular structures (Figure 9.2).

Ophthalmic nerve (V_1)

The ophthalmic nerve provides the major sensory innervation to the eye and orbit. At the level of, or slightly rostral to, the orbital fissure, the ophthalmic branch further divides into the frontal, lacrimal, and nasociliary nerves. The frontal nerve is sensory to most of the upper eyelid skin and medially to the dorsal midline. The lacrimal nerve is a small branch of the ophthalmic nerve and innervates the lacrimal gland. The nasociliary nerve is the continuation of the ophthalmic nerve into the orbit. As it travels through the orbit, projections form the long ciliary nerves that enter the globe and are sensory to the structures of the globe (e.g. choroid, ciliary body, iris, cornea, bulbar conjunctiva). Additionally, this portion of the ophthalmic nerve carries sympathetic post-ganglionic fibers that are motor to the dilator muscle of the pupil. After the long ciliary nerves leave the nasociliary nerve, it further divides into the infratrochlear and ethmoidal nerves. The infratrochlear nerve supplies the medial commissure of the eyelids and the ethmoidal nerve innervates portions of the nasal mucosa and skin of the muzzle.

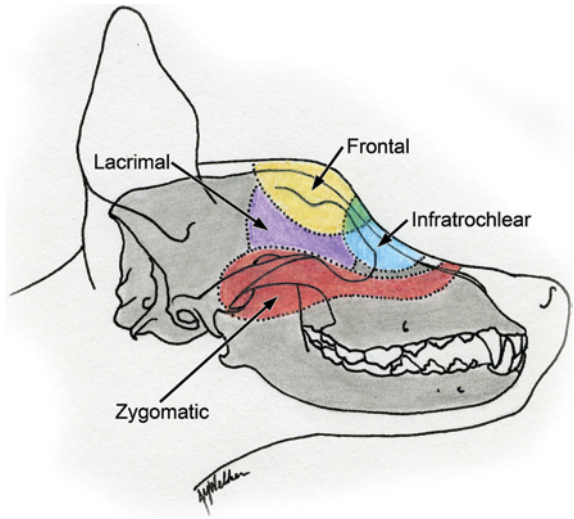

Figure 9.2 Sensation to the eyelids is provided by the ophthalmic and maxillary divisions of the trigeminal nerve (CN V). The frontal, lacrimal, and infratrochlear nerves arise from the ophthalmic branch of CN V, whereas the zygomatic nerve arises from the maxillary branch of CN V. The approximate areas of sensation that would be blocked with each nerve are indicated in yellow (frontal), blue (infratrochlear), red (zygomatic), and purple (lacrimal). Illustration by Jeanie Welker.

Maxillary nerve (V_2)

The maxillary nerve is sensory and gives rise to the zygomatic, pterygopalatine, and infraorbital nerves. The zygomatic branch provides sensory innervation

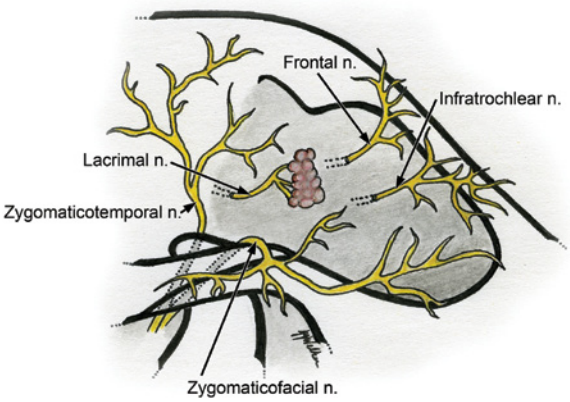

Figure 9.3 Innervation to the canine orbit. Illustration by Jeanie Welker.

to the orbit. It enters the orbit via the rostral alar foramen and divides into the zygomaticotemporal and zygomaticofacial nerves (Figure 9.3). The zygomaticotemporal nerve supplies the lateral portion of the upper eyelid and carries parasympathetic fibers to the lacrimal gland. The zygomaticofacial nerve supplies the lower eyelid, lateral canthus, and ventrolateral aspects of the conjunctiva.

Abducens nerve

The abducens nerve (VI) supplies motor innervation to the lateral rectus and retractor bulbi muscles. It enters the orbit via the orbital fissure. Lesions affecting this nerve will result in medial strabismus, inability to retract the globe in the orbit, and inability to sweep the third eyelid across the cornea.

Facial nerve

The motor function to the eyelids is provided by the facial nerve (VII) as the auriculopalpebral nerve. The facial nerve (VII) supplies both general somatic efferent and special visceral efferent innervation to portions of the head. Facial nerve innervation will be discussed in this chapter as it relates to ocular structures only. At the level of origin of the zygomatic process from the temporal bone, the auriculopalpebral branch of the facial nerve divides into the rostral auricular branches and the zygomatic branch. In turn, the zygomatic branch gives rise to dorsal and ventral palpebral branches that innervate the dorsal and ventral portion of the orbicularis oculi muscle (the major muscle responsible for eyelid closure). The retractor anguli oculi lateralis and the levator anguli oculi medialis also receive innervation from branches of the zygomatic and palpebral nerves. Post-ganglionic fibers of facial nerve origin emanating from the ptergopalatine ganglion provide parasympathetic innervation to the lacrimal gland. Facial nerve injury (or injury to its palpebral branches) results in an inability to blink. An inability to close the eyelids can result in significant compromise to the cornea, as the preocular tear film cannot be normally distributed. If innervation to the retractor bulbi muscle remains unaffected, a patient with facial nerve paralysis may be observed to retract the globe and subsequent third eyelid "sweep" may aid in tear distribution.

General considerations

The eye, adnexa, and orbit are richly innervated. Extensive sensory innervation implies a high potential for pain with ophthalmic disease and surgery. In veterinary ophthalmology in particular, effective pain management through preemptive opioid administration may lead to these drugs being withheld due to concerns of pupillary constriction. Ophthalmology patients are often geriatric, and have multiple medical issues that may preclude the safe administration of NSAIDs. To effectively treat ophthalmic pain, one should have a variety of drugs and delivery options available to plan for various ophthalmic procedures and appropriately address the spectrum of patients' needs. Regional anesthesia can be an effective adjunctive means to achieve excellent postoperative pain control while minimizing systemic side effects. In small animals, regional eyelid blocks are not routinely used during the clinical ophthalmic examination. When used, heavy sedation or general anesthesia is recommended to avoid damaging the globe. Prior to administration of any sedative or anesthetic agent, the patient's general health should be assessed via thorough history taking, complete physical examination, and performance of ancillary tests. The primary ocular condition must also be considered as this may preclude use of certain drug combinations.

Sedation and anesthesia requirements

Caution with drugs causing emesis should be exerted particularly when the integrity of the globe has been compromised (e.g. corneal perforation or a descemetocele). An example of a commonly used combination is dexmedetomidine (0.005–0.01 mg kg^{-1}) and butorphanol (0.1–0.4 mg kg^{-1}).

Phenothiazine agents such as acepromazine maleate (ACP) often do not produce adequate sedation to allow manipulation of the eye or periocular areas. To achieve greater sedation, combining ACP with an opioid analgesic can be helpful. The choice of opioid is dependent on the patient's degree of pain as well as opioid availability. Caution should be exercised when using opioids such as morphine, as their administration may result in emesis leading to a sudden increase in intraocular pressure (IOP).

Ketamine in combination with dexmedetomidine and an opioid or a benzodiazepine can be used in cats to produce profound sedation. This anesthetic plan may allow placement of a local anesthetic block. Ketamine may increase IOP, thus the decision to use this drug should be based on the temperament of the patient, the ophthalmic condition, and the overall health of the cat. Manual restraint of a difficult cat may result in a greater increase in IOP than appropriate sedative drugs. Examples of appropriate ketamine-based combinations include:

- ketamine 3–10 mg kg^{-1}, dexmedetomidine 1–5 mcg kg^{-1}, butorphanol 0.2–0.4 mg kg^{-1};
- ketamine 3–10 mg kg^{-1}, dexmedetomidine 1–5 mcg kg^{-1}, buprenorphine 0.02 mg kg^{-1};
- ketamine 5–15 mg kg^{-1}, midazolam 0.2 mg kg^{-1}; or
- ketamine 5–15 mg kg^{-1}, diazepam 0.2 mg kg^{-1}.

These combinations can be administered intramuscularly (except the combination with diazepam) or intravenously. Selected drugs and dosages will depend on the temperament of the patient and the route of administration.

Opioids alone may not produce adequate chemical restraint for adjunctive regional anesthesia. For patients with compromised cardiovascular function, a combination of fentanyl and midazolam results in a short duration of sedation and minimal cardiovascular and respiratory depression. However, this combination can result in panting which may inhibit the operator's ability to perform the procedure.

General anesthesia is preferred for most patients undergoing regional anesthesia for ophthalmic procedures. Adequate pre-anesthetic medication and smooth induction of anesthesia is essential for ophthalmic patients. Propofol, thiopental, or alfaxalone are common choices for induction, and anesthesia can be maintained with sevoflurane or isoflurane.

Animal positioning

There is no specific recommendation for patient positioning when administering regional anesthesia to small animal ophthalmic patients. Positioning is largely based on operator preference and may be dictated by administration timing (preoperatively, intraoperatively, or postoperatively). Many ophthalmic procedures require the eye (specifically the cornea) to be horizontal to the surgeon and therefore may require the patient's neck to be bent at a relatively acute angle. It is therefore important to ensure that the airway is protected, especially in the sedated patient. Once anesthetized, "reinforced" or "guarded" endotracheal tubes can be used to maintain patency of the upper airway. Among other vital signs, respiratory rate and effort should be carefully monitored. Utilization of capnography and pulse oximetry will facilitate early detection of upper airway obstruction.

Indications for use of ophthalmic local anesthesia

Numerous ophthalmic procedures may be performed with adjunctive local anesthesia. Examples include:

- ophthalmic examination (application of topical anesthetic and rarely, an auriculopalpebral block);
- preoperative analgesia
  - enucleation;
  - evisceration with intrascleral prosthesis;
  - corneal and/or conjunctival surgery;
  - intraocular surgery where central rotation of the globe is desirable;
  - immobilization of the eyelids to enable surgery while maintaining a light plane of anesthesia;

- postoperative analgesia;
  - as for preoperative;
  - infiltration anesthesia following eyelid surgery.

Contraindications

As with performance of all loco-regional blocks, the underlying health of the target tissues should be taken into consideration. Large-scale tissue disruption (e.g. infection) will affect onset and uptake of local anesthetic drugs such that there may be an increased chance of systemic toxicity. Central nervous system toxicity is possible with direct injection of local anesthetic into the perineural optic nerve sheath. Needles should not be placed through potential neoplastic tissue as this may increase potential spread of disease.

Auriculopalpebral nerve block: motor blockade of the eyelid

This technique can be used to facilitate examination of the eye (but in the authors' experience, is rarely used in the small animal practice setting for this purpose), treatment of spastic entropion, and placement of a third eyelid flap (Park et al. 2009).

Equipment

- Sterile 25–27-gauge, 1-inch needle;
- 1–3 mL syringe; and
- local anesthetic.

Technique

The auriculopalpebral nerve supplies the obicularis oculi, the primary muscle responsible for eyelid closure. In the small animal patient, the auriculopalpebral nerve block is induced by inserting a 1.2 cm 25–27-gauge sterile needle through the skin dorsal to the zygomatic process at its caudal one-third and injecting ~0.4 mL of local anesthetic subcutaneously (Park et al. 2009). Eyelid akinesia will disrupt normal tear distribution, thus care should be taken to provide adequate lubrication and protection of the cornea for the duration of this block.

Anatomic landmarks

The auriculopalpebral nerve travels across the zygomatic arch where it divides to form the zygomatic and palpebral branches; the latter supply motor innervation to the upper and lower eyelids. Unlike the horse, the palpebral branch of the auriculopalpebral nerve may not be readily palpable through the skin; it can be difficult to manually "feel" this nerve in some dogs (see section on Clinical tips below). Therefore, local anesthetic is simply infiltrated into the clinician-judged appropriate area based on careful anatomic review (Roberts et al. 1974; Murphy and Pollock 1993; Park et al. 2010). In awake patients, clinicians can test the success of their block by noting a decreased palpebral reflex roughly five minutes after administration of local anesthetic.

Step by step procedure

- Calculate the maximum dose of local anesthetic for the patient to avoid toxic levels.
  - usually no more than 0.5–1 mL of local anesthetic will be required to desensitize the palpebral nerve.
- Palpate the zygomatic arch of the patient and attempt to palpate the nerve (Figure 9.4).

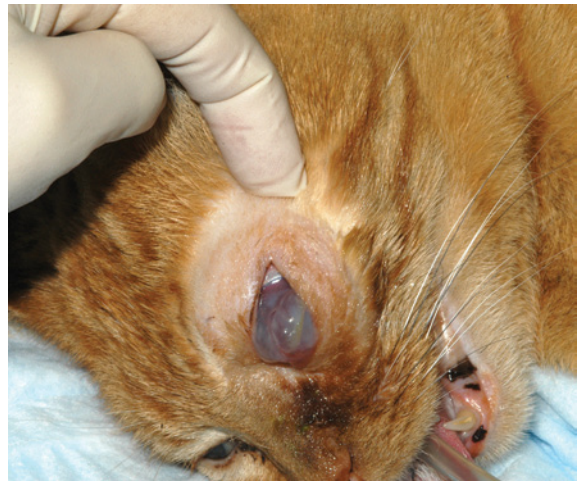

Figure 9.4 Digital palpation of the zygomatic arch in a feline patient in preparation for administration of an auriculopalpebral block prior to enucleation surgery.

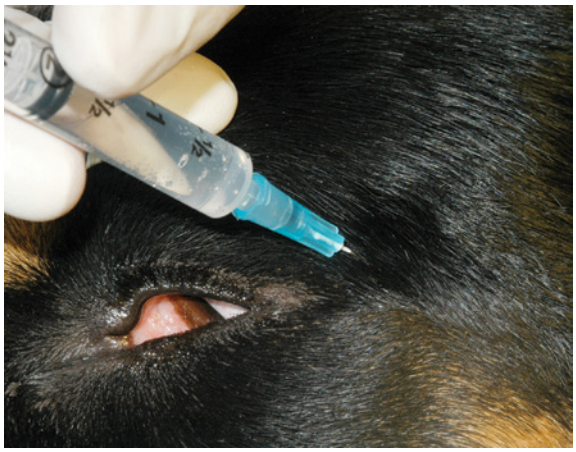

Figure 9.5 Performance of an auriculopalpebral nerve block prior to performing entropion repair in a Rottweiler.

- Locate the lateral canthus.
- Direct the needle caudally from the lateral canthus towards the zygomatic arch.
- Pull back on the syringe immediately prior to infiltrating local anesthetic in a fan-like pattern across the zygomatic arch (Figure 9.5);
  - typically, the needle is redirected within the fascia without withdrawing it through the skin. Aspiration on the syringe prior to infiltration of local anesthetic agent ensures that you are not in a major vessel. See also Figure 9.1.

Clinical tips

If the patient has thick fur, clipping the area over the zygomatic arch may facilitate visualization of this bony landmark and manual palpation of the nerve. Additionally, adequate corneal lubrication is imperative, as desiccation due to inadequate tear film distribution will occur from loss of the normal blink response. This may lead to corneal erosion or ulceration.

Frontal nerve (supraorbital foramen) block: anesthesia of the upper eyelid

Equipment

- Sterile 25–27-gauge, 1-inch needle;
- 1–3 mL syringe; and
- local anesthetic.

Technique

The frontal nerve, a branch of the ophthalmic nerve, passes rostrally between the dorsal oblique and the dorsal rectus muscle. It emerges subcutaneously just caudal to the orbital ligament to terminate by dividing into the supraorbital and supratrochlear nerves. Collectively, these nerves supply cutaneous innervation to the lateral two-thirds of the upper eyelid to the dorsal midline of the head (Evans and Kitchell 1993). To the authors' knowledge, there are no published reports in the veterinary literature that describe a technique for this eyelid block in small animal patients. This is in stark contrast to equine ophthalmology, where the supraorbital foramen is easily palpated and a frontal nerve block is commonly performed in horses to facilitate the ophthalmic examination and/or standing eyelid surgery. In the authors' experience, digital palpation of the frontal nerve is not possible in the small animal patient; therefore, local anesthetic is simply infiltrated into the clinician-judged appropriate area based on careful anatomic review (Figure 9.6). In general, the authors recommend using infiltrative eyelid blocks for regional anesthesia of the upper and/or lower eyelids (see Topical anesthesia below).

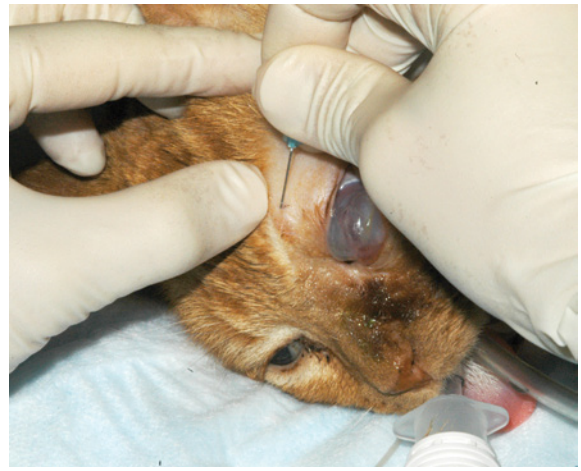

Figure 9.6 Performance of a frontal nerve block in a feline patient prior to enucleation surgery.

Zygomatic and lacrimal nerve block: anesthesia of the lateral portions of the upper and lower eyelids

Equipment

- Sterile 25–27-gauge, 1-inch needle;
- 2 mL syringe; and
- local anesthetic.

Technique

This nerve block consists of injection and diffusion of local anesthetic into the area near the orbital fissure where the ophthalmic (which gives rise to the lacrimal nerve), trochlear and zygomatic (via the alar foramen) nerves exit. As the abducens, oculomotor, and trochlear nerves are all located in close proximity, this block produces akinesia of the globe when these nerves are paralyzed.

Anatomic landmarks

Palpate ventral to the zygomatic process at the level of the lateral canthus.

Step-by-step procedure

- The needle should be inserted ventral to the zygomatic process at the level of the lateral canthus and approximately 0.5 cm rostral to the anterior border of the vertical ramus of the mandible. Note that distances will vary somewhat with size and shape of the skull.
- Advance the needle medially to the mandible in a both mediodorsal and caudal directions.
- The target is the orbital fissure. The exact depth to which the needle is advanced depends on the size and conformation of the small animal patient.
- The maximum patient dose should be calculated for the local anesthetic being used, but it is unlikely that more than 2 mL would be necessary.

Clinical tips

Akinesia of the globe will occur due to the close proximity of the abducens, oculomotor, and trochlear nerves.

Infratrochlear nerve block: anesthesia for the medial canthus

The necessary equipment is the same as for the auriculopalpebral nerve block (see above). These authors have found no specific recommendations for this block in small animals. We recommend using infiltrative eyelid blocks for regional anesthesia of the upper and/or lower eyelids when needed (see Topical anesthesia below).

Retrobulbar block (RBB): regional anesthesia for enucleation, evisceration/prosthesis, and/or intraocular surgery

Equipment

- 1.5-inch 22-gauge spinal needle bent to approximately 20 degree angle, or a retrobulbar needle;
- maximum 2 mL local anesthetic (calculate maximum dose per patient and include other local blocks being performed); and
- 1–5 mL syringe.

Technique and step-by-step procedure

There are five different techniques described, including:

(1) Inferior-temporal palpebral RBB
- The lower eyelid hair may be clipped at the injection site or a transconjunctival approach employed. Routine ophthalmic surgical preparation with dilute povidone-iodine solution is performed.
- A retrobulbar needle can be used or a 1.5 inch 22-gauge spinal needle can be bent to an approximate 20° angle.
- Use the lateral canthus and the middle of the lower eyelid as landmarks. The needle should be positioned midway between those two points, along the inferior eyelid at the level of the orbital rim (Figure 9.7).
- The needle is directed along the floor of the orbit and then redirected dorsally and towards the nose to reach the apex of the orbit.

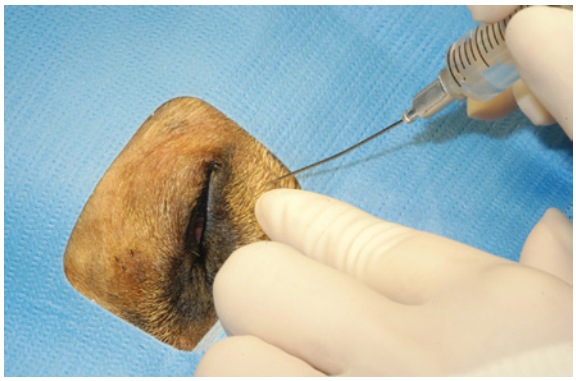

Figure 9.7 Initial approach to the inferior-temporal palpebral retrobulbar nerve block in a canine patient.

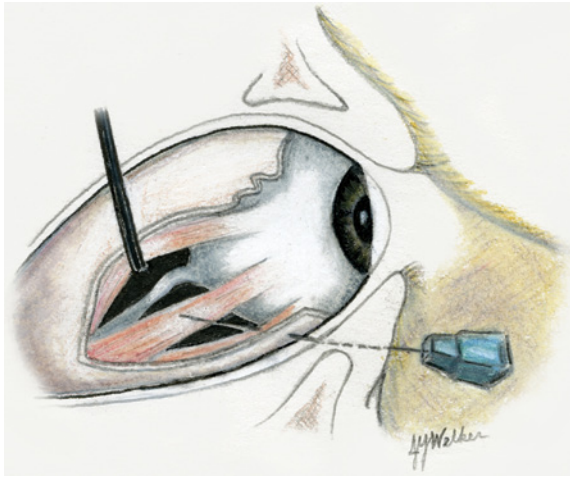

Figure 9.8 Illustration showing the approximate intraconal needle position when performing an inferior-temporal retrobulbar nerve block. Illustration by Jeanie Welker.

- A slight popping sensation may be detected (piercing of the orbital fascia).
- The needle should then be redirected slightly dorsally and nasally toward the orbital apex (Figure 9.8).
- Aspiration prior to injection is warranted and strongly recommended.
- Local anesthetic is slowly injected into the orbit.
- If significant resistance is encountered, draw back and redirect slightly (as the perineural sheath may have been penetrated or the needle may be abutting the bony orbit).

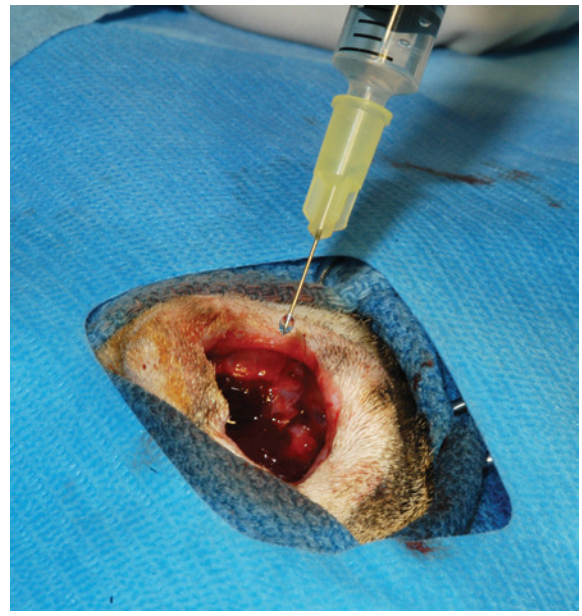

Figure 9.9 Splash block of the canine orbit after the globe has been removed.

(2) Splash block of the orbit (Figure 9.9)
- Useful with ocular or orbital neoplasia due to risk of a RBB seeding the tumor to other tissues.
- After the globe and orbital tissue have been removed and the orbit has been well flushed, local anesthetic is deposited into the orbit and left *in-situ* for three to five minutes.
- The surgeon can begin wound closure during this time.
- The authors recommend not to subsequently flush the orbit after introduction of local anesthetic to avoid dilution and possible alteration of the splash block effects and duration.

(3) Perimandibular technique
- 1.5 inch 22-gauge spinal needle.
- Needle is positioned ventral to the zygomatic process at the same level as the lateral canthus.
- Needle is directed medially to the vertical ramus.
- As the needle is advanced it travels in a mediodorsal and caudal direction until it meets the retrobulbar space.

(4) Lateral canthus technique
- 1.5 inch 22-gauge spinal needle.
- Needle is inserted through the conjunctiva at the lateral canthus.
- Needle is advanced past the globe toward the opposite mandibular joint until the base of the orbit.

(5) Combined superior-inferior peribulbar technique
- 1.5 inch 22-gauge spinal needle.
- Two injections are performed.
- Needle is inserted halfway between the medial and lateral canthi of the superior and inferior lids between the orbital rim and globe.
- Needle is advanced until the tip is just beyond the posterior aspect of the globe.

Comparison of retrobulbar techniques

A study in 2006 examined three of the five retrobulbar injection techniques: the inferior-temporal palpebral, perimandibular, and combined superior-inferior peribulbar techniques described previously in this chapter (Accola et al. 2006). Targets of retrobulbar anesthesia include cranial nerves III, IV, V, and VI and the ciliary ganglion. The authors concluded that of the three techniques, the inferior-temporal palpebral was the preferred method for a retrobulbar block in dogs because it achieved pupil dilation and central rotation of the globe, was easiest to perform, and provided thorough coverage of the intraconal retrobulbar space without complications.

Clinical tips

Aspiration before injection of local anesthetic will help decrease the risk of intravascular injection. Assessing the resistance to injection will also decrease the chance of intraneural injection. The pressure generated by injection into the optic nerve sheath or intrascleral injection is three to four times that produced by injection into the retrobulbar adipose tissue (i.e. 135 vs. 35 mmHg) (Wang et al. 1989).

The inferior-temporal palpebral block appears to yield consistent distribution of injectate and is clinically applicable. No significant difference in intraocular pressure was observed between treated and nontreated eyes, nor were any complications found associated with retrobulbar injection (Accola et al. 2006). Use of a retrobulbar needle will mitigate the need to bend a spinal needle prior to performing a retrobulbar block.

Advantages

If bupivacaine or ropivacaine are used, postoperative analgesia will extend for approximately four to six hours. Use of a RBB reduces ocular movement during surgery and will enable the patient to be comfortably maintained under general anesthesia with less inhalational drug concentrations. A RBB will decrease the need for nondepolarizing muscle relaxants and intermittent positive pressure ventilation, and further reduce the potential complications associated with these drugs (Hazra et al. 2008). The inferior-temporal palpebral technique appears to have minimal morbidity associated with its use.

Complications

Failure to direct the needle into the appropriate site will result in inadequate anesthesia and analgesia of the area. Other complications that may occur with a RBB include the following:

- inadvertent penetration of the globe. This may lead to catastrophic consequences for the eye; however, is unlikely to occur with careful technique.
- intravascular injection. Failure to aspirate prior to injection may result in local anesthetic injection into the ophthalmic artery.
- intrathecal injection. If the optic nerve is directly injected, local anesthetic may come into contact with the subarachnoid space due to its close association with the meninges. Careful attention to the pressure required to inject local anesthetic is warranted and if the veterinarian encounters resistance, the needle should be redirected.
- retrobulbar hemorrhage, due to puncture of the vessels around the globe.
- optic nerve damage/extraocular muscle myopathy/other neuropathy, due to penetration of

the perineural sheath with the needle or toxic effects of the local anesthetic agent.
- proptosis and/or subsequent exposure keratitis. More common when large volumes of local anesthetic are used. Brachycephalic breeds may be predisposed due to shallow orbits.

Peribulbar block: regional anesthesia for enucleation surgery

Equipment

- 1 mL syringe;
- 25–27-gauge needle; and
- conjunctival forceps.

Technique

A small amount (0.1–0.2 mL per site) of local anesthesia is injected subconjunctivally at four positions around the globe to provide regional anesthesia to the areas of extraocular muscle attachment to the globe prior to their transaction during enucleation (subconjunctival approach). This technique also helps the practitioner delineate tissue planes more easily during enucleation. The conjunctiva should be gently held with a fine-toothed forceps while the needle is directed subconjunctivally 2 mm from the limbus at the 12, 3, 6 and 9 o'clock positions around the globe (Figure 9.10).

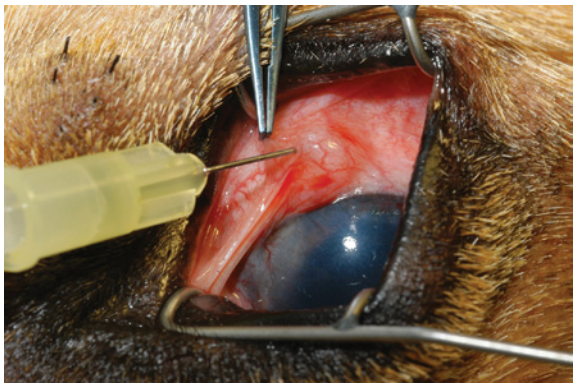

Figure 9.10 Peribulbar block at the 12 o'clock position of the canine globe during an enucleation surgery.

Advantages

- Low risk of penetrating the globe.
- Provides analgesia to sites of extraocular muscle attachment to globe.
- Technically easy to perform, less training required.
- Helps to delineate tissue planes prior to enucleation using a subconjunctival approach.

Disadvantages

- Complete anesthesia of the globe and periocular tissues is not achieved.
- Splash block of the optic nerve after removal of the globe is necessary to provide similar analgesia to that afforded by a RBB.

Infiltration anesthesia

Indications

Infiltration of the eyelids can be used as an adjunct to any eyelid surgery or enucleation surgery. Ophthalmic surgical procedures that may benefit from infiltration anesthesia include canthoplasty, entropion/ectropion repair, wedge resection, laceration repair, extensive eyelid reconstructive procedures (e.g. lip to lid, modified Kuhnt-Szymanowski procedure), enucleation surgery, or as an adjunct to a retrobulbar block (Accola et al. 2006). It may also help to decrease post-surgical entropion by slight eversion of the eyelids. Smoother recovery from anesthesia may be seen because of improved postoperative analgesia.

Local anesthetics used

Longer acting local anesthetics such as bupivacaine or ropivacaine are recommended for optimal postoperative pain control. Mepivacaine and lidocaine have shorter durations of action and are of limited use in this clinical setting. Epinephrine can be added to the local anesthetic to increase duration of action but this must be weighed against the possible decrease in blood flow.

Equipment

- 3–5 mL syringe;
- 25–27-gauge needle; and
- local anesthetic.

Technique

After surgery has been completed but before anesthesia is terminated, local anesthetic can be infiltrated into the area using a small gauge needle and syringe. The needle should be inserted into the skin and subcutaneous tissues adjacent to the wound to infiltrate local anesthetic. It may be useful to insert the needle to the hub and inject local anesthetic as the needle is slowly withdrawn. Typically, two to three different injection sites will be necessary to adequately infiltrate an upper or lower eyelid in its entirety (Figures 9.11 and 9.12).

Clinical tips

Using too large a syringe will increase the pressure required to inject local anesthetic into the subcutis and may result in inadequate levels of anesthetic distribution. Similarly, using too large a needle gauge will result in a needle tract that leaks local anesthetic instead of enabling drug diffusion into the eyelids. Expect the eyelids to swell slightly with local anesthetic administration, which will distort lid conformation. For this reason, we advocate infiltration of the tissues after any reconstructive surgery is planned (e.g. entropion/ectropion repair, Figure 9.11). By contrast, if local anesthetic with epinephrine is used, injection of the eyelid margin prior to their removal in an enucleation procedure will lessen the amount of bleeding encountered.

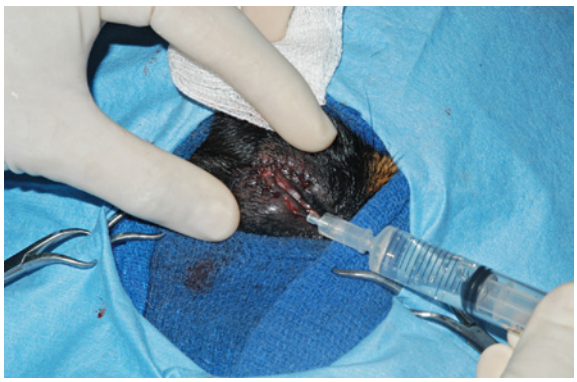

Figure 9.11 Local infiltration with bupivacaine at the conclusion of a canine entropion surgery just prior to placement of the remaining skin sutures.

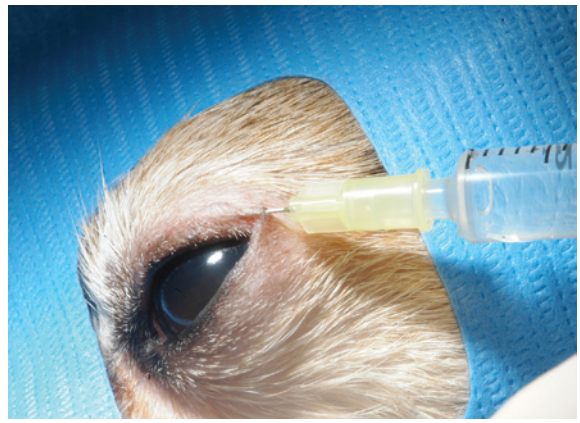

Figure 9.12 Local eyelid infiltration of bupivacaine prior to enucleation surgery.

Advantages and disadvantages

Advantages include improved analgesia in the postoperative period, smoother recovery, and decreased need for opioid analgesia, decreased sedation, and faster recovery time. A surgical advantage of infiltrative anesthesia in eyelid surgery is its "space-occupying" effect. This is particularly relevant in patients with a strong spastic component to their entropion that may be exacerbated from surgical manipulation of the eyelids and result in sutures rubbing on the cornea and possible ulceration during recovery from general anesthesia. Infiltration of local anesthetic to slightly evert the eyelids may negate the need to place additional tacking sutures (Giuliano 2008). Disadvantages of infiltration anesthesia include potentials for delayed wound healing and wound break down. In the authors' opinion, this is rarely encountered when local anesthesia is used once as an adjunct for ophthalmic surgery, and the volume of drug that is injected is small. As with all loco-regional anesthesia, care must be taken to ensure

that toxic systemic doses are avoided. When operating on small dogs or cats, if a greater volume of drug is needed (e.g. when performing an enucleation surgery and a RBB, four-point peritomy block and regional eyelid infiltration are all planned), dilution of the appropriate local anesthetic dose is recommended using sterile saline.

Topical anesthesia

Indications

Topical local anesthesia is routinely used in the ophthalmic examination to facilitate applanation tonometry, corneal and conjunctival scraping or biopsy, and foreign body removal. Topical anesthesia can also be used to supplement analgesia during corneal-conjunctival surgery.

Drugs used

Proparacaine/proxymetacaine

In clinically normal dogs, a single drop of 0.5% proparacaine produced corneal anesthesia for approximately 45 minutes with the maximal effects for 15 minutes (Herring et al. 2005). A second drop applied one minute after initial treatment resulted in an increase of anesthetic effects to 55 minutes with maximum effects for 25 minutes. Recovery from topical anesthesia is dose-dependent, with lower doses having the shortest duration of action (Polse et al. 1978). An increase in duration of anesthesia may be seen in dogs and cats with decreased corneal sensitivity. Decreased corneal sensitivity has been associated with diabetes mellitus (Good et al. 2003), mesaticephalic and brachycephalic skull conformation in dogs, and brachycephalic conformation in cats (Blocker and Van Der Woerdt 2001). Duration of anesthetic effects on the domestic shorthair feline cornea induced by a single topical application of 0.5% proparacaine ophthalmic solution is considerably shorter than the reported duration of corneal anesthesia in dogs (Binder and Herring 2006). One drop of 0.5% proparacaine produced maximal anesthesia for five minutes and lasted for approximately 25 minutes (Binder and Herring 2006).

Tetracaine

Tetracaine is not commonly used in veterinary medicine as it often causes marked conjunctival hyperemia, chemosis, and pain on application. Proparacaine is generally recommended as an alternative (Bartfield et al. 1994). Duration of action has not been reported in dogs or cats.

Other topical anesthetic agents

Limited options have been available for treatment of ocular pain. Topical use of morphine has been shown to control pain associated with corneal wounds in dogs without systemic side effects or delayed corneal wound healing, but is a controlled drug (Stiles et al. 2003). Nalbuphine, a potent synthetic mixed opiate with some analgesic effects is a nonscheduled drug and might represent a useful alternative to topical morphine. However, a pilot study evaluating topical nalbuphine compared with oral tramadol in the treatment of corneal pain in dogs suggests that topical nalbuphine is not effective for treating corneal pain (Clark et al. 2011). Five percent diphenhydramine solution has been shown to have an anesthetic effect when administered topically to rabbits (Suffridge et al. 2009). No studies have reported its topical ophthalmic use in dogs or cats.

Advantages and disadvantages

Certain topical anesthetics will decrease tear production and improve drug bioavailability from the conjunctival sac (Patton and Robinson 1975). Decreased lacrimation will affect results of Schirmer tear test values for at least 45 minutes and possibly longer after the application of one drop of 0.5% proparacaine. Schirmer tear tests aimed at evaluating both basal and stimulated tear production should therefore be performed prior to the application of topical anesthetic (Hamor et al. 2000). Repeat application of topical anesthetics is toxic to the corneal epithelium and should not be used therapeutically (Herse and Siu 1992; Judge et al. 1997; Nam et al. 2006; McGee and Fraunfelder 2007). Sample acquisition for culture from the corneoconjunctival area is recommended prior to instillation of local anesthetic due

to their antimicrobial activity. Finally, storage of proparacaine at room temperature for more than two weeks results in a decrease in drug effect; therefore, refrigeration of opened bottles is recommended (Stiles et al. 2001).

Specific aspects of loco-regional anesthesia of the eye in cats

Intravenous administration of lidocaine is commonly considered to be particularly toxic in cats because of the potential for myocardial and CNS depression (Chadwick 1985; Lemke and Dawson 2000). However, numerous studies evaluating the toxic effects of lidocaine do not support the cat as being particularly sensitive to this drug (Pypendop and Ilkiw 2005). Cats are generally of lower body weight than most dogs, thus care must be taken to calculate the correct volume of local anesthetic drug that can be safely administered to the feline patient (O'Brien et al. 2010). In addition to careful dose calculation, as with dogs, aseptic technique should be used and syringes should be aspirated before local anesthetic injection to avoid inadvertent intravascular administration.

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10 The Oral Cavity

Margherita Gracis

Overview

Indications on how to perform "dental anesthesia" in the dog were published as early as 1928 by Frank (Frank 1928). Local blockade of the nerves serving the oral cavity and face in the dog and cat requires simple equipment and material, readily available at any veterinary practice, including disposable 1.0 and 2.5 mL aspirating syringes and thin, disposable, stainless steel needles. Needle size can vary from 25-gauge to 30-gauge, at 12 mm (that we define as extra short), 25 mm (short) or 36 mm (long) in length. It should be considered that thinner needles may lead to falsely negative aspiration tests because of an increased resistance and are therefore not recommended (Baart and Brand 2009). Multiple-dose vials of anesthetic agents can be used. To minimize damage to the thin needle used for these blocks, some authors suggest using separate needles for withdrawal of the local anesthetic solution and injection (Woodward 2008). Local blocks of the oral cavity can also be delivered by using breech-loading, metallic or plastic, dental cartridge-type, aspirating syringes or computer-controlled local anesthetic delivery systems (Malamed 2004; Baart and Brand 2009); the latter are, however, relatively costly and are rarely available in veterinary practice.

General considerations

Anesthesia requirements

Sedation or general anesthesia is necessary for the delivery of dental nerve blocks, as most of these nerves are deeply located and may be difficult to reach in the conscious nonsedated patient.

Animal positioning

No special positioning is required for the administration of nerve blocks of the oral cavity. Normally, the patient's position is dictated by the planned procedure and/or by personal preference.

Indications and advantages

Procedures for which loco-regional anesthesia may be indicated include dental extractions, periodontal flap surgery, endodontic procedures, restorative

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procedures, implant surgery, oronasal fistula and palatal defect (cleft palate) closure, maxillary and mandibular fracture repairs, post-traumatic soft tissue reconstruction, biopsies, and oncologic surgery with excision of hard (e.g. maxillectomy, mandibulectomy) and soft tissue (e.g. glossectomy, palatectomy). Even dental scaling and polishing may cause a certain degree of discomfort (Gauthier and Gilbert 2004). The efficacy of two of the most commonly used oral local blocks, namely the infraorbital and the inferior alveolar nerve blocks, has been proven in halothane-anesthetized dogs (Gross et al. 1997).

If long-acting local anesthetics are used, the effect may last for some time in the postoperative period (the duration of the effect depends on the drug used as well as on other factors), allowing for a faster, smoother recovery, and continuing the analgesic effect after the end of the procedure itself.

Contraindications and precautions

While delivering a local block, a number of precautions should be taken, most of which will be discussed in detail in the description of the specific technique. Large, blunt, or barbed needles may injure nerves, vessels, and soft tissue. Whenever resistance is felt while advancing a needle in the tissues, especially near a foramen (e.g. infraorbital nerve block, rostral inferior alveolar nerve block), the needle should be withdrawn slightly and then advanced slowly at a different angle. If more than two attempts are necessary to engage into a foramen, the needle should be replaced, as the tip may be deformed and capable of injuring the soft tissues. When multiple blocks are delivered, needles should be changed for each injection.

If positive aspiration (the presence of blood into the syringe) is seen, then the local anesthetic solution should not be injected, the needle should be withdrawn, and a new needle inserted. The entire procedure is repeated until negative aspiration is obtained.

Skin may be prepared whenever a transcutaneous approach is used (e.g. maxillary nerve block-subzygomatic approach). A small area of hair may be clipped and the skin prepared before insertion of the needle. Also, if a transmucosal approach is used (e.g. maxillary nerve block-maxillary tuberosity approach), the oral mucosa in the area may be disinfected with a 0.05–0.1% chlorhexidine solution, and dried before insertion of the needle.

As a general rule, infection or acute inflammation at the injection site will be considered as a technical contraindication.

Choice and dosing of local anesthetics

Local anesthetics currently used in dentistry are of the amide-type, and include articaine, bupivacaine, dibucaine, etidocaine, lidocaine, mepivacaine, prilocaine, and ropivacaine. Ester-type anesthetics (e.g. procaine and propoxycaine) are seldom, if ever, used. Local anesthetics are typically classified according to their approximate duration of action into drugs with short (lidocaine, mepivacaine, prilocaine), intermediate (articaine) and long (bupivacaine, ropivacaine) duration (Table 10.1).

Most local anesthetic solutions possess some degree of vasoactivity (vasodilation) that in turn may cause an increase in their absorption rate, a decrease in their duration of effect, and an increase in the anesthetic plasma concentration and potential for toxicity (Malamed 2004). To offset the vasodilatory action and therefore prolong their duration of action, vasoconstrictor drugs (e.g. epinephrine) can be added to the local anesthetic solution.

Considering that lidocaine and bupivacaine are the most commonly used agents in veterinary den-

Table 10.1 Onset, duration of effect, biotransformation, and excretion of common local anesthetics (Malamed 2004; Rochette 2005; Baart and Brand 2009).

	Agent	Onset (min)	Duration (pulpal anesthesia) (min)	Duration (soft tissue anesthesia) (min)	Biotransformation	Excretion
Short	Lidocaine 2%	2–3	5–10	60–120	Liver	Kidneys
	Mepivacaine 2%	1–2	40	120–180	Liver	Kidneys
	Prilocaine 4%	2–4	40–60	120–240	Liver/lungs	Kidneys
Intermediate	Articaine 4%	1–3	60–75	180–360	Plasma/liver	Kidneys
Long	Bupivacaine 0.5%	6–10	90–180	240–540	Liver	Kidneys

Table 10.2 Examples of recently published recommended dosages and toxic doses of lidocaine and bupivacaine for dental/oral nerve blocks in dogs and cats.

Anesthetic agent	mL per site (cat)	Total max dose (mg kg^{-1}) (cat)	mL per site (dog)	Total max dose (mg kg^{-1}) (dog)	Toxic dose (mg kg^{-1})	Reference
Bupivacaine 0.5%	0.1–0.3	2	0.1–0.5	2		Beckman and Legendre 2002
Bupivacaine 0.25–0.5%	0.25–0.50		0.25–0.5			Lantz 2003
Lidocaine 2%	0.25	2		2–6		Rochette 2005
Bupivacaine 0.5%	0.25	1–2	Up to 1mL in large dogs	1–2		Rochette 2005
Lidocaine 2% and bupivacaine 0.5% (1:1)	0.2–0.25 of the combined solution	1 (of each)	1–3.5 kg: 0.2–0.25 of the combined solution 4–50 kg: 0.25–1.6 of the combined solution	1–3.5 kg: 1 (of each) 4–50 kg: decreasing doses from 1 (of each) to 0.3 (of each)		Beckman 2006
Bupivacaine 0.5%	0.1–0.3	1	0.1–0.5	2	4	Reuss-Lamky 2007
Lidocaine 2%	0.1–0.3	2.5	0.1–0.5	5	10	Reuss-Lamky 2007
Bupivacaine 0.5%	0.1–0.3	1.5–2	0.1–1.0	1.5–2	3.8 IV (cat), 4.3–5.0 IV (dog)	Lemke 2007
Lidocaine 2%	0.1–0.3	6–8	0.1–1.0	6–8	12.0 IV (cat), 20.8–22.0 IV (dog)	Lemke 2007
Lidocaine		<3		<6	10 (dog), 6 (cat)	Carpenter and Marretta 2007
Bupivacaine		<1		<2	3 (dog), 2 (cat)	Carpenter and Marretta 2007
Lidocaine 2%			1–2			Skarda and Tranquilli 2007a
Lidocaine 1–2% or bupivacaine 0.25–0.5%	0.1–0.3					Skarda and Tranquilli 2007b
Any agent	0.1–0.2	2	0.1–0.4	2		Woodward 2008

tistry and maxillofacial surgery, reported recommended doses vary significantly (Table 10.2). Total local anesthetic dose should be based on bodyweight and the number of anticipated sites that need to be blocked. If multiple sites need to be blocked, care should be taken to ensure that toxic doses are not reached. In smaller patients, when the calculated volume is too small, the local anesthetic solution can be diluted with 0.9% saline (Beckman 2006; Reuss-Lamky 2007). On average 0.2–0.25 mL are used for each block in cats and 0.2–0.8 mL in dogs (or more in very large animals) (Beckman 2006).

Maxillary nerve block

Functional and clinical anatomy

Knowledge of the regional anatomy is indispensable if the anesthetist is to place the local anesthetic solution accurately and avoid injuring nearby structures.

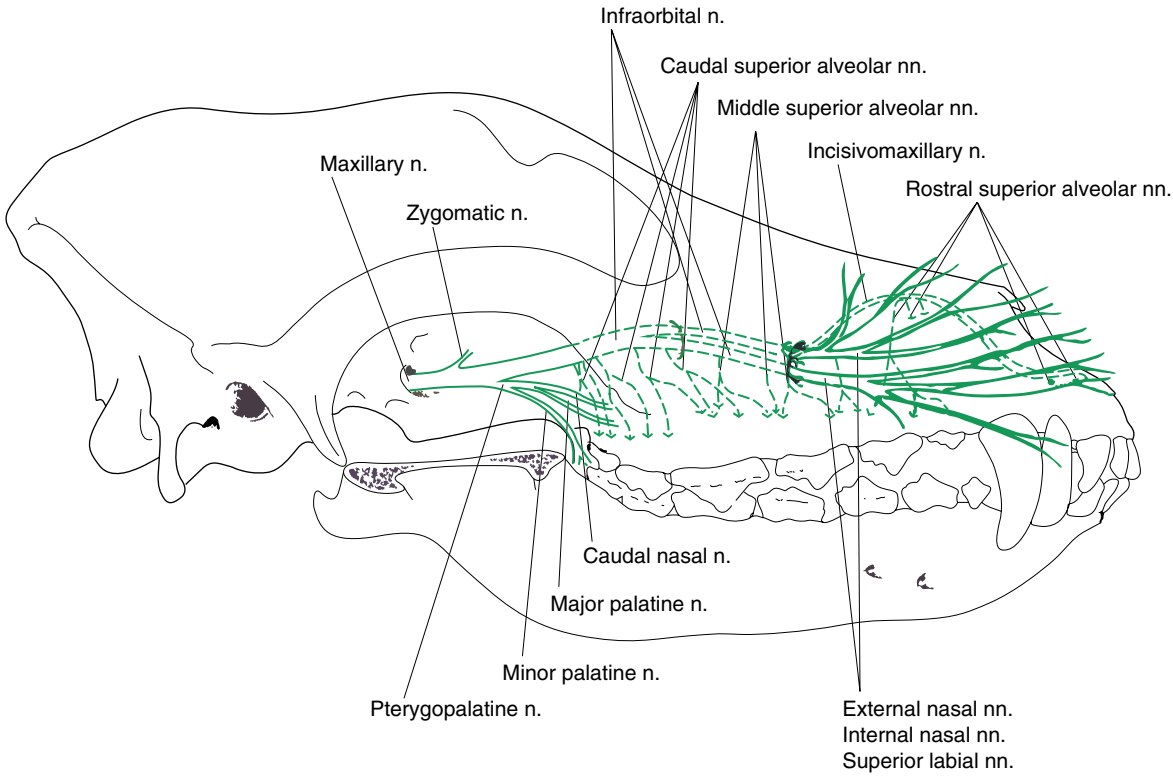

Figure 10.1 Distribution of the maxillary nerve and its oral branches in the dog.

The majority of the sensory innervation of the teeth, bone, and soft tissue of the oral cavity and the facial skin is provided by the right and left trigeminal nerves (V) (Jayne 1898; Evans and Kitchell 1993; Dyce and Molenaar 1996; Done et al. 2009). The motor branch of the trigeminal nerve (the mandibular branch, V_3) supplies the muscles of mastication and other muscles of the region. The three branches of the sensory root [ophthalmic (V_1), maxillary (V_2), and mandibular (V_3) branches] supply the skin of the face and the mucous membranes of eyes, nose, and oral cavity, except for the pharynx and the base of the tongue. Those structures are innervated by the glossopharyngeal nerve (IX) that serves the pharynx and the base of the tongue, and the vagus nerve (X) that serves the pharynx. These branches come off as the trigeminal nerve emerges from the trigeminal canal, on the rostromedial aspect of the petrosal bone. The maxillary branch runs through the round foramen, the alar canal, and the rostral alar foramen into the caudal portion of the pterygopalatine fossa, and then courses rostrally on the dorsal surface of the medial pterygoid muscle (Figure 10.1). In the rostral part of the pterygopalatine fossa it leaves off the zygomatic and the pterygopalatine nerves and continues as the infraorbital nerve into the maxillary foramen and the infraorbital canal (Figure 10.1). It exits from the infraorbital foramen on the side of the face (Figures 10.1, 10.2a, e, f, and 10.3a, e, f). In its course, the infraorbital nerve gives off the caudal superior alveolar, middle superior alveolar, and the incisivomaxillary nerves (with the rostral superior alveolar nerves) to supply the maxillary teeth (Figure 10.1). The caudal superior alveolar branches arise from the maxillary nerve in the pterygopalatine fossa. They run in a rostroventral direction and enter the alveolar canals via the alveolar foramina of the maxilla to supply the roots of the molar teeth (Figure 10.1). The middle superior alveolar branches originate from the infraorbital nerve in the pterygopalatine fossa in cats and within the infraorbital canal in dogs. They supply the fourth premolar tooth (and possibly the third premolar tooth

Figure 10.2 Canine skull. (a) Dorsoventral view. (b) Palatal surface of the upper jaw. (c) Lateral side of the left rostral mandible. (d) Medial side of the left caudal mandible. Dash line: imaginary line between the angular process and the last molar tooth, useful to locate the mandibular foramen. (e) Lateral view. (f) Rostral view. AP: angular process of the mandible; CMF: caudal mental foramen; CP: coronoid process of the mandible; IOC: infraorbital canal; IOF: infraorbital foramen; MaF: mandibular foramen; MMF: middle mental foramen; MPF: major palatine foramen; MTu: maxillary tuberosity; MxF: maxillary foramen; PB: pterygoid bone; RMF: rostral mental foramen; VasN: vascular notch (mandible); ZA: zygomatic arch.

in cats) (Figure 10.1) (Godinho and Getty 1975; Rosenzweig 1993). Just before the infraorbital nerve exits through the infraorbital foramen, located dorsal to the distal root of the third premolar tooth (Figures 10.2e and 10.3e), it gives off the incisivomaxillary nerve (Figure 10.1) (Godinho and Getty 1975; Gracis 1998, 1999). This nerve enters the incisivomaxillary canal, and runs rostrally and dorsally in the width of the maxillary bone. At the apex of the canine tooth it curves ventrally and medially, apically to the incisive teeth. It leaves off the rostral superior alveolar branches to the second premolar tooth in cats and the first three premolar teeth in dogs, as well as to the canine tooth and the ipsilateral incisor teeth both in dogs and cats.

The infraorbital nerve, after running into the homonymous canal, exits from the infraorbital foramen and divides into external and internal nasal branches and superior labial branches, supplying the soft tissues of the rostral portion of the face (Figure 10.1).

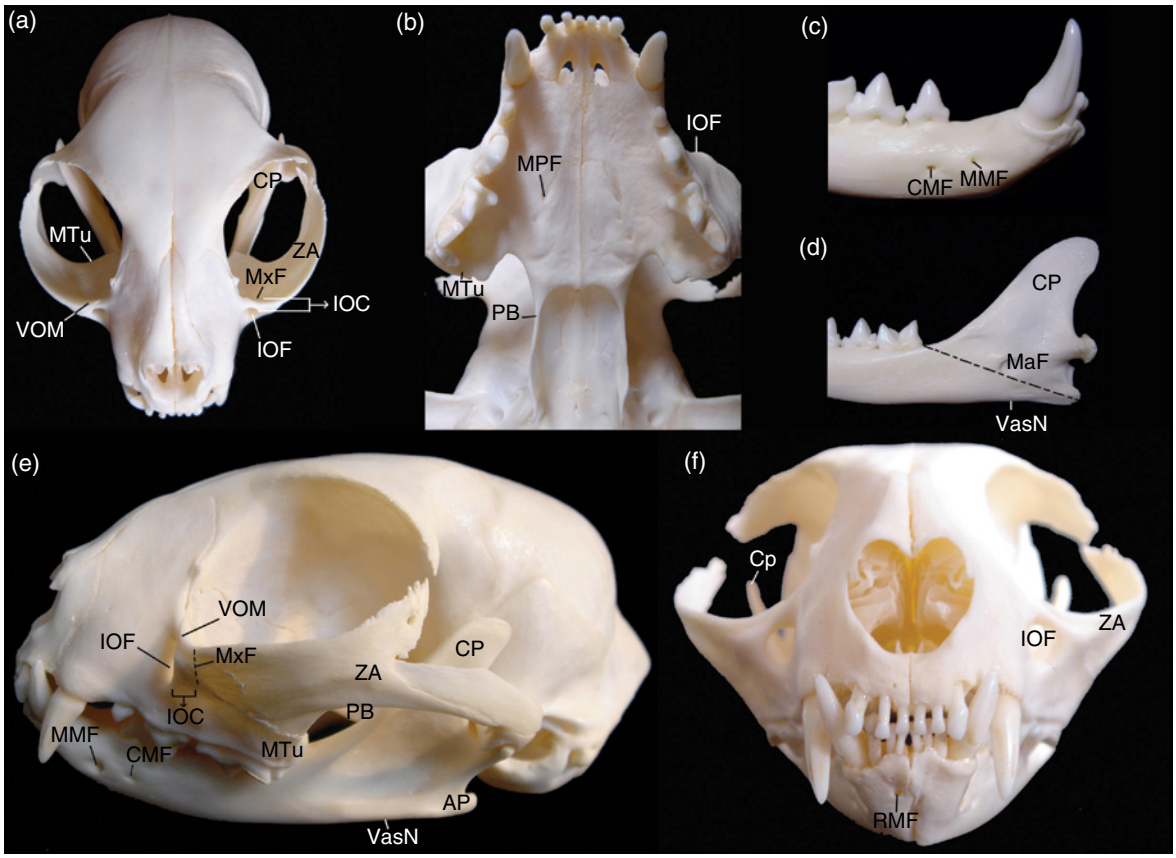

Figure 10.3 Feline skull. (a) Dorsoventral view. (b) Palatal surface of the upper jaw. (c) Lateral side of the right rostral mandible. (d) Medial side of the right caudal mandible. Interrupted line: imaginary line between the angular process and the last molar tooth, useful to locate the mandibular foramen. (e) Lateral view. (f) Rostral view. AP: angular process of the mandible; CMF: caudal mental foramen; CP: coronoid process of the mandible; IOC: infraorbital canal; IOF: infraorbital foramen; MaF: mandibular foramen; MMF: middle mental foramen; MPF: major palatine foramen; MTu: maxillary tuberosity; MxF: maxillary foramen; PB: pterygoid bone; RMF: rostral mental foramen; VasN: vascular notch (mandible); VOM: ventral orbital margin; ZA: zygomatic arch.

Distribution of local anesthesia and analgesia

By placing an anesthetic solution in the pterygopalatine fossa, near the maxillary foramen, it is possible to anesthetize all maxillary teeth and associated soft tissues, including the skin of the nose, cheek, and upper lip. The palate and the lateral aspect of the nasal mucosa of the same side (the medial aspect is served by the ethmoidal nerve, a branch of V_1) are also likely desensitized, as the pterygopalatine nerve branches from the maxillary nerve just before the maxillary foramen (Figure 10.1). For these reasons, this block is useful when performing procedures on any tooth or on soft and hard tissues (e.g. maxillectomy procedures) of the ipsilateral maxilla.

Equipment

- Disposable or sterile gloves as needed;
- local anesthetic solution;
- 1.0–2.5 mL aspirating syringes;
- 25–27-gauge, 25 mm long needle (dogs; giant size dogs may require longer needles); and
- 27–30-gauge, 12 mm long needle (cats).

Note that the distance between the cutaneous surface or the mucosal surface and the maxillary nerve is approximately 1.5–2 cm in medium size dogs and less than 1 cm in cats. A slightly greater distance exists between the infraorbital foramen and the pterygopalatine fossa.

Technique (Table 10.3)

Anatomic landmarks

The maxillary nerve is blocked at its distal end, right before it enters the maxillary foramen, in the rostral portion of the pterygopalatine fossa. The nerve runs close to the maxillary artery medial to the zygomatic arch, ventral to the ocular globe, dorsomedial to the zygomatic salivary gland, and dorsal to the maxillary tuberosity and the maxillary molar teeth. The deep facial vein can also be found in the vicinity (Done et al. 2009), and therefore extreme caution needs to be taken not to puncture it.

Step-by-step procedure

Three techniques (one intra- and two extraoral approaches) have been described. They all involve blind placement of the anesthetic solution into the pterygopalatine fossa:

- Maxillary tuberosity
- Subzygomatic
- Infraorbital

Maxillary tuberosity approach

The first technique, similar to the so-called high tuberosity approach used in humans, requires the introduction of the needle intraorally, behind the last molar tooth and the maxillary tuberosity, which is the thin caudal margin of the maxilla covering the roots of the last molar tooth (Figures 10.2a, b, e, 10.3a, b, e, and 10.4) (Malamed 2004).

With the animal under general anesthesia or deeply sedated, and its mouth kept open using a gag, the operator's nondominant hand is introduced into the patient's mouth and the maxillary tuberosity is palpated. A short needle is then inserted between the operator's finger and the bone, as perpendicularly as possible to the hard palate or with a slight medial direction, with the bevel directed rostrally. Depth of insertion varies between 5 and 10 mm in cats and up to 25–30 mm in dogs, depending on the size of the patient. Once in place, next to the maxillary nerve area, aspiration is performed to avoid inadvertent intravascular injection, and the local anesthetic solution is injected slowly. In some patients, the correct angle of insertion of the needle may be difficult to obtain because of the limited possibility to extend the mandible. Bending the needle before introduction may predispose it to breakage and is therefore not recommended. Puncturing the zygomatic salivary gland during this block is possible or even likely.

Subzygomatic approach

The maxillary nerve block may also be performed using a transcutaneous approach, with insertion of the needle between the caudal margin of the maxilla and the coronoid process of the mandible, below the rostroventral border of the zygomatic arch (Figure 10.5).

These structures can be easily palpated on the side of the face, just below the ocular globe (Figures 10.2e, 10.3e, and 10.5). The needle is inserted perpendicularly to the skin surface and advanced a short distance (dictated by the size of the patient), to reach the pterygopalatine fossa and the maxillary nerve. Aspiration is performed to avoid inadvertent intravascular injection, and the local anesthetic solution is injected slowly.

Infraorbital approach

A third option for delivering the maxillary nerve block is through the infraorbital canal itself (Figure 10.6).

This technique involves insertion of a thin, needle (12 mm long in cats, up to 25–30 mm long in dogs) through the skin of the upper lip or the vestibular mucosa over the infraorbital foramen, entering the homonymous canal and exiting from the maxillary foramen, to inject the solution in the pterygopalatine fossa, next to the maxillary nerve (see also the description of the infraorbital nerve block). Some authors suggest considering the medial canthus of the eye as the point of reference for the caudal extent of the infraorbital canal (Woodward 2008). Because of the long distance to be covered, however, there may be a high risk of injuring the neurovascular structures

Table 10.3 Nerve blocks of the oral cavity and corresponding anesthetized nerves and anatomic structures.

Technique	Anesthetized nerves	Anesthetized structures
Maxillary nerve block (high tuberosity approach)	Maxillary nerve, infraorbital nerve, caudal, middle and superior alveolar dental nerves., incisivomaxillary nerve and rostral superior alveolar dental nerves. *Possibly pterygopalatine nerve and caudal nasal nerve*	Ipsilateral maxilla (i.e. teeth, bone and soft tissues), skin of the nose, cheek, upper lip. *Possibly ipsilateral hard and soft palate (pterygopalatine nerve), and nasal mucosa (caudal nasal nerve)*
Maxillary nerve block (transcutaneous approach)	Same as above	Same as above
Maxillary nerve block [infraorbital approach (transcutaneous or transmucosal)]	Same as above	Same as above
Caudal palatine nerve block (high tuberosity approach)	Pterygopalatine nerve, minor and major palatine nerves, accessory palatine nerve, caudal nasal. *Possibly maxillary nerve, infraorbital nerve, caudal, middle and rostral superior alveolar dental nerves, incisivomaxillary nerve*	Bone and soft tissue of ipsilateral hard and soft palate. *Possibly ipsilateral maxilla (i.e. teeth, bone and soft tissues), skin of the nose, cheek, upper lip (maxillary nerve, infraorbital nerve, caudal, middle and rostral superior alveolar dental nerves, incisivomaxillary nerve).*
Caudal palatine nerve block (transcutaneous approach)	Same as above	Same as above
Caudal palatine nerve block [infraorbital approach (transcutaneous or transmucosal)]	Same as above	Same as above
Rostral (major) palatine nerve block	Major palatine nerve	Bone and soft tissue of ipsilateral hard palate
Caudal infraorbital nerve block (intraoral approach)	Infraorbital nerve, middle and rostral superior alveolar dental nerves, incisivomaxillary nerve, external nasal, internal nasal and superior labial nerves	Ipsilateral premolar, canine and incisor teeth and associated soft tissues, skin of the muzzle and the upper lip
Caudal infraorbital nerve block (transcutaneous approach)	Same as above	Same as above
Rostral infraorbital nerve block (intraoral approach)	Infraorbital nerve, incisivomaxillary nerve, rostral superior alveolar dental nerves, external nasal, internal nasal and superior labial nerves	Ipsilateral third to first premolar teeth, canine and incisor teeth and associated soft tissues, skin of the muzzle and the upper lip
Rostral infraorbital nerve block (transcutaneous approach)	Same as above	Same as above
Caudal inferior alveolar nerve block (intraoral approach)	Inferior alveolar nerve, caudal, middle and rostral mental nerve, incisive nerve *Possibly lingual nerve and mylohyoid nerve*	Ipsilateral mandibular molar, premolar, canine and incisor teeth and associated labial tissues, rostral lower lip, rostral intermandibular tissues. *Possibly tissues lingual to the mandible, floor of the mouth and rostral two-thirds of the tongue (lingual nerve), the skin of the lower lip and cheek, and the caudal intermandibular region (mylohyoid nerve)*
Caudal inferior alveolar nerve block (transcutaneous approach)	Same as above	Same as above

Table 10.3 (*cont'd*).

Technique	Anesthetized nerves	Anesthetized structures
Mental nerve block (intraoral and transcutaneous approach)	Middle mental nerve	Ipsilateral rostral lower lip, rostral intermandibular tissues
Rostral inferior alveolar nerve block (intraoral and transcutaneous approach)	Rostral portion of the inferior alveolar nerve, middle and rostral mental nerves. *Possibly caudal mental nerve*	Ipsilateral mandibular first and second premolar, canine and incisor teeth, and labial soft tissues, rostral lower lip, rostral intermandibular tissues
Splash block	Terminal nerve endings at the injection site	Soft and hard tissues at the surgical site (i.e. alveolus)
Infiltration	Terminal nerve endings at the injection site and at the apex of the tooth	Bone, soft tissues, apical and pulpal tissues of a single tooth
Intraosseous injection	Terminal nerve endings at the injection site and at the apex of the tooth	Bone, soft tissues, apical and pulpal tissues of a limited area or a single tooth
Intraseptal injection	Terminal nerve endings at the injection site and at the apex of the tooth	Bone, soft tissues, apical and pulpal tissues of a limited area or a single tooth
Periodontal ligament injection	Terminal nerve endings at the injection site and at the apex of the tooth	Bone, soft tissues, apical and pulpal tissues of a single tooth
Intrapulpal injection	Terminal nerve endings at the injection site	Pulp tissues of a single tooth

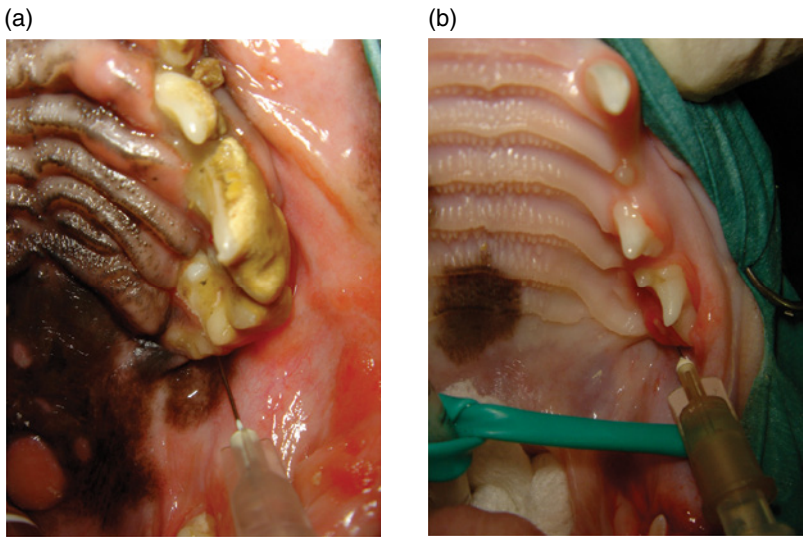

Figure 10.4 Maxillary nerve block (high tuberosity approach) in the dog (a) and the cat (b). The same puncture site is used in the caudal palatine nerve block (high tuberosity approach).

contained in the infraorbital canal, and other techniques may be preferable when caudal teeth need to be anesthetized.

Overinsertion or underinsertion, and subsequently ineffective administration of the anesthetic drug, are possible complications with any of the described maxillary nerve block techniques.

Clinical tips

In the subzygomatic approach, if a needle is introduced too deeply, the tip may contact the lateral side (plate) of the pterygoid bone. Should this occur, the needle must be withdrawn for a short distance before injecting the solution.

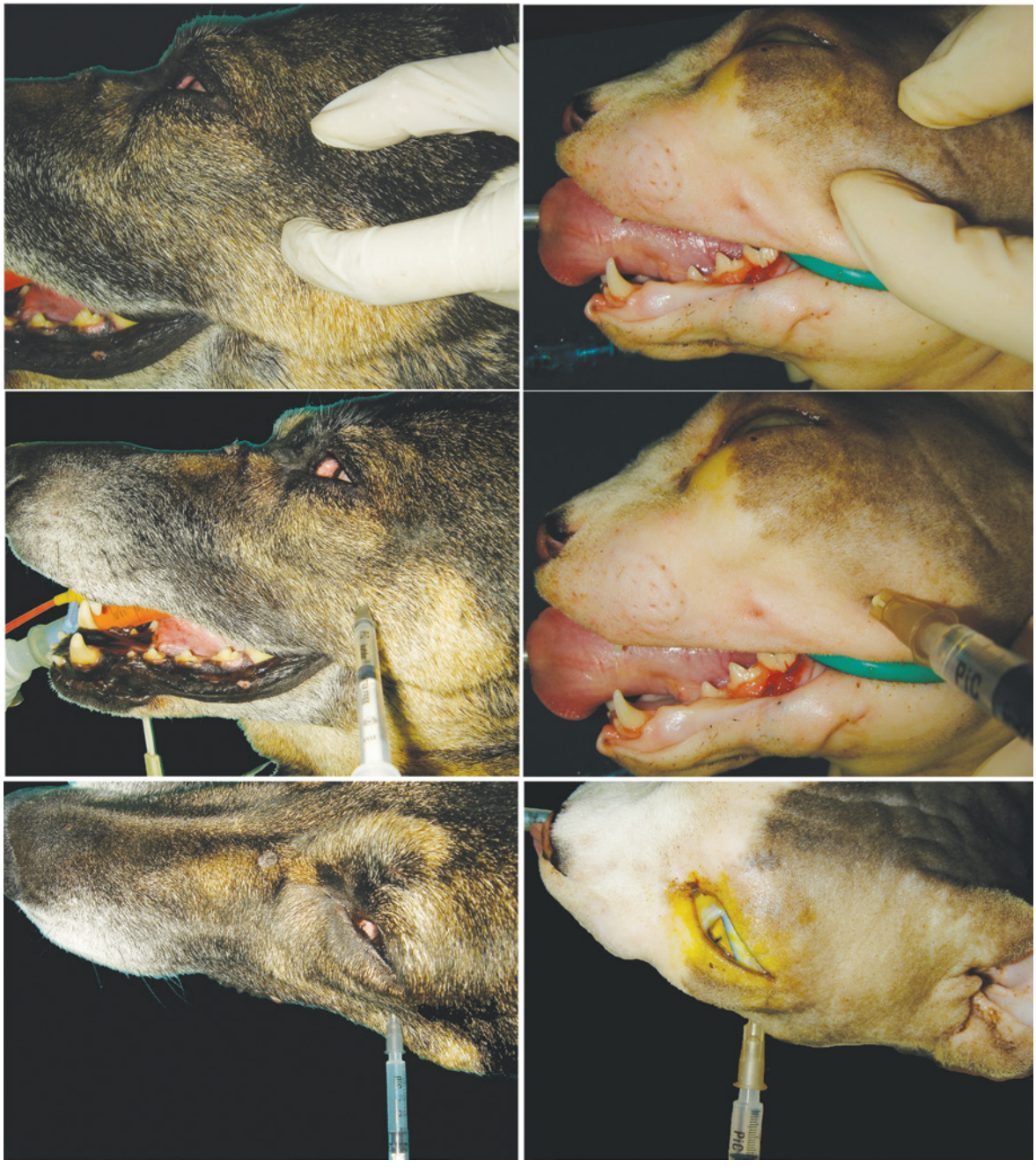

Figure 10.5 Maxillary nerve block in the dog (left) and the cat (right) using a transcutaneous approach. The index finger is placed over the ventral margin of the rostral portion of the zygomatic arch. The needle is inserted in this location, perpendicular to the skin. The location corresponds roughly to the lateral canthus of the eye. The same puncture site is used in the caudal palatine nerve block (transcutaneous approach).

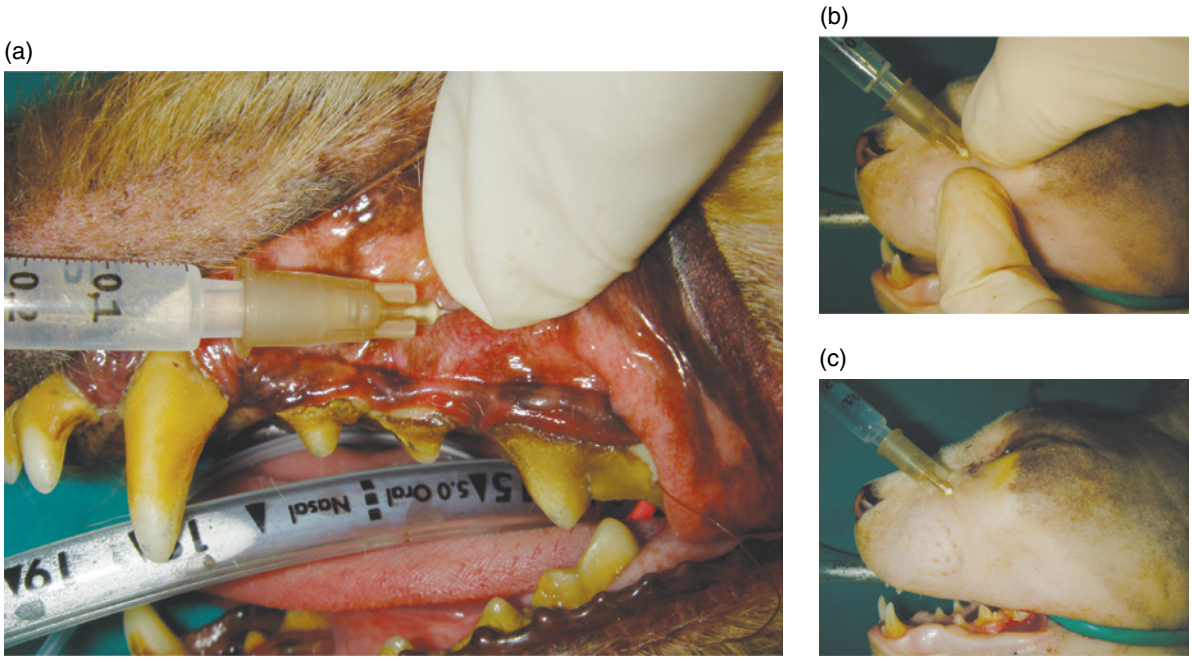

Figure 10.6 Infraorbital nerve block. The infraorbital foramen is on the lateral side of the maxilla, slightly rostroventral to the eye, dorsal to the distal root of the maxillary third premolar tooth. The thumb of the free hand is placed on the foramen, and the needle inserted below it to engage into the foramen itself. (a) Dog (transmucosal approach). (b) and (c) Cat (transcutaneous approach). The same puncture sites are used for the maxillary nerve block (infraorbital approach) and the caudal palatine nerve block (infraorbital approach).

Caudal and rostral palatine nerve blocks

Functional and clinical anatomy

The mucosa of the soft and hard palates of each side is innervated by the minor, the accessory, and the major palatine nerves (Evans and Kitchell 1993; Dyce and Molenaar 1996; Done et al. 2009). The minor and major palatine nerves arise from the pterygopalatine nerve, which in turn originates from the maxillary nerve in the pterygopalatine fossa (Figure 10.1). The minor palatine nerve runs around the rostral edge of the medial pterygoid muscle and supplies the soft palate. The major palatine nerve gives off the accessory palatine nerve, which innervates the caudal portion of the hard palate. Then it enters the palatine canal and exits through the major palatine foramen on the oral side of the palatine process. The major palatine nerve runs rostrally with the major palatine artery to supply the mucosa of the hard palate. The caudal nasal nerve is the continuation of the pterygopalatine nerve (Figure 10.1). It enters the nasal cavity through the sphenopalatine foramen in the pterygopalatine fossa, and supplies the nasal mucosa of the ventral part of the nasal cavity, maxillary sinus, and palate (Dyce and Molenaar 1996).

Distribution of local anesthesia and analgesia

By blocking the pterygopalatine nerve in the pterygopalatine fossa, which following the human nomenclature, may be called a caudal palatine nerve block, both the hard and the soft palatal mucosa (as well as the nasal mucosa) will be desensitized. The entire ipsilateral maxilla is likely to be anesthetized, as the anesthetic solution likely diffuses around the maxillary nerve too.

If the major palatine nerve is blocked through an intraoral approach (rostral or major palatine nerve block), only the mucosa of the hard palate of that side will be desensitized. This block does not

provide anesthesia to the dental pulp of the maxillary teeth.

A bilateral palatine nerve block may be useful when performing surgical procedures on the palate hard and soft tissues.

Equipment

- Disposable or sterile gloves as needed;
- local anesthetic solution;
- 1.0–2.5 mL aspirating syringes; and
- 25–30-gauge, 12–25 mm long needle (depending on patient's size).

Note that, as described for the maxillary nerve block, the rostral palatine nerve block requires extra short, small gauge needles.

Technique (Table 10.3)

Anatomic landmarks

To provide local anesthesia to the soft and hard palatal mucosa, the anesthetic solution should be inoculated in the pterygopalatine fossa in a location proximal to where the pterygopalatine nerve leaves the maxillary nerve, using a caudal palatine nerve block. For the rostral or major palatine nerve block the solution is placed at the major palatine foramen, at the maxillopalatine suture, midway between the palate midline and the dental arcade, usually at the level of the mesial roots of the maxillary fourth premolar tooth in cats and the distal root of the same tooth in dogs (Figures 10.2b and 10.3b), even if some variation in rostrocaudal position of the foramen is possible. The foramen cannot be palpated because of the marked thickness of the palatal mucosa. Therefore the solution is injected using only the described anatomic landmarks.

Step-by-step procedure

There are four different approaches:

- Maxillary tuberosity
- Subzygomatic
- Infraorbital
- Rostral or major palatine

Maxillary tuberosity approach

The maxillary tuberosity approach is achieved by inserting the needle intraorally through the mucosa caudal to the last molar and the maxillary tuberosity, as perpendicularly as possible to the hard palate (Figure 10.4).

Subzygomatic approach

To use an extraoral subzygomatic approach, the patient is placed in lateral recumbency and the needle is inserted for a short distance perpendicularly to the skin, between the caudal margin of the maxilla and the coronoid process of the mandible, ventral to the rostral portion of the zygomatic arch (Figure 10.5).

Infraorbital approach

As previously explained for the maxillary nerve block (infraorbital approach), the insertion of the needle through the infraorbital canal to reach the pterygopalatine fossa (Figure 10.6) is not advised because of the high risk of injuring the infraorbital neurovascular structures within the canal. Once the needle is in place, aspiration is performed to avoid inadvertent intravascular injection, and the local anesthetic solution is injected slowly.

Rostral or major palatine approach

The hard palatal mucosa can also be desensitized by injecting the solution near the major palatine nerve as it exits from the major palatine foramen, using a rostral or major palatine nerve block (Figure 10.7).

To perform this block, the patient should preferably be placed in dorsal recumbency and the mouth opened. The needle is then advanced through the palatal mucosa midway between the midpalatal suture and the dental arcade, slightly rostral to the mesial roots of the maxillary fourth premolar tooth. The needle is angled 30–45°, and advanced caudally to reach the foramen. The bevel should be directed towards the bone. With the tip of the needle next to the major palatine foramen, and after negative aspiration, the solution is inoculated very slowly, as rapid injection produces high tissue pressure (visible as ischemia or whitening of the soft tissues at the injection site), which may cause ischemic injury to the palatal soft tissue and cause localized pain when the anesthetic effect

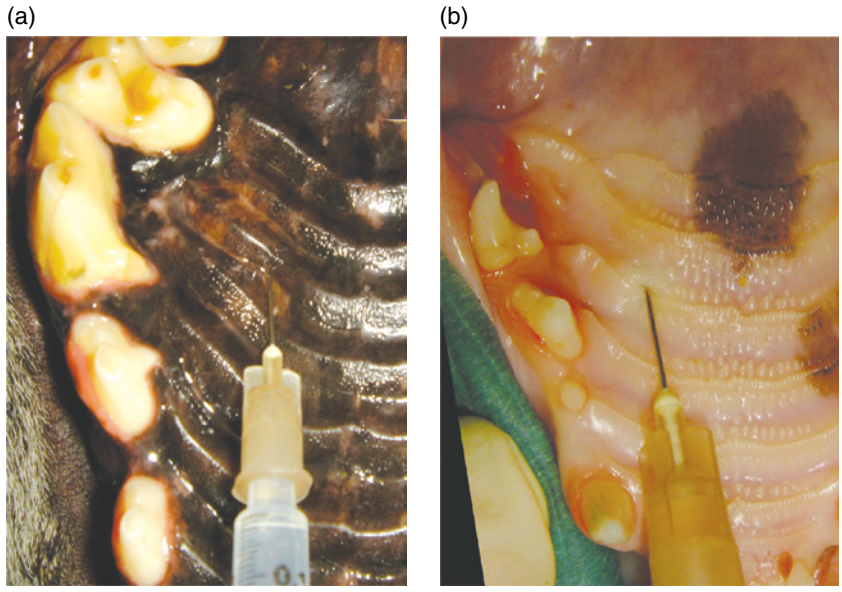

Figure 10.7 Rostral palatine nerve block. The needle is inserted through the palatine mucosa just rostral to the distal (a, dog) and mesial (b, cat) roots of the maxillary fourth premolar tooth. The needle is advanced in a caudal direction.

wears off. Therefore, only a small amount of solution should be injected (usually, 0.1 mL of solution is used in small size animals, and 0.2–0.4 mL in larger patients).

Clinical tips

Because of their limited size, it is difficult (if not impossible and unnecessary) to insert needles into the palatine foramen and canal, especially in cats and small dogs. Furthermore, damage to the nerve is a possible complication when inserting a needle in such a restricted location (Baart and Brand 2009).

Other techniques used in human patients to achieve anesthesia of specific palatal areas are the nasopalatine nerve block (anterior third of the palate), local infiltration of the palate (soft tissues in the immediate vicinity of the injection), the anterior middle superior alveolar nerve block (maxillary incisor, canine and premolar teeth and their gingival and corresponding palatal tissues), and the palatal approach-anterior superior alveolar (maxillary incisor and canine teeth and corresponding palatal and periodontal tissues) (Malamed 2004; Baart and Brand 2009). These have not been described in veterinary patients, but could have potential application.

Infraorbital nerve block

Functional and clinical anatomy

The infraorbital nerve is the rostral continuation of the maxillary nerve (Figure 10.1) (Evans and Kitchell 1993; Dyce and Molenaar 1996; Done et al. 2009). Within the pterygopalatine fossa, the maxillary nerve gives off the caudal superior alveolar nerves and, within the infraorbital canal, the middle superior alveolar nerves. These dental branches serve the caudal maxillary teeth. Additionally, just before exiting the infraorbital foramen, the infraorbital nerve gives the incisivomaxillary nerve that, with its anterior superior alveolar branches, supplies all premolar teeth rostral to the fourth premolar tooth, as well as the canine tooth and the incisor teeth of the ipsilateral maxilla (Figure 10.1). The incisivomaxillary nerve enters the incisivomaxillary canal through an opening located on the medial side of the infraorbital canal (Gracis 1998, 1999). In cats, the opening is closer to the maxillary foramen than it is to the infraorbital foramen (Jayne 1898; Rosenzweig 1993). Finally, once out of the infraorbital foramen, the infraorbital nerve divides into external nasal,

internal nasal, and superior labial branches, supplying the soft tissues of the external nose and upper lip (Figure 10.1).

Distribution of local anesthesia and analgesia

This block is useful when dental procedures are performed on any maxillary tooth, or when major surgical procedures on the hard and soft tissues of the ipsilateral maxilla are performed. The number of teeth and extent of tissue affected by the block depends on the volume of the injected anesthetic solution and the location of the needle tip (or the distance at which the needle is inserted into the infraorbital canal). It needs to be noted that placement of the anesthetic agent outside the infraorbital foramen will only anesthetize the skin of the muzzle and the upper lip (Woodward 2008).

Equipment

- Disposable or sterile gloves as needed;
- local anesthetic solution;
- 1.0–2.5-mL aspirating syringes; and
- 25–30-gauge needles.

Note that needle length is dictated by the size of the patient and the nerves (teeth) to be anesthetized.

Technique (Table 10.3)

Anatomic landmarks

The infraorbital foramen is on the lateral side of the maxilla, rostroventrally to the eye, dorsal to the distal root of the maxillary third premolar tooth (Figures 10.1 and 10.2a, e, f). In dogs, it can normally be palpated through the skin or vestibular mucosa at mid-height of the maxilla. The large infraorbital neurovascular bundle may also be palpated by gently running a finger in a dorsoventral direction on the lateral surface of the maxilla. Once located, it can be followed caudally where it exits from the infraorbital foramen. In cats, the foramen is just ventral to the ventral margin of the orbit, where a clear bony ridge (the lateral wall of the foramen) may be palpated (Figure 10.3a, e, f).

Step-by-step procedure

- This is a basic level nerve block as the landmarks are very clear and easy to find, and accurate placement of the solution can be confirmed by correct engagement in a relatively large foramen. The thumb of the nondominant hand is placed on the foramen, and the needle inserted underneath it to engage into the foramen itself (Figure 10.6). The depth at which the needle is inserted will determine the placement of either a rostral or a caudal infraorbital nerve block (note that this difference may be more didactic than practical).
- In dogs, the long axis of the needle should be kept parallel to the gingival margin or the palate (Figure 10.6a). The canal is only about 1–2 cm long (and even shorter in brachycephalic dogs), so overly long needles are not necessary (Figure 10.2a, e). If the anesthetic solution is deposited caudal to, or at the level of, the maxillary foramen, the entire ipsilateral dental quadrant will be anesthetized. If the fourth premolar tooth (or any more mesial tooth) needs to be anesthetized, the needle should either be inserted at least midway into the infraorbital canal in order to achieve a caudal infraorbital nerve block, or the amount of solution deposited at the infraorbital foramen will need to be large enough to migrate caudally and reach the middle superior alveolar nerves (Reuss-Lamky 2007).
- In case any more mesial tooth is to be anesthetized (e.g. from the third premolar tooth to the first incisor of the same side), a rostral infraorbital nerve block can be performed. A short needle may be used as it should just engage into the infraorbital foramen, where the incisivomaxillary nerve leaves the infraorbital nerve and before it enters the incisivomaxillary canal. Once the needle is in place, aspiration is performed to avoid intravascular injection, as positive aspiration may be relatively common. The solution is then slowly injected. Gentle pressure should be exerted over the injection site during the procedure and for 30–60 seconds after withdrawing the syringe to increase the volume of solution entering into the canal.

Clinical tips

Some authors believe that elevating the head of the patient and maintaining digital pressure over the foramen during the administration of a rostral infraorbital nerve block may help to encourage caudal migration of the solution into the infraorbital canal and achieve a caudal block without inserting the needle any further into the canal (Reuss-Lamky 2007).

In cats, the tight upper lip often makes it difficult to insert the needle through the vestibular mucosa at the correct angle. For this reason, in this species an extraoral transcutaneous approach is preferred over an intraoral approach (Figure 10.6b, c). The index of the free hand is placed on the ventral margin of the orbit, and the thumb underneath it, on the bony prominence made by the junction of the maxillary process of the zygomatic bone and the maxillary bone, where the foramen is located (Figure 10.6b). A 27–30-gauge, 12 mm needle should be introduced aiming ventrally at about 45° angle (Figure 10.6c) and for a very short distance (2–3 mm) or slightly more in depth in case a maxillary nerve block (infraorbital approach) is to be achieved. The infraorbital canal in cats is very short (approximately 4 mm long) (Figure 10.3a, e). Therefore, if the syringe is not kept with the correct dorsoventral angle, it is possible to direct the needle in any direction and injure the ocular globe. Interestingly, the infraorbital canal was found to be double in 12.5% of 250 feline skulls in one study, with a smaller dorsal and a larger ventral foramen (Jayne 1898). If the size of the foramina makes it difficult to insert the needle, then a maxillary nerve block with either a maxillary tuberosity or a subzygomatic approach may be performed instead.

Caudal inferior alveolar nerve block

Functional and clinical anatomy

The mandibular branch (V_3) of the trigeminal nerve (V) is motor to the muscles of mastication and the mylohyoideus muscle, and sensory to the hard and soft tissues of the mandible (including the mandibular teeth, the buccal mucosa, and the lower lip), the tongue, part of the skin of the head, and the mucosa of the intraosseous part of the external ear canal (Evans and Kitchell 1993; Dyce and Molenaar 1996; Done et al. 2009). Its major branches are from caudal to rostral: the masticator nerve (to the rostral belly of the digastricus, the masseter, and the deep temporal muscles), the lateral and medial pterygoid nerves (to the homonymous muscles), the tensor tympani nerve (to the tensor tympani muscle of the malleus), the tensor veli palatini nerve (to the homonymous muscle of the soft palate), the buccal nerve (to the skin and mucosa of the cheek), the auricolotemporal nerve (to the external acoustic meatus, the tympanic membrane, the parotid salivary gland, the pinna, the skin of the side of the face), the inferior alveolar nerve (to the mandibular teeth, the rostral lip, and the rostral intermandibular region), the mylohyoid nerve (to the rostral belly of the digastricus muscle, the skin of the lower lip and cheek, the mylohyoideus muscle, and the caudal intermandibular region), and the lingual nerve (sensory to the rostral two-thirds of the tongue, the buccal mucosa of the isthmus of the fauces, and the sublingual mucosa) (Figure 10.8).

The mylohyoid nerve and the lingual nerve may arise directly from the inferior alveolar nerve, which leaves the mandibular nerve at the level of the pterygopalatine fossa, on the lateral aspect of the medial pterygoid muscle. The inferior alveolar nerve then runs ventrorostrally, and enters the mandibular foramen on the medial side of the mandibular ramus (Figures 10.2d and 10.3d). It runs inside the mandibular canal, ventral to the roots of the teeth, giving off caudal, middle and rostral mandibular alveolar dental branches (Figure 10.8). Rostrally, it supplies three terminal branches, the caudal, middle, and rostral mental nerves, exiting through the homonymous foramina on the lateral side of the mandible (Figures 10.2c, e, f, and 10.3c, e, f) and supplying the rostral lower lip and the rostral intermandibular region (Figure 10.8).

Distribution of local anesthesia and analgesia

Using this technique, any mandibular tooth, rostral lower lip and the rostral intermandibular region will be anesthetized. Desensitization of the soft

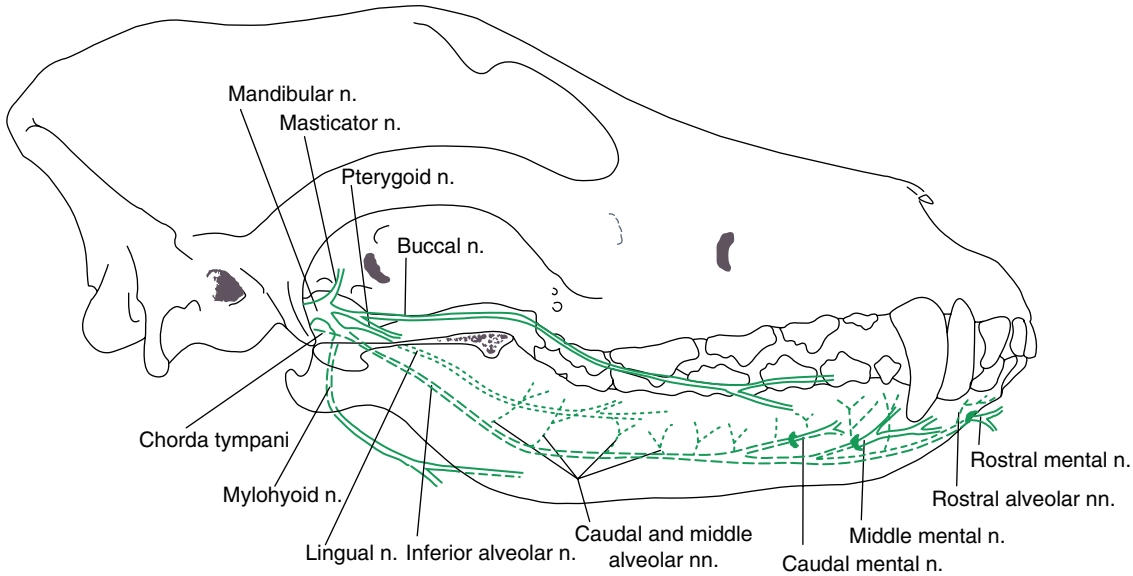

Figure 10.8 Distribution of the mandibular nerve and its oral branches in the dog.

tissue and periosteum of the lingual side of the mandible, floor of the mouth, and rostral two-thirds of the tongue may develop as well if the local anesthetic solution diffuses to the lingual nerve.

Equipment

- Disposable or sterile gloves as needed;
- local anesthetic solution;
- 1.0–2.5-mL aspirating syringes;
- 25–27-gauge, 25 mm long needle (dogs; giant size dogs may require longer needles); and
- 27–30-gauge, 12–16 mm long needle (cats).

Note that, in dogs, a short to long needle may be used to reach the mandibular foramen, both with intraoral and extraoral approaches.

Technique (Table 10.3)

Anatomic landmarks

The local anesthetic solution should be located next to the mandibular foramen, on the medial side of the mandible, ventral to the attachment of the temporalis muscle and rostral to the belly of medial pterygoid muscle. The foramen can be found midway through an imaginary line drawn between the angular process of the mandible and the last molar tooth, from 0.5 cm (cats and small dogs) to 2 cm (large dogs) dorsal to the facial vascular notch, a slight concavity of the ventral margin of the mandibular ramus that is just rostral to the angular process (Figures 10.2d, e, and 10.3d, f) (Martinez et al. 2009). In cats and some dogs the notch may be very shallow and difficult to identify. In this case, different anatomic landmarks can be used to locate the foramen. Some authors suggest drawing an imaginary vertical line from the lateral canthus of the eye and the midpoint of the zygomatic arch to the ventral aspect of the mandible (Beckman and Legendre 2002; Rochette 2005). The puncture site is located on the medial aspect of the mandible.

Step-by-step procedure

Intraoral and extraoral techniques may be used to administer the caudal inferior alveolar nerve block.

Intraoral approach

When an intraoral approach is chosen, the mouth of the patient is kept wide open (a mouth gag can be used) and the tongue displaced to the contralateral side (Figure 10.9).

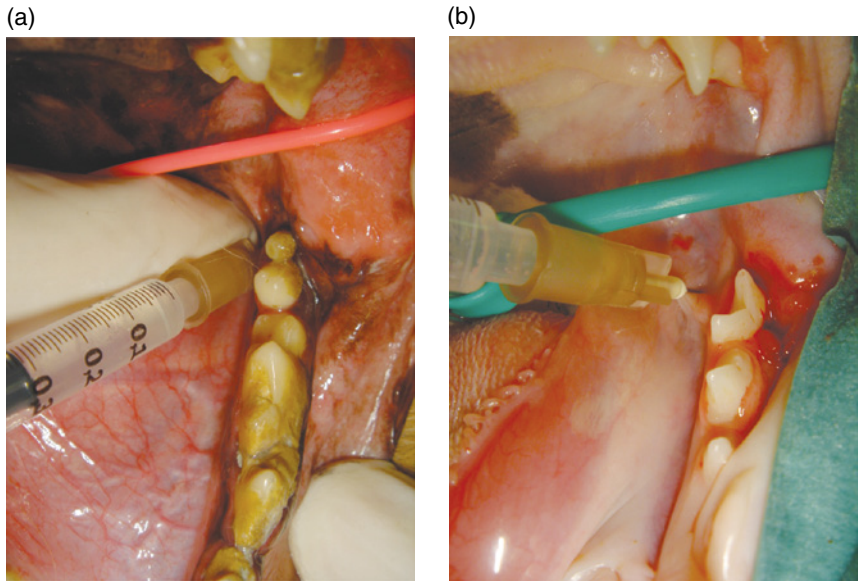

Figure 10.9 Caudal inferior alveolar nerve block (intraoral approach) in the dog (a) and the cat (b). The mandibular foramen can be palpated with a finger of the free hand. The needle is advanced through the mucosa medial to the mandible, at the level of the last mandibular molar tooth. The needle should be directed ventrocaudally towards the angular process to reach the mandibular foramen.

The mandibular foramen can be palpated with a finger of the nondominant hand. The needle is then advanced through the mucosa medial to the mandible, at the level of the last mandibular molar tooth. The needle is directed ventrocaudally, towards the angular process, between the operator's fingers and the mandibular bone, to reach the mandibular foramen. Negative aspiration should be obtained before slowly injecting the anesthetic solution. On palpation, the tissues at the injection site should swell while injecting.

Extraoral (transcutaneous) approach (Figure 10.10)

The animal is placed in lateral recumbency, with the side to be blocked uppermost and the patient's mouth opened. A mouth gag should be placed to prevent the operator's hand from being bitten if the patient abruptly closes its mouth. The nondominant hand is placed intraorally, between the patient's tongue and mandible. A finger is advanced ventrocaudally along the mandible until the foramen can be palpated at the rostral margin of the medial pterygoid muscle. Using the dominant hand, the needle is then advanced medially, perpendicular to the ventral margin of the mandible, at the level of the facial vascular notch that is located rostral to the angular process (Figures 10.2d, e, 10.3d, e, and 10.10). The bevel of the needle is directed toward the bony surface and the tip of the needle is slowly advanced medial to the mandible to the mandibular foramen that is still being palpated intraorally. The needle tip can thus be precisely directed to a location over the foramen (and nerve). Aspiration is performed to avoid intravascular injection, and the solution is slowly injected. If performed correctly, swelling of the tissues should be detected through intraoral palpation of the injection site.

Clinical tips

It is very important to keep the needle next to the mandible and with the bevel directed toward the bony surface both with the intraoral and the extraoral techniques so the nerve is exposed to the local anesthetic solution.

In cats, the mandibular foramen is very shallow and relatively difficult to palpate (Figure 10.3d). It is therefore particularly important to know and identify the anatomic landmarks.

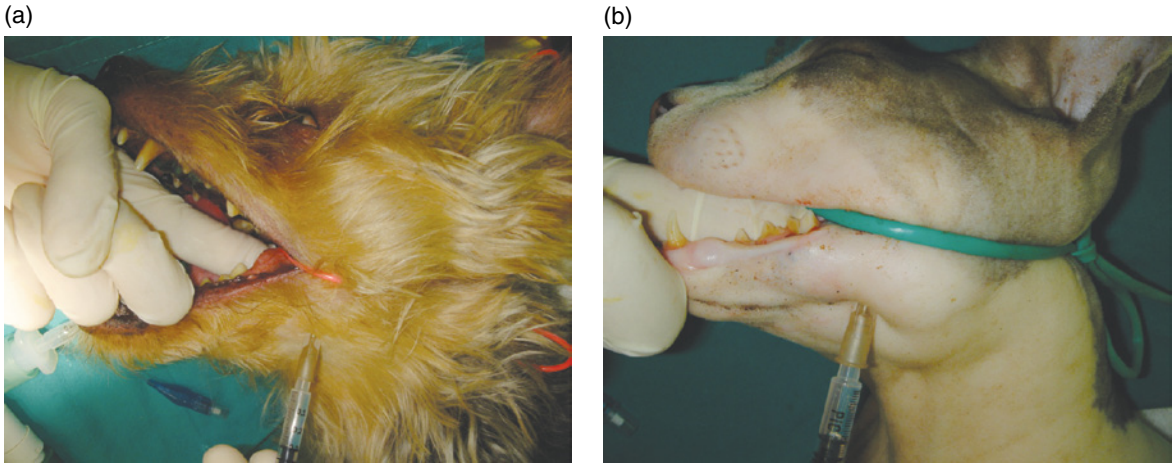

Figure 10.10 Caudal inferior alveolar nerve block (transcutaneous approach) in the dog (a) and the cat (b). A finger is pushed ventrocaudally and placed on the foramen. The needle is inserted perpendicularly to the ventral margin of the mandible, at the level of the vascular notch, rostral to the angular process. The bevel is directed toward the bony surface, and the tip of the needle advanced medial to the mandible, up to the foramen, under the operator's fingers.

Complications and how to avoid them

The lingual nerve may originate from the mandibular nerve just rostral to the inferior alveolar nerve, or directly from it (Figure 10.8). Therefore, it is possible that with the inferior alveolar nerve block, the lingual nerve, and the chorda tympani (which joins the lingual nerve shortly after it branches from the mandibular nerve) can be desensitized as well. In this case, as the lingual nerve conveys tactile and pain sensation (as well as thermal sensation and taste) from the rostral two-thirds of the tongue, self-inflicted chewing injuries may be possible in the recovery period, until normal sensation reappears. However, this is a rather rare event, possibly because the lingual motility, regulated by the lingual muscles that are innervated by the hypoglossal nerve, is maintained. The author has seen postoperative, self-inflicted lingual injuries in only three dogs out of hundreds of dogs and cats to which she has administered inferior alveolar blocks in the past 14 years. In all cases, bilateral caudal inferior alveolar nerve blocks had been administered. Possibly, the solution may have been placed improperly and/or have reached not only the lingual nerve but also the hypoglossal nerve. In fact, the tongue was subjectively considered to be scarcely movable for a short period of time, immediately after extubation and during recovery. In humans, bilateral (caudal) inferior alveolar nerve blocks are discouraged because of the lingual anesthesia, as patients may self-injure the tongue, and because they may feel unable to swallow and to enunciate well for a certain period of time (Malamed 2004). Some authors suggest positioning small animal patients recovering from anesthesia in sternal recumbency, to preclude the tongue deviation expected when the patient is in lateral recumbency, and therefore avoid lingual trauma (Beckman 2006). Appropriate assistance during the recovery period is warranted.

Middle mental nerve block and rostral inferior alveolar nerve block

Functional and clinical anatomy

The mental nerves leave the inferior alveolar nerve in the rostral portion of the mandible, and exit through the caudal, middle, and rostral mental foramina, to supply the rostral lower lip and the rostral intermandibular region (Figure 10.8). The foramina are located on the lateral aspect of the mandible, ventral to the third

premolar tooth, ventral to the mesial root of the second premolar tooth, and ventral to the first incisor tooth, respectively (Figures 10.2c, e, f, and 10.3c, e, f).

Distribution of local anesthesia and analgesia

Injecting an anesthetic solution next to the middle mental foramen (the largest mental foramen in both dogs and cats) will block the middle mental nerve and anesthetize most of the rostral labial soft tissues of the lower jaw (Evans and Kitchell 1993; Dyce and Molenaar 1996; Done et al. 2009). The middle mental nerve block is useful when surgery is performed on the rostral lower lip.

However, when it is necessary also to anesthetize the rostral mandibular teeth, an inferior alveolar nerve block (either caudal or rostral) should be performed. The mucogingival tissues lingual to the mandible are not anesthetized with either a mental or a rostral inferior alveolar nerve block. If this is desired, a caudal inferior alveolar nerve block (and concomitant lingual nerve block) should be performed instead.

Equipment

- Disposable or sterile gloves as needed;
- local anesthetic solution;
- 1.0–2.5-mL aspirating syringes; and
- 25–27-gauge, extra short or short needle.

Note that if the needle is inserted into the foramen, it may be advisable to use a 27–30-gauge needle.

Technique (Table 10.3)

Anatomic landmarks

Normally only the middle mental nerve is blocked, as the caudal and the rostral nerves are of very small dimensions. In dogs, the middle mental foramen is located ventral to the mesial root of the second premolar tooth, at the level of the canine's root apex, at mid-height of the mandibular body or slightly closer to the ventral margin of the mandible than to the alveolar margin (Figure 10.2c) (Evans and Kitchell 1993; Martinez et al. 2009). Sometimes, the caudal and the middle foramina merge into a larger foramen, which may be positioned in an intermediate position ventral to the distal root of the second premolar tooth.

In cats the middle mental foramen is located equidistant between the third premolar tooth (the first tooth after the canine tooth in cats) and the canine tooth, under the lip frenulum, at mid-height of the mandible (Figure 10.3c).

Step-by-step procedure

Both the middle mental nerve and rostral inferior alveolar nerve blocks may be administered by inserting the needle through the skin or the mucosa over the mental foramen (Figure 10.11).

The thumb of the nondominant hand is placed against the lateral aspect of the body of the mandible, in the first premolar tooth region in dogs and the canine-third premolar interproximal area in cats. It is then glided gently rostrocaudally to identify the concavity of the middle mental foramen. If lateral radiographs of the rostral mandible are available, the mental foramen may be located even more definitively. The finger is kept on the foramen, and the needle inserted through the skin or the mucosa of the labial frenulum, advancing it in a caudal, slightly medial direction, to reach the foramen, between the finger and the bony surface. The bevel should be kept towards the bone. With the tip of the needle next to the foramen, aspiration is performed and the solution injected slowly.

For the rostral inferior alveolar nerve block, the needle is inserted for a short distance into the middle mental foramen and the solution injected directly into the bony canal after negative aspiration. Gentle finger pressure is maintained over the injection site to ensure maximum caudal diffusion of the solution into the canal.

Clinical tips

In small sized patients, rostral inferior alveolar nerve block should not be attempted because of the high risk of iatrogenic damage to the middle mental nerve.

Entering the mental foramen for the rostral inferior alveolar nerve block may be difficult

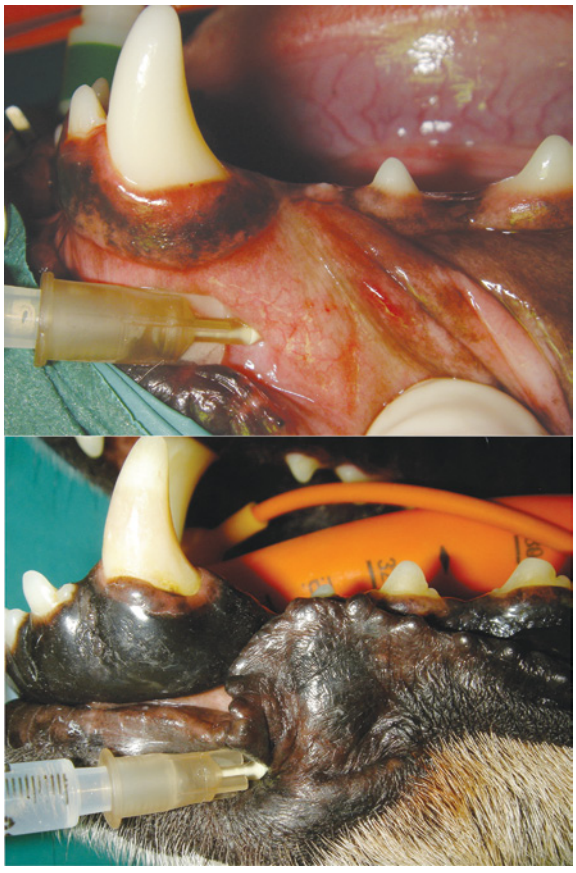

Figure 10.11 Middle mental nerve block and rostral inferior nerve blocks in the dog. The thumb of the free hand is placed against the lateral side of the body of the mandible, in the first premolar tooth region in dogs and the canine-third premolar interproximal area in cats. It is then moved gently rostrocaudally to identify the concavity of the middle mental foramen. The finger is kept on the foramen, and the needle inserted through the skin or the mucosa of the labial frenulum, advancing it in a caudal, slightly medial direction, to reach the foramen, between the finger and the bony surface. The bevel should be kept toward the bone. Transmucosal approach (upper) and transcutaneous approach (lower).

because of its angle relative to the bony surface, and the presence of the thick labial frenulum over it. In middle to large size dogs, the foramen can be easily palpated underneath or just caudal to the labial frenulum, whereas in cats and very small dogs it may be difficult to impossible to detect (Figure 10.3c). Alternative techniques (e.g. caudal inferior alveolar nerve block) should be used instead.

Splash block

A "splash block" is the placement of anesthetic solution directly into a surgical site, such as the body wall after abdominal surgery, or the ovarian ligaments during ovariohysterectomy (Table 10.3). It can also be used in an emptied alveolus after dental extraction (Woodward 2008) or in the resection site following mandibulectomy or maxillectomy. The area is gently flushed and dried, and the anesthetic solution dripped from a syringe. The analgesic effect occurs by diffusion of the solution into surrounding tissues (Charlier 2006; Reuss-Lamky 2007). The use of a splash block requires the addition of other techniques to achieve preemptive analgesia, given that the surgical procedure (dental extraction) is performed prior to blockade. Splash blocks may represent an alternative to specific nerve blocks in case of technical difficulties, unsuccessful primary blocking technique, contraindications to a more specific block, etc.

Infiltration anesthesia

Infiltration anesthesia is achieved by injecting the anesthetic solution under the oral mucosa, just above the apex of the tooth of interest (Table 10.3) (Baart and Brand 2009). The syringe is held parallel to the long axis of the tooth, contact with the bone or periosteum is avoided, and a small amount of solution is injected slowly using an extra short, 27-gauge needle. In areas of thin cortical bone (e.g. rostral mandible and maxilla), the anesthetic agent will diffuse through the bone and anesthetize the pulp tissues. Deposition of an anesthetic agent on the palatal side of the maxillary teeth (where the distance between the dental apices and the possible injection sites may be excessive), and next to the mandibular premolar and molar teeth (where the bone is relatively thick) may be only partially effective or ineffective.

Intraosseous anesthesia

Intraosseous anesthesia is achieved by placing an anesthetic solution into the bone supporting the teeth (Table 10.3). As with infiltration anesthesia, it is used when it is necessary to anesthetize a very

limited area or just one tooth (bone, soft tissues, and apical and pulpal tissues). This is rarely the case in small animal patients, and to avoid multiple injections, local nerve blocks are preferred whenever procedures involve larger areas of the mouth. Also, as with any other block, it may be ineffective in case of infection or inflammation at the injection site (e.g. periodontal or endodontic disease) (Rochette 2005).

Possible techniques include the intraosseous injection, the intraseptal injection, and the periodontal ligament injection, also known as the intraligamentary injection. The intraosseous injection is the deposition of local anesthetic solution into the interproximal bone between two adjacent teeth, and is normally achieved with dedicated devices able to perforate the bone. The intraseptal injection is the placement of the anesthetic solution in the interdental papilla. The periodontal ligament injection requires the use of an especially dedicated periodontal ligament syringe (capable of generating over two times the pressure of a conventional syringe) with a 27–30-gauge short needle. Small volumes of anesthetic solution are injected, up to 0.2 mL per root (Rochette 2005; Woodward 2008). The needle is inserted through the gingival sulcus, next to the tooth, with the bevel pointing toward the tooth surface, on the mesial or distal aspect of each root, until a resistance (the alveolar margin) is felt. Aspiration is not necessary, as intravascular injection is very unlikely. A significant resistance should be felt, and ischemia of the soft tissues should be noted during injection. The solution diffuses along the periodontal space and into the marrow spaces of the bone surrounding the teeth, to the dental apex (Smith and Walton 1983; Tagger et al. 1994). The periodontal ligament injection is relatively safe for the endodontic and periodontal tissues, with minimal damage only in the area of needle penetration, as shown by studies performed also in dogs (Fuhs et al. 1983; Roahen and Marshall 1990; Pertot and Déjou 1992) and cats (Lin et al. 1985). However, the periodontal ligament injection should not be used in deciduous teeth, as it may cause enamel hypoplasia or hypomineralization of the developing permanent tooth. Also, if excessive pressure is exerted during injection or excessive volumes of solution are used, there may be an increase in hydrostatic pressure within the periodontal space, with the risk of tooth avulsion.

Intrapulpal injection

A local anesthetic solution may be injected directly into the pulp system of an endodontically compromised tooth during root canal therapy, before pulp extirpation is performed (Table 10.3) (Malamed 2004). In humans, the intrapulpal injection is recommended when other techniques fail to obtain adequate anesthesia of the tooth under treatment, and if it is preferable to avoid anesthesia of the lips and tongue, common after administration of local nerve blocks. The discomfort felt by human patients during the deposition of the anesthetic is not a concern in deeply anesthetized veterinary dental patients. For the injection to be effective, a small amount (0.2–0.3 mL) of anesthetic solution should be slowly injected under pressure into the endodontic canal using a thin 25–27-gauge needle. The onset of action is almost immediate, but the duration rather short. This technique is likely to be ineffective if the pulpal tissues are considered to be infected (which is common in endodontically compromised teeth).

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11 The Thoracic Limb

Luis Campoy and Matt R. Read

Overview

Regional anesthetic techniques for the canine thoracic limb have been practiced for over 50 years. Sound anatomic knowledge is required to increase the success rate and minimize the possible complications associated with these blocks. In the majority of dogs, the brachial plexus is formed by the ventral branches of the C6, C7, C8, and T1 spinal nerves that exit the spinal column through their respective intervertebral foramina. The most relevant nerves, from cranial to caudal, are the suprascapular, subscapular, axillary, musculocutaneous, radial, median, and ulnar nerves. The axillary artery and vein are also located in the axillary space cranial to the first rib (Figures 11.1a, b and 11.2).

As many potentially invasive and painful procedures are performed on the thoracic limb, it is important to be able to safely and effectively provide local and regional anesthesia to this part of the body. The cervical paravertebral block (Hofmeister et al. 2007; Lemke and Creighton 2008) is a technique that can be used to provide anesthesia and analgesia to the upper thoracic limb, including the proximal areas of the shoulder and humerus. Campoy et al. (2010) recently described an ultrasound-guided approach that targets the roots of the brachial plexus. This technique provides anesthesia of proximal structures including the humerus, as well as those that are more distal. The traditional approach that has been used for performing brachial plexus blocks (at the level of the scapulohumeral joint) will typically provide anesthesia to the elbow and structures distal to it (Futema et al. 2002; Mahler and Adogwa 2008). Recently, Mosing et al. (2010) published the results of their successful clinical use of brachial plexus blocks for cats undergoing distal thoracic limb orthopedic surgeries.

Single injection is the most frequently used technique. However, the placement of perineural catheters is possible even though it presents the additional challenge of preventing early catheter displacement once patients become ambulatory (Moens and Caulkett 2000; Mahler and Reece 2007).

Small Animal Regional Anesthesia and Analgesia, First Edition. Edited by Luis Campoy and Matt R. Read.

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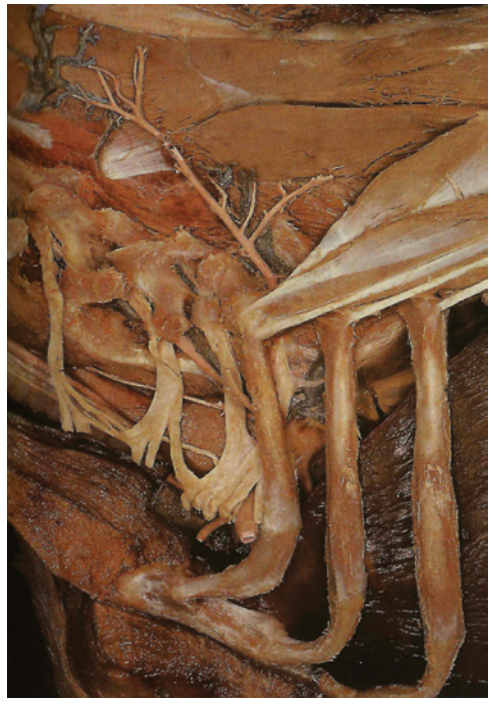

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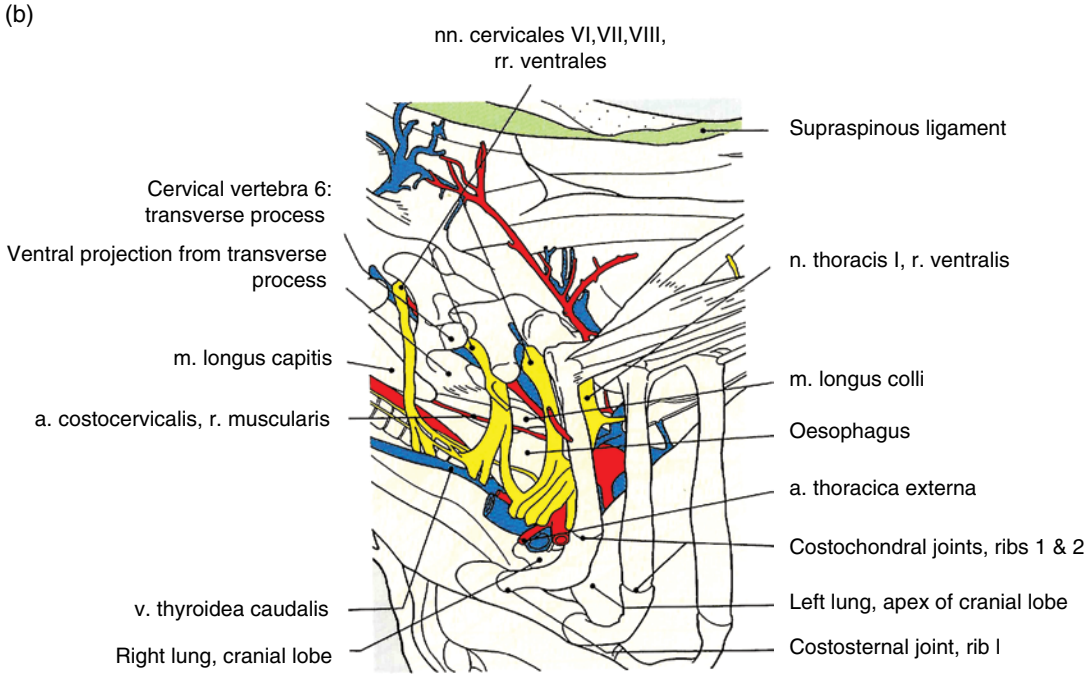


Figure 11.1 (a), (b) Deep structures at the thoracic inlet of a dog. Brachial plexus, vertebral, and deep cervical vessels: left lateral view. From Done et al. 2009. Used with permission.

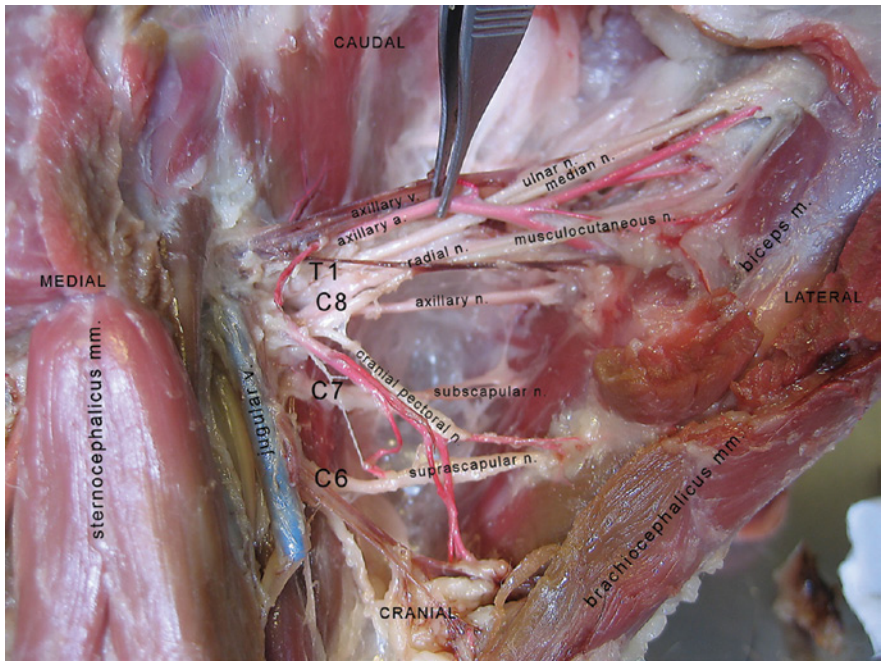


Figure 11.2 Dissection of the right axillary area of a dog in dorsal recumbency showing the anatomy of the brachial plexus. Note the intimate relationship of the brachial plexus roots located immediately dorsal to the axillary vessels. From Campoy et al. 2010. Used with permission.

General considerations

Sedation/anesthesia requirements

To prepare the patient for the procedure, an intravenous catheter should be placed. For sedation, a combination of either intravenous fentanyl 2–5 $\mu g\,kg^{-1}$ or dexmedetomidine (0.5 $\mu g\,kg^{-1}$) and propofol 2–4 $mg\,kg^{-1}$ can be administered. Note that the higher doses of the drugs may be required if electrolocation is used by itself, compared with when it is used in combination with ultrasound-guided techniques as higher current outputs are used and patients may be more likely to respond to this stimulus. Oxygen may need to be provided to the patient in order to minimize possible drug-induced hypoxemia caused by drug-induced ventilatory depression and the patient breathing room air. The use of patient monitoring devices during the procedure is also highly recommended. Additionally, it may be helpful to use local infiltration with a local anesthetic such as lidocaine 1–2% at the puncture site if the patient is sedated rather than anesthetized.

Animal positioning

For a cervical paravertebral or traditional brachial plexus approach, the patient should be positioned in lateral recumbency with its legs resting naturally, perpendicular to the long axis of the body. The leg to be blocked should be positioned uppermost. For the ultrasound-guided axillary approach, the patient should be positioned in dorsal recumbency with its front legs flexed in a natural position. Patient positioning is an important aspect of these procedures, as nerves are flexible structures whose location can vary somewhat depending on the position of the limbs. Standardized positioning helps ensure a good quality block and has the potential to minimize complications.

Special considerations for electrolocation techniques

- Before injecting the local anesthetic solution, it is important to verify that the needle is not positioned either intravascularly or intraneurally. Negative blood aspiration should first be

observed. Additionally, the current output of the nerve stimulator should be decreased to 0.2 mA and absence of obvious motor stimulation should be verified. Next, the intensity should be increased to 0.4 mA to re-establish the twitch, and the first 1 mL of local anesthetic should be injected. This will cause the motor response to cease as the local anesthetic solution will dissipate the current by acting as an electrolyte (Tsui and Kropelin 2005). It is also imperative to ensure that no resistance is encountered during the injection. Intraneural injections are associated with high injection pressures (>20 psi, 138 kPa) (Kapur et al. 2007). If resistance to injection is experienced, the needle should be repositioned before further local anesthetic is injected.

- During and after the block, watch for potential adverse effects in the patient such as tachycardia, hypotension, arrhythmias, muscle twitches, tremors, or seizures. These observations might suggest that a local anesthetic systemic toxicity is occurring, necessitating immediate treatment.

Special considerations for ultrasound-guided techniques

- During injection, watch for fluid to begin spreading around the target nerves. The anesthetic solution will appear as a hypoechoic (black) "cloud" around the nerve, referred to as the "doughnut sign" (Robards et al. 2008). While injecting, the position of the needle can be slightly modified to improve diffusion of the solution around the nerve roots.
- For an adequately imaged ultrasound-guided nerve block, a positive motor response to nerve stimulation does not actually increase the success rate of the block. If an adequate image is obtained, these blocks are usually effective, even in the absence of a motor response (Beach et al. 2006).
- Provided the needle is perfectly in plane with the transducer, as the local anesthetic is being injected, you should be able to see its dispersion around the nerve. If not, it may indicate an intravascular injection (even if there was no prior blood aspiration) as the pressure applied by the transducer may occlude venous structures, resulting in a false negative aspiration test (Robards et al. 2008).

Principal indications

Anesthesia or analgesia of the entire thoracic limb can be provided. A cervical paravertebral or axillary brachial plexus will be necessary for shoulder or humeral procedures. Procedures involving the elbow and or radius and ulna can be blocked with a brachial plexus (traditional approach), whereas procedures involving the carpus can be successfully blocked just proximal to the elbow using a radial, ulnar, median, and musculocutaneous (RUMM) block. Intra-articular analgesia can also be used for a variety of procedures and to provide pain relief into the postoperative period.

Principal contraindications/precautions

The phrenic nerve originates from C5, C6 and C7, runs along the ventral border of the scalenus muscle, and provides motor innervation to the diaphragm. Although it has not been investigated, bilateral axillary or cervical paravertebral blockade has the potential to result in diaphragmatic paralysis. When brachial plexus blockade is performed using the traditional approach at the level of the shoulder, blockade of the phrenic nerve would seem to be an unlikely complication. However, in patients with respiratory compromise, caution should be used even with unilateral blocks at this location.

In the axillary space, the axillary artery and vein are in close proximity to the caudal aspect of the brachial plexus. The vessels run parallel to the nerve roots, following the general direction of the nerves. The vessels sit immediately ventral to the C8 and T1 nerve roots. Understanding the location of these vessels relative to the brachial plexus is important for minimizing the possibility of lacerating these structures. During the ultrasound-guided technique, the axillary vessels provide a key anatomic landmark that can be used during needle positioning.

Choice of local anesthetics and adjuncts

Bupivacaine 0.5%, with or without the addition of dexmedetomidine (0.5 $\mu g\,mL^{-1}$), is most commonly

used by the authors to provide surgical anesthesia. Ropivacaine 0.5–0.75% in combination with dexmedetomidine (0.5 µg mL^{-1}) can also be used with similar results.

Cervical paravertebral block

The cervical paravertebral block is considered an advanced level technique and was first described by Lemke and Dawson (2000). In 2007, Hofmeister et al. performed an anatomic study using dog cadavers and assessed methylene blue staining following use of a blind technique. They had a relatively low success rate (only three out of nine cadavers had successful staining of all four nerve roots). The following year, Lemke described an updated and revised technique in more detail (Lemke and Creighton 2008).

This block may be useful for providing analgesia and muscle relaxation for surgical procedures involving the scapula, shoulder, and brachium including their associated soft tissues. Benefits are reported to be the ability to successfully achieve anesthesia of the thoracic limb using simple anatomic landmarks; the smaller volumes of local anesthetic solutions that are required to achieve nerve blockade; and the more precise control over local anesthetic placement when compared with performing a traditional axillary brachial plexus block. When performing a cervical paravertebral block, the goal is to deposit local anesthetic solution near the C6 and C7 nerves as they cross the cranial and caudal margins of the large ventral wing of the transverse process of sixth cervical vertebra, and near the C8 and T1 nerves as they cross the cranial and caudal margins of the head of the first rib before they coalesce at the brachial plexus (Figure 11.1).

The cervical paravertebral block is difficult to perform in overweight and obese patients as anatomic landmarks are difficult or impossible to palpate. This block should not be performed if the transverse process of the sixth cervical vertebra and the head of the first rib cannot be palpated, as these are the major bony landmarks that are used to perform the block using this technique (Lemke and Creighton 2008).

More recently, Rioja et al. (2012) reported the results of a study that evaluated the use of methylene blue injections using a modification of Lemke and Creighton's technique. They compared use of blind injections (using anatomic landmarks), electrolocation (to identify the component nerves), and an ultrasound-guided technique. A total of 34 adult dogs were enrolled in their study. The low overall success rate of the three techniques for staining the target nerves and the high incidence of potentially serious complications (dye-staining of the cervical spinal cord) led the authors to exert a word of caution until further research is done.

Functional and clinical anatomy

The primary contributors to the sensory and motor function of the thoracic limb involve the ventral branches of the C6, C7, C8, and T1 spinal nerves. In a very small number of dogs, individual variation may result in additional contributions from C5 and T2. Spinal nerves have both dorsal and ventral branches (rami). As each nerve exits its associated intervertebral foramen, it separates into the dorsal and ventral branches. The dorsal branches of the cervical spinal nerves course dorsally and provide sensory innervation to the dorsal skin dermatomes.

There is considerable overlap of sensory input in these areas, with each part of the skin receiving sensory innervation from two or even three contiguous segments. The ventral branches leave the intervertebral foramina and course ventrally, joining with adjacent nerves and forming connecting branches. These connections are exaggerated at their area of origin of the thoracic limb, where the nerves enter the axillary area through the ventral border of the scalenus muscle before forming the brachial plexus and its associated peripheral branches that serve the limb. The brachial plexus supplies almost all of the innervation to the structures of the thoracic limb, except for a few muscles (trapezius, omotransversarus, brachiocephalicus, and rhomboideus) and the skin over the dorsal shoulder region.

The phrenic nerve also originates in this general area, with contributions from the ventral branches of the C5, C6, and C7 spinal nerves (Figure 11.3). The fibers that will become the phrenic nerve come off proximal to those that will continue ventrally

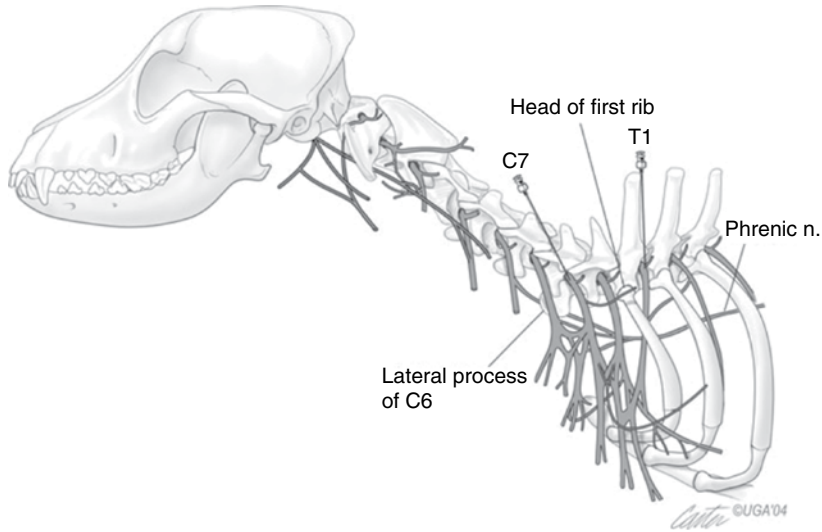


Figure 11.3 Anatomic landmarks for performing cervical paravertebral block in the dog. Note the angle of insertion for the needle at the first three sites (45°) is different from the angle of insertion for the needle at the caudal most site (90°). From Hofmeister et al. 2007. Used with permission.

and contribute to the formation of the brachial plexus. The fibers of the phrenic nerve course ventral to the scalenus muscle before forming a trunk that passes medial to the brachial plexus before entering the mediastinum between the first and second ribs.

Distribution of local anesthesia and analgesia

The cervical paravertebral block is a technique that can be used to potentially provide anesthesia and analgesia to the entire thoracic limb, including proximal areas such as the scapula, shoulder joint, and the humerus and its associated soft tissues.

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small dogs, 20-gauge 100 mm for medium and large dogs);
- sterile gloves;
- syringes/needles; and
- local anesthetic ± adjuvant.

Technique

Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost.
- Clip the caudolateral cervical region of the affected side from the mid-cervical region to the level of the scapula, and from ventral midline to near-dorsal midline.

Anatomic landmarks

The scapula is retracted caudally to allow for palpation and identification of landmarks.

- The bony transverse processes of the caudal cervical vertebrae are palpated, and the large transverse process of C6 is identified.
- The head of the first rib is palpated and identified.
- If one or both of these structures are not readily identifiable, the block cannot be performed.

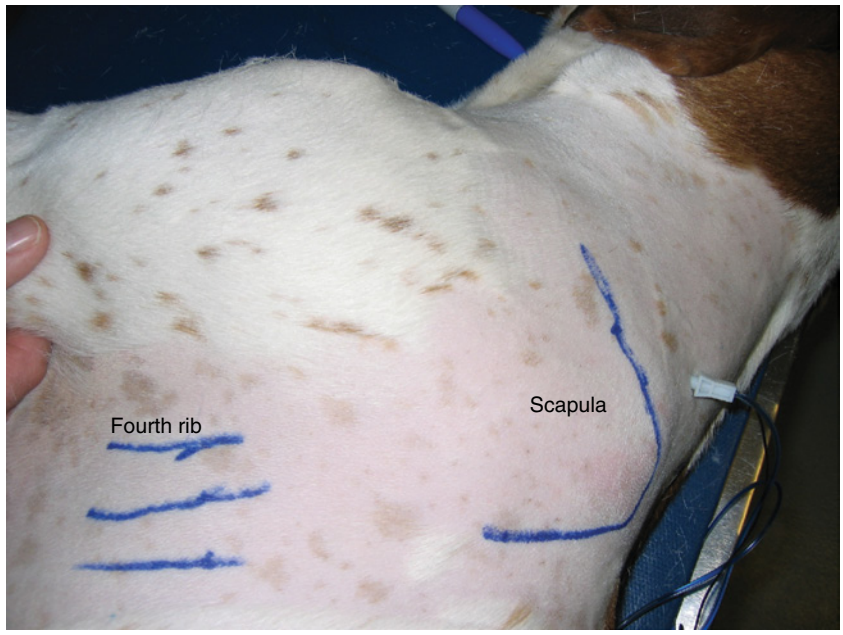


Figure 11.4 A dog cadaver positioned in right lateral recumbency to demonstrate needle positioning for cervical paravertebral block. The markings indicate the position of the fourth, fifth, and sixth ribs, and the dorsal aspect of the scapula. Note the dorsal approach of the needle towards the C6 nerve root.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- The scapula should be retracted with the nondominant hand, keeping the dominant hand sterile for palpating the sites for needle placement.
- The scapula is shifted caudally to expose the transverse process of C6 and the first rib.
- The index finger of the dominant hand should be used to palpate the cranial and caudal margins of the transverse process.
- From a dorsolateral starting point, the needle should be advanced in a caudal direction until the transverse process is encountered. By advancing the needle in a caudal direction, the potential for inadvertent epidural or intrathecal injection through an intervertebral foramen can be minimized (Figure 11.4).
- The tip of the needle is then gently walked off the cranial and caudal margins of the transverse process until the ventral branches of the nerves are encountered.
- While continuing to retract the scapula caudally with the nondominant hand, the index finger of the dominant hand is used to palpate medial to the cranial margin of the scapula to identify the thoracic inlet, the first rib, and the head of the first rib.
- After identifying the head of the first rib, the needle is slowly advanced in a caudomedial direction until the rib is encountered at this dorsal location. The needle is then gently walked off the first rib medially at its cranial and caudal margins until the C8 and T1 nerves are encountered.
- Once the tip of the needle is within the appropriate range of each of the intended spinal nerves, contractions of the associated muscles will be seen (see Table 11.1).
- In each case, decrease the current gradually to 0.4 mA (threshold current) in 0.2 mA increments, until the same response can be elicited, repositioning the needle if necessary.

Lemke's modified approach (Lemke and Creighton 2008)

Using Lemke and Dawson's original approach to performing the cervical paravertebral block,

Hofmeister et al. (2007) performed an anatomic study using canine cadavers to document staining of target nerves with dye. Nine cadavers were used, ranging from 10–30 kg, and body condition scores were 3/5 or less. A 20-gauge spinal needle was used to inject 3–5 mL of dilute methylene blue at the target sites. Dissection was subsequently performed to confirm accuracy of the injections. A successfully placed injection was defined as dye staining on the spinal nerve at the level of the intervertebral foramen. The anatomic landmarks were readily identifiable in all of the cadavers. Three of the nine cadavers had staining of all four nerves, whereas the remaining six cadavers had staining of three of the four nerves. The C6 nerve was stained in all of the cadavers, whereas the C7, C8, and T1 nerves were stained variably in seven of the nine cadavers. Although the dye was not directly on these nerves, it was in close proximity. Whether or not a local anesthetic would have diffused across to the nerves in adequate amounts to successfully block the nerves in a clinical patient is not known. No dye staining of any of the phrenic nerves was observed. The pleural space was not evaluated to assess whether interpleural injections were made during approach to the C8 and T1 nerves at the location of the first rib. Although this study demonstrated the relative ease of depositing dye solution on the desired nerves in canine cadavers, no evaluation of the clinical efficacy of this technique could be made. Since then, Lemke and Creighton (2008) published a more detailed description of the technique, including a modification (below).

Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost.
- Clip the caudolateral neck region of the affected side from the mid-cervical region to the level of the scapula, and from ventral midline to near-dorsal midline.

Anatomic landmarks

- The scapula is retracted caudally to allow for palpation and identification of landmarks.
- The bony transverse processes of the caudal cervical vertebrae are palpated, and the large transverse process of C6 is identified.
- The head of the first rib is palpated and identified.
- The axillary artery and costochondral junction of the first rib as secondary landmarks are also palpated and identified.
- The ventral branches of C8 and T1 nerves converge along the cranial margin of the first rib 1–2 cm dorsal to the axillary artery and the costochondral junction.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- While the scapula is still retracted, the costochondral junction of the first rib and the axillary artery are palpated.
- The needle is advanced towards a location on the rib 1–2 cm dorsal to the costochondral junction.
- Local anesthetic is injected along the cranial margin of the first rib at one or two sites.
- This will successfully block the nerves as they converge, instead of blocking each one individually at its point of origin (as the original description suggests).
- The recommended volume to be injected is 1–3 mL per site.

Potential complications and how to avoid them

- With either of these approaches, it is very important to identify the thoracic inlet and avoid inadvertent needle placement within the thoracic cavity.
- Because of the proximal location of the phrenic nerve to the nerves that we specifically target for local anesthesia of the limb, it is possible to block one or more of the components of the phrenic nerve during local anesthetic administration. When this occurs, hemidiaphragmatic paresis can result. Moreover, bilateral paralysis in anesthetized and non-anesthetized animals has been reported to elicit a compensatory increase in the activity

of the inspiratory intercostal muscles, including the parasternal intercostals, the external intercostals, and the levator costae (Nochomovitz et al. 1981; De Troyer and Kelly 1982; Katagiri et al. 1994). As a result, these muscles shorten more during inspiration, and the elevation of the ribs and expansion of the ribcage is augmented. Ventilation ($ETCO_2$) is maintained within reasonable limits with uni- or bilateral paralysis (De Troyer and Kelly 1982; Katagiri et al. 1994). The increase in external intercostal and levator costae inspiratory activity was commonly greater than anticipated on the basis of the increased $PaCO_2$ (Brichant and De Troyer 1997).

- However, even hemiparalysis poses a direct detrimental effect on the expansion of both lungs. This may explain why ventilation is reduced in both lung bases in patients with hemidiaphragmatic paralysis (De Troyer et al. 2009).
- It should be remembered that the innervation to the diaphragm originates from the ventral branches of C6, C7, and C8, and the phrenic nerve runs medial to the brachial plexus. Using this technique to achieve successful unilateral blockade of sensory and motor nerve roots at these proximal sites can potentially result in blockade of the ipsilateral phrenic nerve and cause hemidiaphragmatic paralysis. Close monitoring of the anesthetized patient's respiratory function should be undertaken, including monitoring of arterial oxygen saturation (using pulse oximetry or arterial blood gas analysis) and adequacy of ventilation (using capnography). One would expect the duration of any such paralysis and supportive intervention to be dependent on the particular local anesthetic that was used for the block. Although unilateral and bilateral diaphragmatic blockade do not appear to significantly compromise respiratory function in healthy awake and anesthetized dogs, caution should taken in patients with pre-existing diseases affecting pulmonary function. To date, no specific studies have been conducted in veterinary patients to document the potential negative respiratory effects of bilateral cervical paravertebral blockade. Although absolute contraindications to performing this block are not yet documented, the veterinarian should exercise caution when performing this block in compromised patients and should be prepared to provide support as indicated.
- At this proximal location, the nerve roots are in very close proximity to the vertebral arteries, and as a result if the needle tip is placed too close to the intervertebral foramen, inadvertent vascular puncture can occur.
- Epidural migration of local anesthetic can occur (Figure 11.5). In people, a documented risk of performing paravertebral blocks using certain techniques is the risk of local anesthetic diffusion from the site of administration back through the intervertebral foramen, resulting in epidural spread of the local anesthetic and more widespread side effects. With lumbar paravertebral blocks in people, this complication has been shown to be related to the injection pressure associated with the delivery of the local anesthetic (Gadsden et al. 2008). Although this rarely results in serious compromise to the patient when a lumbar injection is made, epidural spread of local anesthetic in the cervical region could potentially result in bilateral phrenic nerve paralysis and other effects. Although this complication was not seen by Hofmeister et al. (2007) in their cadaver study, in the report by Rioja et al. (2012), 29–39% of dogs developed staining of the cervical spinal cord following performance of this block. Unreported cadaver studies (L. Campoy, unpublished data) also observed epidural spread of dye when individual cervical spinal nerve roots were stained using a similar technique (Figure 11.5).
- In human studies, it is not the close proximity to the intervertebral foramen that increases risk of this complication, but the pressure with which the solution is injected (Gadsden et al. 2008). Whether or not there is a significant risk in clinical veterinary patients is not known, but, taken together, these observations and reports suggest that proximal injection of local anesthetics near the cervical intervertebral foramina under increased pressure during this block deserves some attention.

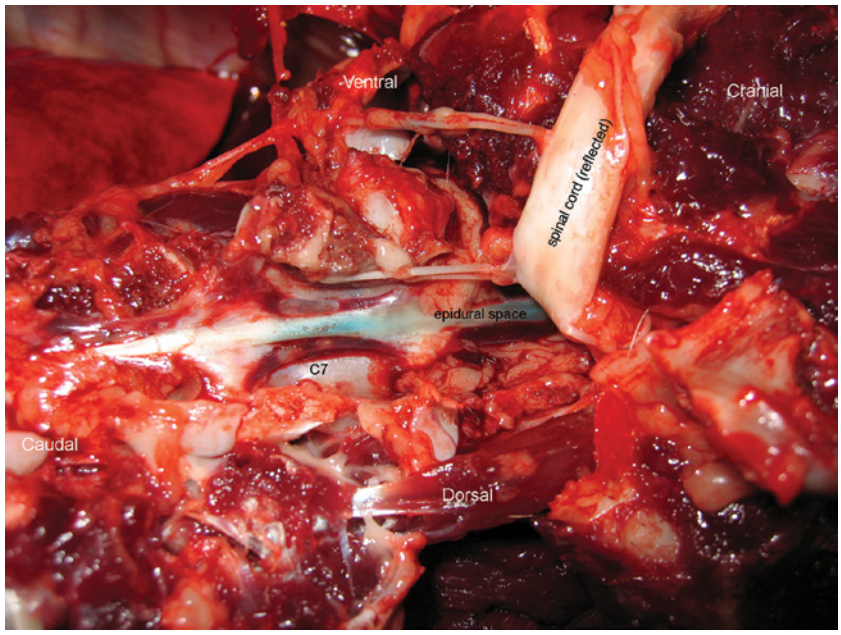


Figure 11.5 Migration of methylene blue dye into the cervical epidural space adjacent to the C6 and C7 areas following cervical paravertebral block in a dog cadaver.

Brachial plexus block

The brachial plexus block is considered an intermediate level technique. This block has historically been described to provide anesthesia for structures distal to the elbow. However, using nerve stimulation to guide the block, investigators have been successful blocking structures from the mid-humerus distally (Futema et al. 2002), which is consistent with many people's clinical experiences.

Functional regional nerve anatomy

The brachial plexus of the dog is formed from the ventral branches of the C6, C7, C8, and T1 spinal nerves (Figures 11.2 and 11.3). After the roots emerge through the intertransversarius musculature, there is an exchange of nerve fibers between them. The four roots then cross the ventrolateral border of the scalenus muscle and divide to form the brachial plexus. The phrenic nerve also runs along the ventral border of the scalenus muscle. After the roots cross the axillary space, the plexus divides to form the individual nerves that provide the sensory and motor innervation to the thoracic limb. The most important nerves, moving from cranial to caudal, are the suprascapular, subscapular, axillary, musculocutaneous, radial, median, and ulnar nerves. The axillary artery and vein are also located in the axillary space, immediately caudal to the median and ulnar nerves and cranial to the first rib (Figure 11.2).

- The ventral root of C6, with some input from C7, is the main contributor to the suprascapular nerve.
- The ventral root of C7, with some input from C6, is the main contributor to the musculocutaneous and subscapular nerves.
- The ventral root of C8, with some input from T1, is the main contributor to the radial nerve.
- The ventral root of T1, with some input from C8, is the main contributor to the median and ulnar nerves.

Distribution of local anesthesia and analgesia (Table 11.1)

Table 11.1 Sensory and motor distributions of the nerves of the thoracic limb.

Nerve	Spinal Nerve Contributions	Sensory to ___	Motor to ___ muscle
Suprascapular nerve	C6, C7	Lateral aspect of scapulohumeral joint	Supraspinatus, infraspinatus, subscapularis
Subscapular nerve	C6, C7		Subscapularis
Musculocutaneous nerve	C6, C7	Craniomedial forearm (antebrachium) distal to elbow	Coracobrachialis, biceps brachii, brachialis
Axillary nerve	C7, C8	Caudal aspect of scapulohumeral joint capsule, craniolateral aspect of arm (brachium) and part of forearm (antebrachium)	Brachiocephalicus, teres major, teres minor, deltoideus
Radial nerve	C7, C8, T1	Lateral aspect of elbow joint, dorsal aspect of forearm (antebrachium) and paw	Triceps, anconeus, extensor carpi radialis, common and long digital extensor, extensor carpi ulnaris, supinator, abductor pollicus longus, ulnaris lateralis
Median nerve	C8, T1	Medial aspect of elbow joint, medial and palmar aspects of forearm (antebrachium) and paw	Flexor carpi radialis, superficial and deep digital flexors, pronator teres, pronator quadratus
Ulnar nerve	C8, T1	Caudal aspect of elbow joint, caudolateral aspect of forearm (antebrachium) and paw	Flexor carpi ulnaris, deep digital flexors

Nerve stimulation-guided brachial plexus block (Traditional approach)

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small and medium breeds, 21-gauge 100 mm for large breeds);
- sterile gloves; and
- syringes/needles; and
- local anesthetic ± adjuvant.

Technique

Patient positioning

- Position the patient in lateral recumbency (Figure 11.6).
- The leg to be blocked should be placed uppermost and held in a natural position perpendicular to the longitudinal axis of the body.
- Clip the shoulder area.

Anatomic landmarks

The major landmarks for the procedure include:

- Scapulo-humeral joint
- Acromion
- Greater tubercle
- Trachea
- Jugular vein
- First rib

The puncture site is located cranial to the acromion and medial to the subscapularis muscle (Figure 11.7).

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Use of a sterile drape over the needle puncture site can be used to prevent needle contamination during the procedure.
- Draw an imaginary line between the acromion and the cranial border of the greater tubercle.
- A second line is drawn perpendicular to the first, from the cranial border of the acromion.

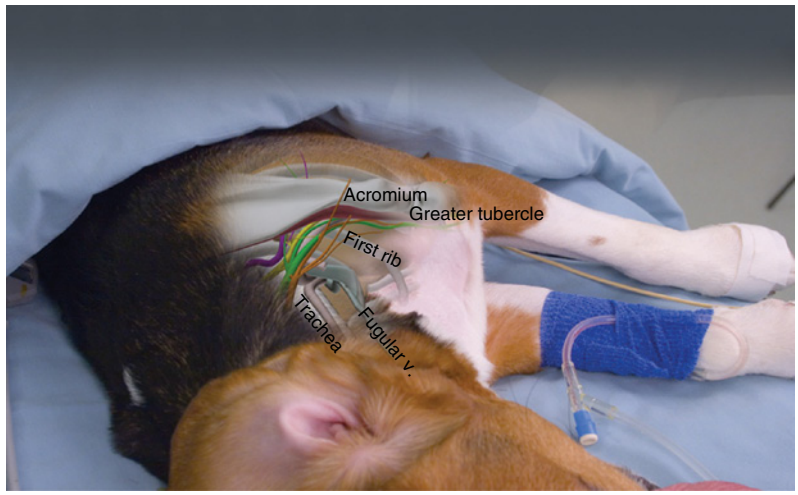


Figure 11.6 Tridimensional animation of the left cervical area of a dog in right lateral recumbency. Note the position of the acromion, greater tubercle, trachea, jugular vein and first rib relative to the brachial plexus. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

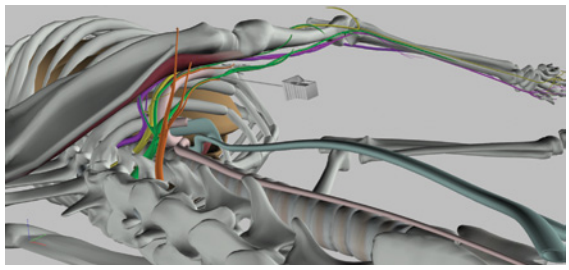


Figure 11.7 Needle position for performance of a brachial plexus block in a dog using nerve stimulation. The puncture site is located cranial to the acromion and medial to the subscapularis muscle. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

This line provides the direction of needle advancement (Mahler and Adogwa 2008) (Figure 11.8).

- To assess the maximum depth of the needle insertion, the first rib is palpated under the scapula and a line is drawn to indicate its position. A second line is drawn along the jugular vein, extrapolating its course as the vein disappears under the thoracic limb. The intersection of these two lines indicates the caudal aspect of the brachial plexus. The axillary vessels are located at the caudal edge of this line. To avoid accidental vessel penetration, care must be taken not to advance the needle past this line.
- Insert the needle and carefully advance it medial to the scapula in a caudal direction (Figure 11.9).
- Once the tip of the needle is within the appropriate range of the musculocutaneous nerve, contractions of the biceps brachii muscle will result in flexion of the elbow (Table 11.2).
- Once the twitch is elicited, decrease the current gradually to 0.4 mA (the threshold current) in 0.2 mA increments, until the same motor response can be elicited, repositioning the needle if necessary.
- The recommended volume of local anesthetic solution to be injected is 0.25–0.3 mL kg^{-1} (Campoy et al. 2008).

Clinical tips

- The authors commonly use bupivacaine 0.5% with or without the addition of dexmedetomidine (0.5 µg mL^{-1}). This combination provides 12–28 hours of blockade. Alternatively, ropivacaine 0.75% combined with dexmedetomidine (0.5 µg mL^{-1}) can be used with similar expected results.
- The musculocutaneous nerve (seen as flexion of the elbow) is the most cranial nerve within the brachial plexus and in a medium-sized dog, it is approximately 1–2 cm deep to the skin. While advancing the needle, if you do not find the appropriate motor response at the anticipated depth, the needle should be carefully repositioned.

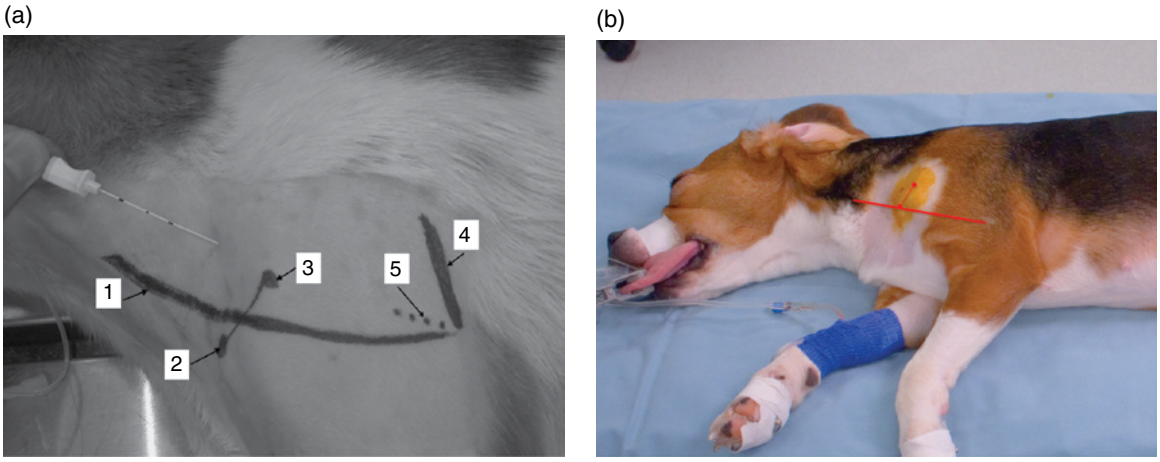


Figure 11.8 (a) Anatomic landmarks used to locate the left brachial plexus in a dog. The site of insertion is cranial to the acromion. The direction of the needle is perpendicular to the line connecting the acromion and the cranial border of the greater tubercle. The caudal end of the brachial plexus is at the intersection of the first rib and the jugular vein. 1) jugular vein; 2) cranial border of the greater tubercle; 3) acromion; 4) first rib; 5) location of the nerves, at the ventral border of the scalenus muscle. From Mahler and Adogwa 2008. Used with permission. (b) Landmarks for a brachial plexus block in a dog. Draw an imaginary line between the acromion and the cranial border of the greater tubercle. A second line is drawn perpendicular to the first, from the cranial border of the acromion. This line provides the direction of needle advancement. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

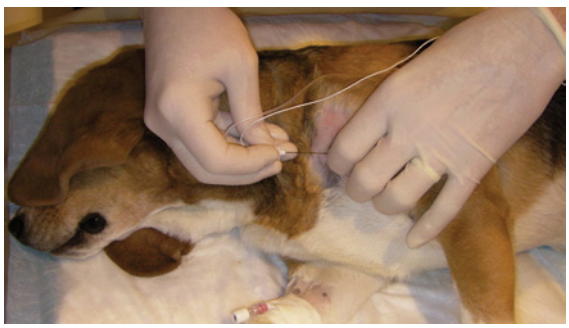


Figure 11.9 An insulated needle is being used to perform a brachial plexus block in a dog.

Extreme caution must be exercised during deep needle insertions, as the axillary vessels lie in the caudal aspect of the plexus and any further needle advancement runs the risk of vascular puncture.

- Extension of the elbow (radial nerve response) is also an acceptable end point. However, note that an injection at this point will most likely miss the musculocutaneous nerve, as it lies in a more cranial position. Additionally, care must be taken as the axillary vessels lie just ventral to this position and any further needle advancement runs the risk of vascular puncture.
- Pronation of the extremity (median/ulnar nerve response) should not be considered an acceptable

Table 11.2 Motor responses to electrical stimulation of peripheral nerves during brachial plexus block.

Peripheral nerve stimulation	Muscle response ("twitch")	Region to be blocked
Musculocutaneous nerve	Contraction of biceps group (flexion and supination of elbow)	Medial antebrachium (forearm)
Radial nerve	Contraction of triceps brachii (elbow extension)	Craniolateral aspect of antebrachium (forearm), skin of the dorsum and the palmar surfaces of the paw, except fifth digit (also some median component in the palmar aspect)
Median and ulnar nerve	Contraction of flexor carpi radialis (flexes carpus), pronator teres (pronates forearm), and pronator quadratus (pronates paw)	Caudal aspect of antebrachium (forearm), palmar surface paw, palmar surface of the fifth digit

Table 11.3 Motor responses to electrical stimulation of the roots of the brachial plexus.

Nerve root	Motor response ("twitch") to electrical stimulation
C6	Inward rotation of shoulder, outward rotation of shoulder
C7	Contraction of biceps, outward rotation of brachium, inward rotation of brachium, contraction of triceps, extension of carpus
C8	Contraction of triceps, extension of elbow, carpus and digits
T1	Flexion of carpus and digits

end point. These nerves lie in the most caudal part of the brachial plexus. Injection at this location will most likely miss the musculocutaneous and radial nerves. In addition, extreme care must be taken as the axillary vessels lie just ventral to this position and any further needle advancement runs the risk of vascular puncture.

- Extension, flexion, or rotation of the shoulder (suprascapular nerve response) should not be considered an acceptable end point as this nerve crosses over the scapula, coming into a lateral position. Injections in this location will most likely miss the major nerves of the brachial plexus.

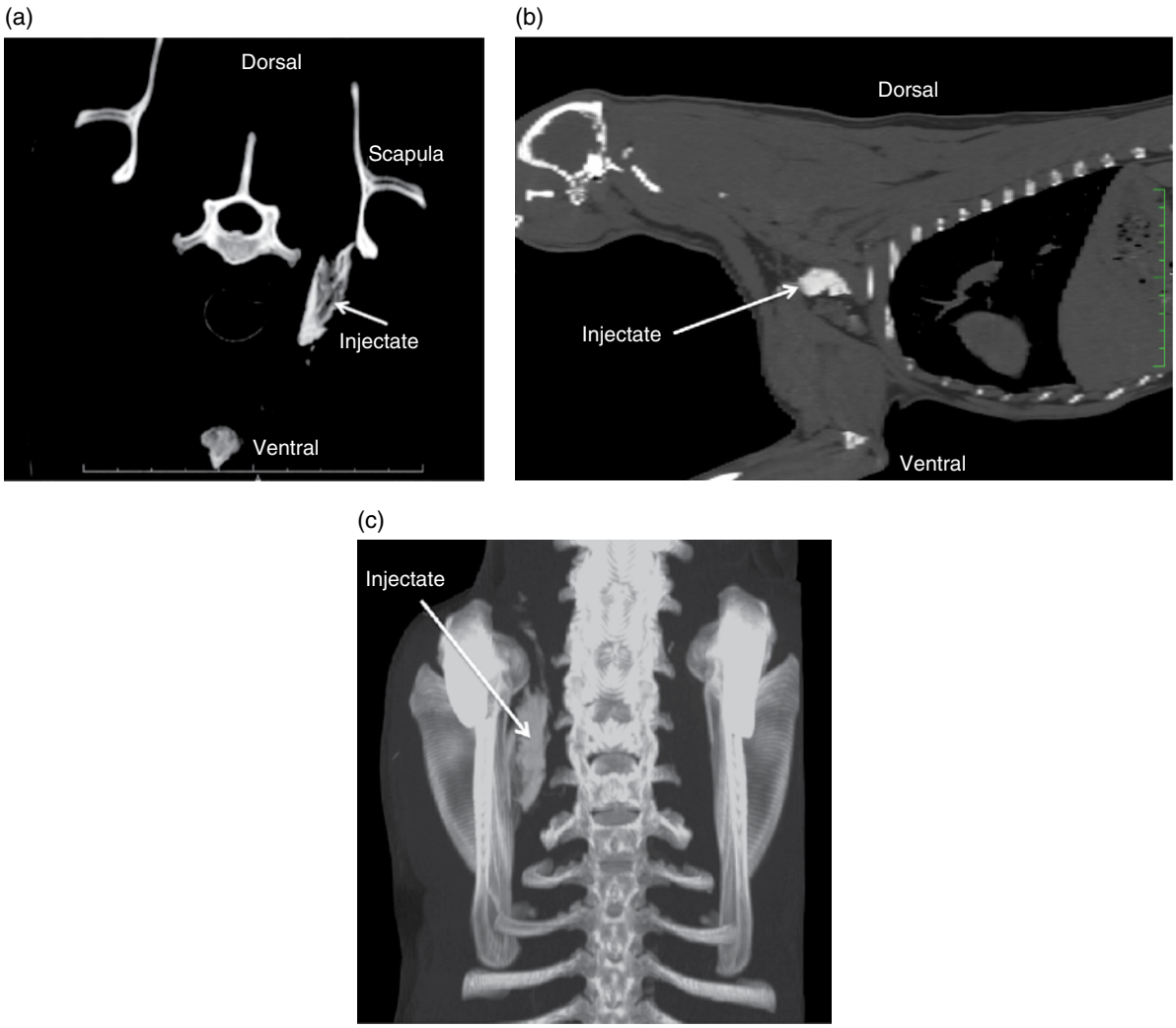


Figure 11.10 (a), (b), (c) Computed tomographic (CT) images of a dog. A brachial plexus block has been performed using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The arrow indicates the location of contrast enhancement (hyperattenuation) medial to the scapula at the level of C7.

Figure 11.11 This dog has been recovered following sedation and administration of a brachial plexus block for demonstration purposes. Note the characteristic signs of radial nerve paralysis in the left thoracic limb.

Combined ultrasonography/ electrolocation-guided brachial plexus block

Advantages

The combination of ultrasound-guidance and electrolocation offers the advantages of both anatomic and electrophysiologic confirmation of nerve identification and needle placement. The stimulating needle is advanced through the tissue using real-time ultrasonographic imaging, and can be used to confirm correct needle placement by stimulating the nerve. Both nerve location techniques require a thorough understanding of the relevant regional anatomy.

Equipment

- High frequency transducer (9–15 MHz);
- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small dogs, 21-gauge 100 mm for medium and large dogs);
- sterile gloves;
- syringes/needles;
- isopropyl alcohol; and
- local anesthetic ± adjuvant.

Technique (Campoy et al. 2010)

Patient positioning

- Position the patient in dorsal recumbency with the thoracic limbs flexed in a natural position.
- Clip scanning area and puncture site.

Anatomic landmarks (ultrasound anatomy) (Figure 11.2)

The brachial plexus in the dog is formed from the ventral branches of the C6, C7, C8, and T1 spinal nerves, which exit the spinal column through their respective intervertebral foramina. After the roots emerge through the intertransversarius musculature, there is an exchange of nerve fibers between them. The four roots then cross the ventrolateral border of the scalenus muscle and divide to form the brachial plexus. The phrenic nerve also runs along the ventral border of the scalenus muscle. After the roots cross the axillary space, they form the individual nerves that provide the sensory and motor supply to the thoracic limb.

- The ventral root of C6, with some input from C7, is the main contributor to the suprascapular nerve.
- The ventral root of C7, with some input from C6, is the main contributor to the musculocutaneous and subscapular nerves.
- The ventral root of C8, with some input from T1, is the main contributor to the radial nerve.
- The ventral root of T1, with some input from C8, is the main contributor to the median and ulnar nerves.

The transducer is placed over the axillary region, in the fossa between the manubrium of the sternum and the supraglenoid tubercle of the scapula oriented in a parasagittal plane (Figure 11.12).

In the corresponding ultrasound image, in the near field, the most superficial structure found is the pectoralis superficiales muscle. Dorsal or deep to it is the pectoralis profundus muscle. Dorsal to these muscles and, within the axillary space, are the axillary artery and vein. These vessels serve as important anatomic landmarks for the procedure. Seen in cross-section, they form what is described as the "double-bubble" sign (Tran et al. 2008). Surrounding the axillary vessels, are the roots of the brachial plexus, visible as four small rounded hyperechoic structures. The C8 root is located immediately dorsal to the axillary artery. Cranial to the artery, C7 and C6 can be found. T1 is located caudal to C8 (Figure 11.13).

Step-by-step procedure

- If desired, a sterile drape can be placed over the needle puncture site to prevent needle contamination during the procedure.
- Using the nondominant hand, place the transducer over the axillary region, in the fossa

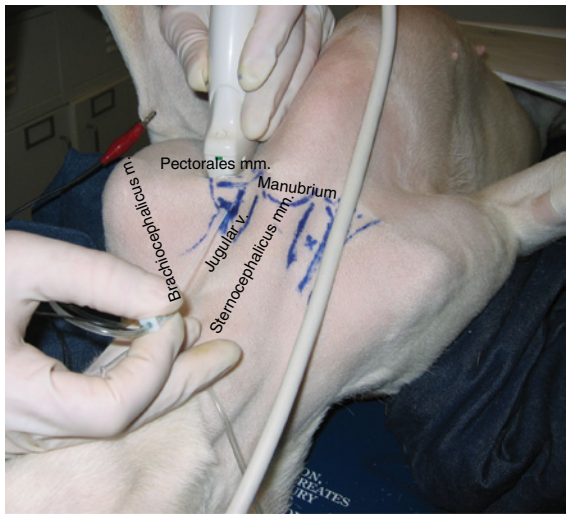


Figure 11.12 Dog in dorsal recumbency. The transducer is placed into the axillary region, in the space between the manubrium of the sternum and the supraglenoid tubercle of the scapula. The transducer is oriented in a parasagittal plane. The following landmarks were drawn on the skin: jugular vein, cranial border of pectorales muscles, medial border of brachiocephalicus muscle, and cranial border of sternum. The puncture site is indicated with an X. Note that the stimulating needle is being advanced in a cranial to caudal direction in-plane with respect to the ultrasound transducer. From Campoy et al. 2010. Used with permission.

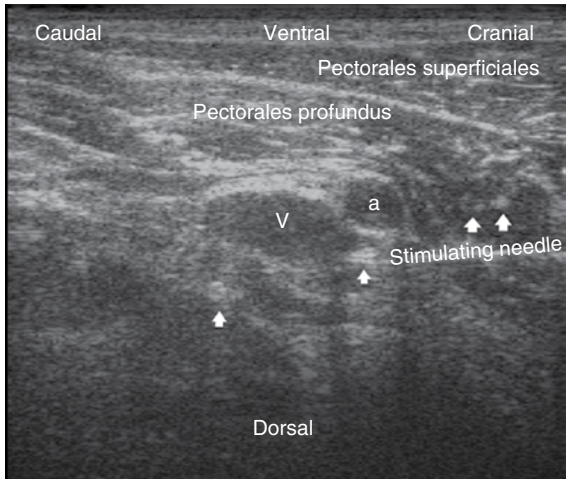


Figure 11.13 Ultrasound image of the axillary region. The stimulating needle (horizontal hyperechoic line) has been advanced to a position dorsal to the axillary artery. (v: axillary vein; a: axillary artery; solid arrows: C6, C7, C8, and T1 nerve roots). From Campoy et al. 2010. Used with permission.

between the manubrium of the sternum and the supraglenoid tubercle of the scapula (Figure 11.12).

- Orient the transducer in a parasagittal plane. Glide, rotate, or tilt the transducer until the axillary vein and artery in cross-section come into the field of view ("double-bubble" sign). The vessels will appear as anechoic (black) round structures and the artery will pulse (Figure 11.13).
- Immediately dorsal to these vessels, identify the rounded hyperechoic root of C8, also seen in cross-section. In most patients, the anesthetist should also be able to locate the C6, C7, and T1 roots.
- Once C8 has been identified, insert the stimulating needle "in-plane" dorsal to the cranial edge of the pectoralis muscle and lateral to the jugular vein.
- Advance the needle in a cranial-to-caudal direction, keeping the needle tip in the field of ultrasound view at all times. Aim the needle for the area directly dorsal to the axillary artery, in close proximity to the C8 root. In a study by Campoy et al. (2010), the needle was inserted 2.2 (± 0.3) cm in a craniocaudal direction when its tip was located immediately dorsal to the axillary artery.
- Watch for the characteristic contractions of the triceps brachii muscle, resulting in elbow extension (Table 11.3).
- As the local anesthetic solution is injected, watch for fluid to begin spreading around the nerves. The anesthetic solution will appear as a hypoechoic cloud around the nerves, ruling out intravascular needle placement (Robards et al. 2008).
- The total volume of local anesthetic to be injected should be approximately 0.15–0.2 mL kg^{-1}.

Clinical tips

- The final injection volume should be assessed by monitoring the ultrasound image. If adequate coverage is obtained before the calculated volume has been injected, the full dose of local anesthetic does not need to be administered.
- The injection location can be fine-tuned to target specific roots for certain surgical procedures. For example, the needle can be repositioned cephalad and ventral to C8 in order to block the C7 or C6 roots.

- Stimulation of C7 will result in contraction of the biceps brachii muscle, resulting in elbow flexion.
- Stimulation of C6 will result in contraction of the supra and infraspinatus muscles, resulting in shoulder rotation, flexion, or extension.
- If radial nerve responses are obtained, realize that an injection at this location will most likely miss the musculocutaneous nerve, as it lies in a more cranial position. Additionally, care must be taken as the axillary vessels lie just ventral to this position and any further needle advancement runs the risk of vascular puncture.
- If a median/ulnar response is encountered (pronation of the limb), extreme care must be taken. The axillary vessels lie just ventral to this position and any further needle advancement runs the risk of vascular puncture. These nerves lie in the most caudal part of the brachial plexus. Injection at this point will most likely miss the musculocutaneous and radial nerves.

Continuous brachial plexus block

Adequate experience with single-shot techniques is necessary to master continuous peripheral nerve block techniques. Indwelling catheters have been used for continuous nerve blocks, and their placement has been previously described in dogs (Moens and Caulkett 2000). Mahler and Reece (2007) described the use of electric nerve stimulation to aid in correct catheter placement for brachial plexus block in a traumatized dog. Catheter displacement occurred approximately 11 hours post-placement, and the authors concluded that catheter stabilization is a challenge once the patient is mobile again postoperatively.

Choice of continuous peripheral nerve block (CPNB) catheters

See Chapter 5 for more information (Figure 11.14).

Placement of and securing CPNB catheters

- Look for musculocutaneous nerve responses when placing the needle, and radial nerve responses when introducing the stimulating catheter.

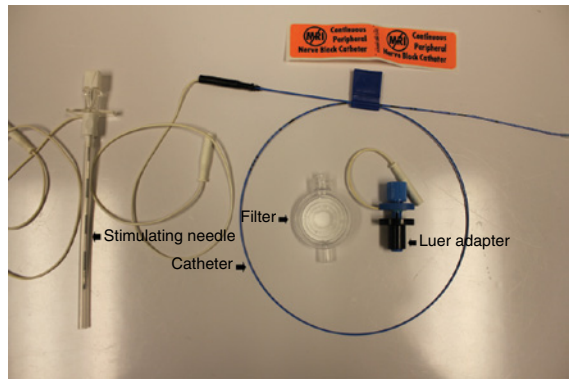


Figure 11.14 Components of a stimulating catheter kit that can be used to provide continuous peripheral nerve blockade.

- If a nonstimulating catheter is used, look for musculocutaneous nerve responses when placing the needle, then blindly advance the catheter 4–5 cm.
- The initial bolus of local anesthetic should be given through the needle (referred to as a "primary block") if a nonstimulating catheter is being used, and through the catheter itself if a stimulating catheter is used (referred to as a "secondary block").
- Orient the bevel of needle in the direction that the catheter will be advanced. Use of a Tuohy needle makes this easier.
- Advance the needle with the nerve stimulator set to 1 mA until the appropriate twitches are elicited.
- Decrease the nerve stimulator output as the needle tip moves closer to the nerve.
- Connect the catheter to the nerve stimulator (the muscle twitches should resume).
- Advance the catheter 3–5 cm past the needle tip.
- If muscle twitches are unchanged, the needle can be carefully removed and the catheter secured in place.
- The catheter can be tunneled subcutaneously to minimize the chances for dislodgement (Figure 11.15).
- Connect the catheter to a luer adapter.
- Connect the adapter to the nerve stimulator and check for appropriate twitches to confirm it is still in an acceptable position. Prior to subsequent drug administration, the nerve stimulator can be used to stimulate through the

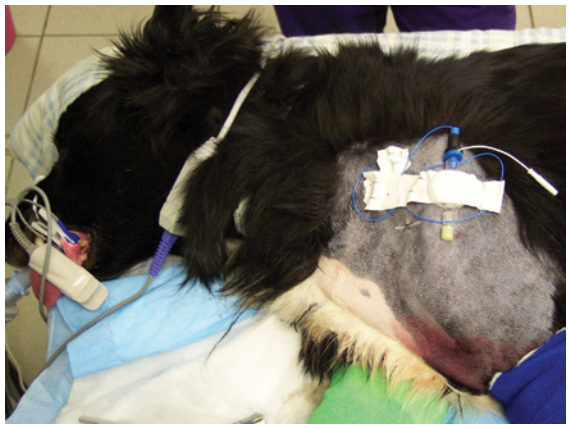


Figure 11.15 An indwelling brachial plexus catheter has been placed in a dog following surgery of its left thoracic limb. This stimulating catheter will be left in place postoperatively and can be used to "recheck" correct catheter position prior to drug administration by connecting a nerve stimulator to the white electrode.

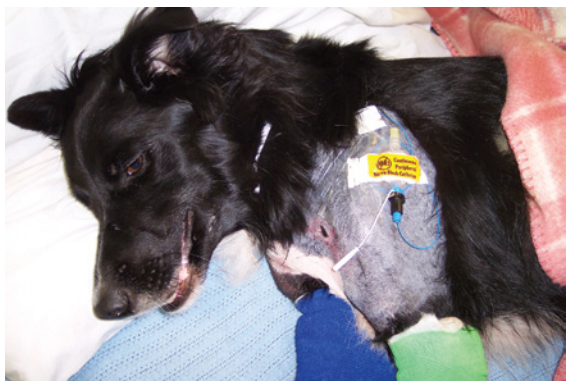


Figure 11.16 The same dog as in Figure 11.15 on postoperative Day 2. The indwelling brachial plexus catheter is still in position and has been used to provide intermittent local anesthesia to the dog. The catheter was removed on postoperative Day 3 when the dog returned to ambulation and the catheter migrated from its correct position.

catheter in order to double-check the catheter's location (Figure 11.16).

Drug choice and infusion rates of local anesthetics

- Initial volume 0.3 mL kg^{-1} followed by an infusion of 0.05–0.07 mL kg^{-1} h^{-1} of bupivacaine (0.12–0.25%) with or without dexmedetomidine (0.5 µg mL^{-1}). Alternatively, intermittent boluses of bupivacaine can be used instead of the infusion. In many cases, administration of bupivacaine every 8–10 hours appears to provide adequate analgesia in the postoperative period.

Potential complications and how to avoid them

Table 11.4 Potential complications of a brachial plexus block and how to minimize their incidence or severity.

Potential complication	How to avoid
Intravascular injection	Aspirate syringe before injecting. Look for "doughnut sign" if performing an ultrasound-guided block.
Hemorrhage	Look for musculocutaneous response. Do not advance needle past the expected depth at which the musculocutaneous nerve is expected to be.
Pneumothorax	Do not advance needle past the level of first rib.
Lung laceration	Do not advance needle past the level of first rib.
Cervicothoracic ("stellate") ganglion block with associated Horner's syndrome	Unilateral blockade of the phrenic nerve may also occur. Potentially more common in the axillary approach (ultrasound-guided technique), as the injection is made at a more proximal level. Unilateral blockade does not appear to compromise ventilatory function in conscious or anesthetized dogs (Lemke and Dawson 2000).
Nerve irritation	Local anesthetic should never be injected when resistance is encountered during the injection. Check for absence of overt muscular twitch at a current output less than 0.2 mA (this is of special importance when using only the electrolocation technique). Perform a Raj test to help rule out intraneural injections. Local anesthetic should never be injected when a patient overtly reacts during the injection (if patient is sedated rather than anesthetized).
Infection	Observe sterile technique.

Radial, ulnar, median, and musculocutaneous (RUMM) nerve blocks in dogs and cats

Functional and clinical anatomy

The radial nerve emerges between the medial and lateral heads of the triceps and brachialis muscle in the laterocaudal aspect of the mid-humerus.

The musculocutaneous, median, and ulnar nerves run adjacent to the brachial artery on the medial aspect of the limb. There is some separation between the musculocutaneous nerve and median and ulnar nerves. At the level of the mid-humerus, these nerves are surrounded by connective tissue and fat.

Distribution of local anesthesia and analgesia

Blockade of these three nerves will provide anesthesia for procedures involving the distal thoracic limb, including the carpus and the manus (paw).

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm);
- sterile gloves;
- syringes/needles; and
- local anesthetic ± adjuvant.

Technique (Lamont and Lemke 2002; Trumpatori et al. 2010)

Patient positioning

- Position the patient in lateral recumbency with the leg to be blocked uppermost for the radial nerve block (Figure 11.17), or lowermost for the musculocutaneous, median, and ulnar nerve blocks. The elbow should be held in a flexed position to facilitate palpation and manipulation of the relevant musculature.
- Clip the puncture sites.

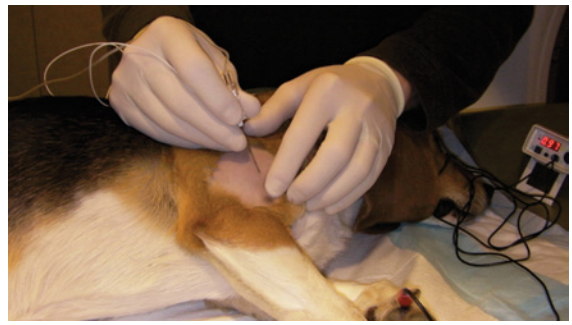


Figure 11.17 A stimulating needle is used to approach the radial nerve of a dog during performance of a RUMM block.

Anatomic landmarks

- Elbow joint
- Greater tubercle of the humerus
- Lateral and medial epicondyles of the humerus
- Lateral head of the triceps muscle
- Medial head of the triceps muscle
- Brachialis muscle
- Biceps brachialis muscle
- Brachial artery

The puncture site for the radial nerve block is on the lateral side of the thoracic limb, between the long head of the triceps and the brachialis muscle, caudal to the humerus, at the level between the middle and distal thirds of the humerus (Figure 11.18).

The puncture site for the ulnar, median, and musculocutaneous nerves is on the medial side of the limb. The pulse of the brachial artery can be palpated just proximal to the elbow joint between the biceps brachialis and the medial head of the triceps. The puncture site will be mid-humerus, cranial and caudal to the brachial artery (Figure 11.19).

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Insert the needle and carefully advance it towards the target nerve(s).
- Once the tip of the needle is within the appropriate range, appropriate contractions will result in extension of the carpus (extensor carpi twitch) for the radial nerve (Lamont and Lemke 2002), flexion and pronation of the antebrachium (flexor carpi, pronator teres twitch) for

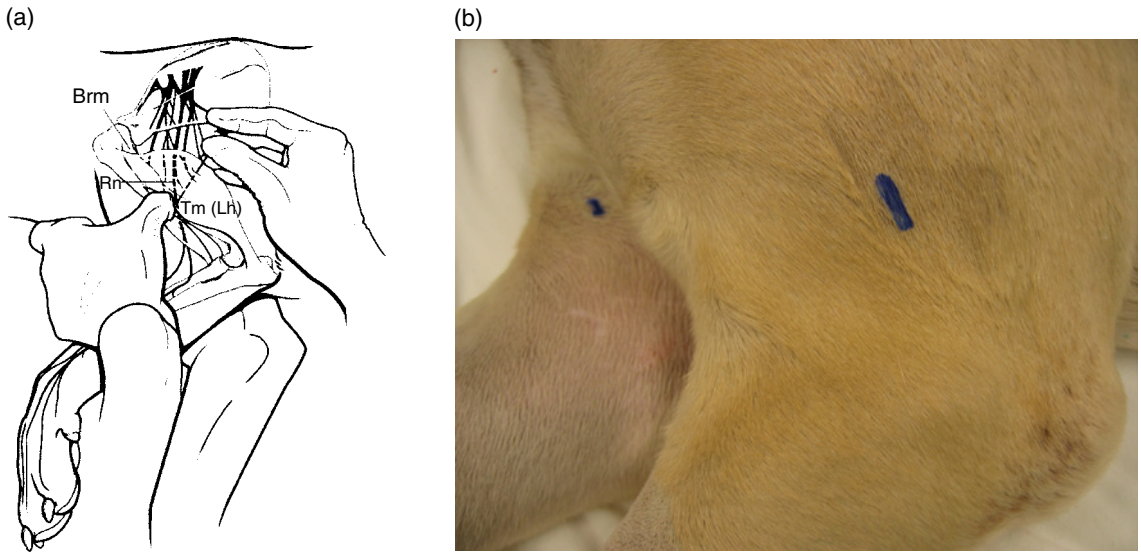


Figure 11.18 (a) Canine thoracic limb; lateral view illustrating the technique for lateral (radial nerve) block. Tm (Lh), lateral head of the triceps muscle; Brm, brachialis muscle, Rn, radial nerve. From Trumpatori et al. 2010. Used with permission. (b) Puncture site for the radial nerve is marked between the long head of the triceps and the brachialis muscle, between the mid- and distal-thirds of the humerus on the lateral aspect of the thoracic limb.

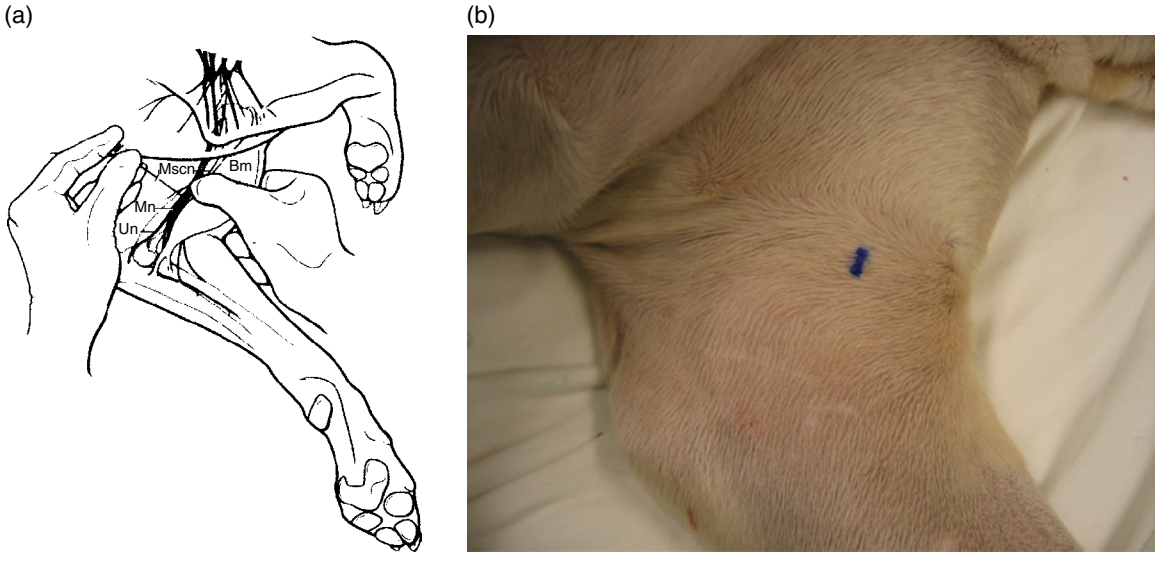


Figure 11.19 (a) Canine thoracic limb; medial view illustrating the technique for medial (ulnar, musculocutaneous, and median nerve) block. Bm, biceps brachialis muscle; Un, ulnar nerve; Mscn, musculocutaneous nerve; Mn, median nerve. From Trumpatori et al. 2010. Used with permission. (b) The puncture site for the median and ulnar nerves is located on the medial aspect of the thoracic limb, between the biceps and the medial head of the triceps, caudal to the brachial artery.

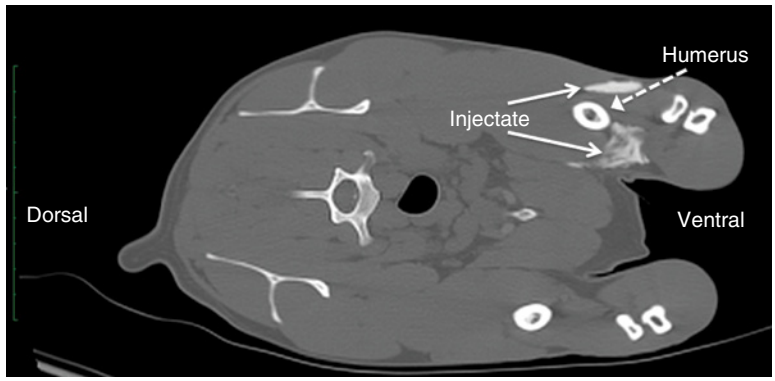


Figure 11.20 Computed tomographic (CT) image from a dog. A RUMM block has been performed using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The arrows indicate the location of contrast enhancement (hyperattenuation) on both sides of the mid-distal humerus.

the median nerve, or flexion of the forepaw (flexor carpi) for the ulnar nerve.
- Once the nerves are located (i.e. with a nerve stimulator), the local anesthetic is injected.
- The recommended volume to be injected for the radial nerve (lateral site) is $0.1\,mL\,kg^{-1}$ (Trumpatori et al. 2010).
- The recommended volume to be injected for the musculocutaneous/median/ulnar nerves (medial side) is $0.15\,mL\,kg^{-1}$ (Trumpatori et al. 2010).

Potential complications (Table 11.5)

Table 11.5 Potential complications of a RUMM block and how to minimize incidence or severity.

Potential complication	How to avoid
Hematoma	Avoid repeated approaches. Apply pressure for two to five minutes.
Intravascular injection	Always aspirate before injecting.

Intra-articular elbow and shoulder joint analgesia

General considerations

The analgesia provided by intra-articular administration of various drugs in the postoperative period is controversial. The intra-articular administration of local anesthetic agents has proven effective for knee arthroscopy in people (Reuben et al. 2001); however, pain control is more difficult to achieve for shoulder surgery (Singelyn et al. 2004).

Purpose

- Provision of perioperative analgesia.
- Provision of pain relief in patients suffering from chronic pain such as advanced osteoarthritis.
- As a diagnostic tool to confirm intra-articular pain when physical examination and diagnostic imaging fail to provide conclusive answers (Van Vynckt et al. 2010).

Indications

Indications for intra-articular drug administration include:

- shoulder or elbow surgical procedures (mainly arthroscopic procedures);
- osteoarthritis; and
- inflammatory arthritis.

Drugs used

Local anesthetics, opioids, steroids, and other adjuvants such as clonidine or dexmedetomidine are the drugs commonly administered for intra-articular pain relief.

Local anesthetics

Chu et al (2008) demonstrated *in vitro* chondrotoxic effects in human and bovine chondrocytes exposed to 0.5% and 0.25% bupivacaine. A time-dependent reduction in viability, with longer exposure times resulting in higher cytotoxicity was also observed (Chu et al. 2008).

Chu et al. (2010) further evaluated these effects *in vivo* in 48 Sprague-Dawley rats. They saw up to a 50% reduction in chondrocyte density following a single intra-articular injection of 0.5% bupivacaine when compared with a control group (saline). The articular surfaces of bupivacaine-injected joints, however, remained intact on gross and histological examinations. A variety of factors, including joint fluid, bleeding, articular cartilage integrity, and bupivacaine absorption may have reduced the effective concentration to a level that did not result in observable immediate chondrocyte death. This study shows that the chondrotoxic effect of a single intra-articular injection of 0.5% bupivacaine is subtle and would be difficult to detect clinically (Chu et al. 2010). Recently, there have been two case series published on this controversial topic (Bailie and Ellenbecker 2009; Anderson et al. 2010).

Opioids

Since the discovery of opioid receptors on peripheral nerves and joints (Stein et al. 1989), several studies have described the analgesic effect of opioids (mainly morphine) after arthroscopy or joint surgery in humans (Stein et al. 1991). The effectiveness of opiates in inflamed tissues has been explained by a disruption in the perineurium, allowing for easier access of opioids to neuronal receptors. This may also be associated with an unmasking or up-regulation of inactive opiate receptors (Reuben and Sklar 2000). Low doses of intra-articular morphine can significantly reduce pain after knee surgery through an action specific to local opioid receptors that reaches its maximal effect three to six hours after injection (Stein et al. 1991).

Steroids

Clinical efficacy has been shown for intra-articular injections of steroids in the treatment of rheumatoid arthritis in people (Furtado et al. 2005). Intra-articular steroids seem to reduce the number of lymphocytes, macrophages, and mast cells; this, in turn, reduces phagocytosis, lysosomal enzyme release, and the release of inflammatory mediators (Snibbe and Gambardella 2005). Steroids such as triamcinolone hexacetonide have been used in osteoarthritic joints in dogs. Pelletier et al. (1995) presented data showing the protective effect of corticosteroid injections on osteoarthritic cartilage lesions not only under prophylactic, but also therapeutic, conditions.

Other adjuvants

Clonidine potentiates morphine analgesia in the animal model as assessed in the mouse tail flick assay (Spaulding et al. 1979). In a study by Reuben and Sklar (2000), the combination of clonidine and morphine resulted in decreased postoperative pain and analgesic use for outpatient arthroscopic knee surgery, as well as an increased analgesic duration compared with use of either drug alone. Intra-articular use of clonidine (Reuben and Connelly 1999) or dexmedetomidine (Al-Metwalli et al. 2008) also enhances analgesia following arthroscopic knee surgery in people. Autologous adipose-derived mesenchymal stem cell therapy is currently being developed as part of the treatment of osteoarthritis in dogs, with promising results (Black et al. 2008).

Distribution of local anesthesia and analgesia

The intra-articular injection of local anesthetic provides blockade of intra-articular structures only, therefore excluding extra-articular structures such as subcondral bone, extra-articular soft tissue, and skin. As a result, requirements for supplemental analgesics are not eliminated in cases when open surgical procedures of joints are performed.

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- sterile gloves;
- syringes; and
- hypodermic (stifle joint) or spinal (hip joint) needles (22- to 23-gauge).

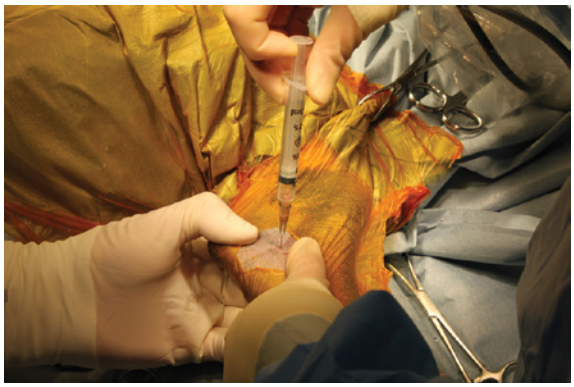


Figure 11.21 Intra-articular injection of the left elbow joint of a dog during surgery. Note the presence of synovial fluid in the needle, confirming correct position prior to drug administration.

Techniques

Elbow joint analgesia

Anatomic landmarks (Figure 11.21)

- Medial epicondyle
- Anconeal process

Step-by-step procedure

- A finger should be placed on the medial epicondyle and the limb is palpated distally until the approximate level of the joint is reached.
- The puncture site is slightly caudal to this location.
- To ensure placement within the joint, a syringe is attached to the needle and used to aspirate synovial fluid.
- The joint is filled with injectate until moderate pressure is felt against the plunger. Overfilling may lead to rupture of the joint cavity and loss of injectate into the peri-articular soft tissues.

Scapulohumeral joint analgesia

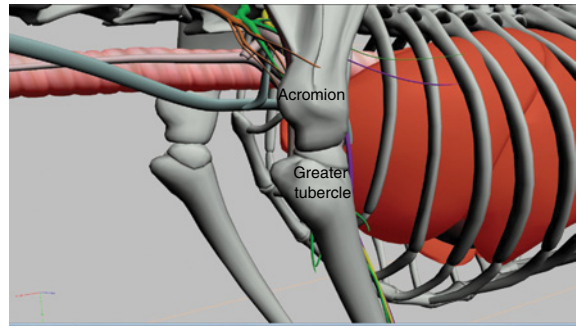
Anatomic landmarks (Figure 11.22a)

- Greater tubercle
- Acromion

Step-by-step procedure

- The shoulder is palpated to locate the superior ridge of the greater tubercle.
- The acromion is located and the space craniodistal to its border is palpated.
- A needle is inserted at the craniocaudal midpoint of the ridge (Figure 11.22b).

(a)



(b)

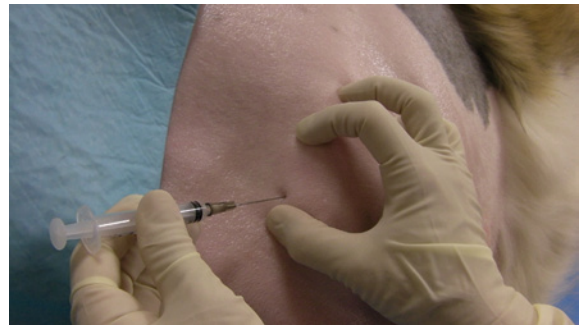


Figure 11.22 (a) Tridimensional animation of the left shoulder of a dog. Note the position of the acromion and greater tubercle. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu. (b) A 22-gauge needle is being advanced into the scapulohumeral joint of a dog. The anesthetist's index finger is being used to palpate the acromion, and the thumb is being used to palpate the greater tubercle of the humerus.

- The needle should be directed caudally and medially at a 70° angle from the perpendicular.
- If synovial fluid is not easily aspirated, Lactated Ringer's solution can be injected into the joint. If the needle is located in the joint, this fluid is easily injected into the joint space.

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12 The Trunk

Matt R. Read and Carrie A. Schroeder

This chapter will discuss the local and regional anesthetic approaches to providing analgesia to the thorax and the cranial abdomen of dogs and cats. There are several different approaches that can be used including selective intercostal nerve blocks, interpleural analgesia, and thoracic epidural anesthesia (discussed in Chapter 14). Each method will be discussed in terms of its clinical utility, technique, drug selection, and potential for complications. In addition, a brief discussion of the new techniques that are being increasingly used in the human medical field will highlight areas for future consideration and investigation in animals. These techniques include thoracic paravertebral nerve blocks and transversus abdominis plane (TAP) blocks.

Overview

Diseases of the thoracic cavity are commonly encountered in veterinary patients. Small animals frequently undergo painful diagnostic and therapeutic procedures of the chest and cranial abdomen. They also present with a variety of preexisting painful conditions including thoracic trauma and fractured ribs. In many of these situations, pain results in restricted ventilation and altered breathing patterns as the animal is unable to take normal breaths without experiencing pain. Hypoventilation and postoperative changes resulting from general anesthesia and surgery can result in further alterations in respiratory function, including alterations in respiratory mechanics such as decreased compliance, increased pulmonary resistance and work of breathing, and decreased pulmonary reserve, inspiratory capacity, and vital capacity. Overall, these changes can lead to ventilation–perfusion mismatch and reduced arterial oxygen tension (Stobie et al. 1995; Dhokarikar et al. 1996).

Regardless of the inciting cause of the thoracic pain, managing pain appropriately is very important for providing humane care and promoting return to normal function. Although many different types of analgesics are available for use in treating pain in animals, the most effective method of analgesia is reducing or eliminating the nociceptive input from a painful site via interruption of neuronal transmission. This is best accomplished by using a peripherally administered local anesthetic; these agents have been shown to be some of the most effective for treating

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thoracic pain (Berg and Orton 1986; Flecknell et al. 1991; Pascoe and Dyson 1993; Conzemius et al. 1994; Stobie et al. 1995). The use of local anesthesia prevents transmission of input from the periphery and reduces central sensitization of the nociceptive pathways at the level of the spinal cord. The use of local anesthesia is essential if surgery is to be performed humanely in awake or sedated patients, and provides a great number of benefits to patients under general anesthesia through multimodal analgesia (Lemke and Dawson 2000).

One aspect of thoracic and thoracoabdominal procedures that has received close attention in both people and animals is the ability for these surgeries to negatively impact the patient's ventilatory function. Postoperative pain following thoracic surgery in humans causes a reduction in normal tidal ventilation, which can result in the subsequent development of hypoxia. Similar effects have been reported in animals (Flecknell et al. 1991; Conzemius et al. 1994). Several studies have documented the changes associated with lateral or median sternotomy thoracotomy in dogs, and have shown that even short-term procedures in healthy dogs can cause significant and clinically important changes that can last up to 24 hours. These changes include hypoxemia, hypoventilation, respiratory acidosis, increased work of breathing, decreased lung compliance, elevations in A-a gradient, decreased inspiratory time, and increases in peak expiratory flow rate (Berg and Orton 1986; Stobie et al. 1995, Dhokarikar et al. 1996). Although many of these changes are predictable consequences of general anesthesia and open-chest procedures, others appear to be associated with pain. These changes can be clinically significant in otherwise healthy patients, and could become even more important in patients that may not have the ability to compensate for alterations in respiratory function, such as those with preexisting pulmonary or cardiac disease.

Of the methods that can be used to provide anesthesia and analgesia to the trunk, selective intercostal blockade and the infusion of local anesthetics into the interpleural space have been investigated for providing analgesia for thoracic procedures in dogs and can easily be incorporated into the anesthetic and analgesic plan for these patients. Fortunately, these techniques are relatively easy to perform and do not impose significant risk to the patient when performed correctly. Thoracic paravertebral blocks and transversus abdominis plane (TAP) blocks are relatively new techniques that are being increasingly used as alternatives for providing thoracic and upper abdominal analgesia to selected patients in human medicine. Currently, not much is known about the efficacy, safety, or utility of these techniques in animals and there are limited published reports available in the veterinary literature.

Although studies of intercostal and interpleural analgesia have historically been performed and reported in dogs, based on limited interspecies differences in thoracic innervation, these techniques can be used in cats undergoing similar thoracic procedures with the same expected benefits. Bearing this in mind, definitive studies should still be conducted in cats to uncover and document the inevitable species differences that may exist. By doing so, we can better deliver effective analgesia while at the same time balancing risks to feline patients.

Each of the regional anesthetic techniques described here has its own advantages and disadvantages, as well as requirements for technical skill to be performed properly to balance patient safety with analgesic efficacy. The specific techniques described below can and should be used in combination with other modes of analgesia to provide optimal pain relief. Rarely is a single analgesic technique indicated for use on its own.

Regional nerve anatomy

The thoracic and cranial lumbar (L1, L2) spinal nerves are responsible for sensory innervation of the trunk (Dyce et al. 2010). In addition to serving the thorax, the ventral branches of the first two thoracic spinal nerves (T1 and T2) also supply fibers to the radial, median, and ulnar nerves of the brachial plexus and therefore contribute to motor and sensory innervation to the thoracic limb. The ventral branches of remaining thoracic spinal nerves (T2–T13) contribute to the peripheral nerves that run ventrally within the intercostal spaces between adjacent ribs. Respective intercostal nerves lie in close proximity to the intercostal arteries and

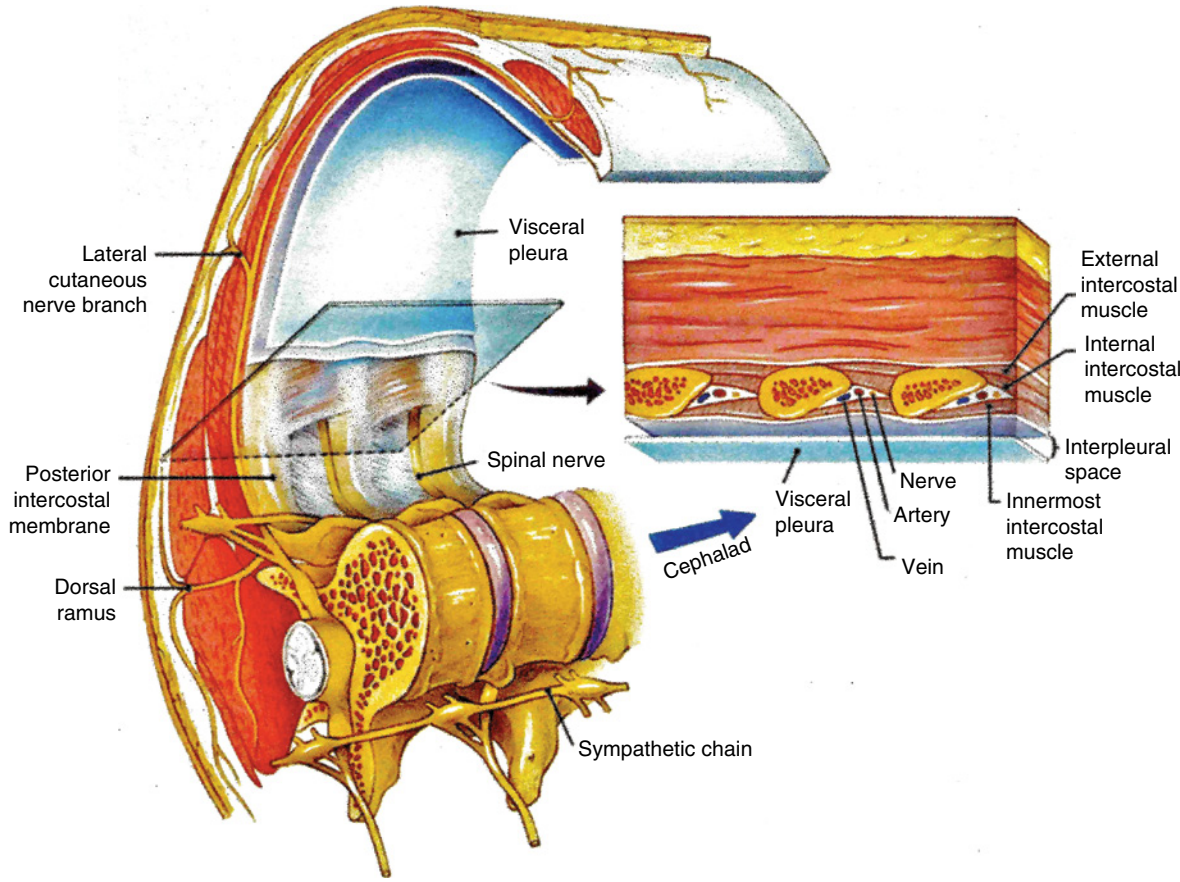


Figure 12.1 Anatomy of the intercostal nerve. From Stromskag and Klevin 1998. Used with permission.

veins that course ventrally directly beneath the parietal pleura along the caudal aspect of the associated ribs (Figure 12.1).

Some fibers supply motor function to the intercostal muscles, whereas others detach lateral branches to provide sensory innervation to the skin lying over the lateral and ventral aspects of the chest wall and abdominal floor. Although each intercostal space is associated with a specific nerve, there is significant overlap of sensory dermatomes, and as a result, any regional anesthetic technique used must take this distribution into consideration. For example, if a lateral thoracotomy is to be performed at the fifth intercostal space, nerves serving the adjacent third, fourth, sixth, and seventh spaces should also be blocked to provide complete analgesia to the surgical field (Berg and Orton 1986; Thompson and Johnson 1991).

Intercostal nerve blocks in dogs and cats

General considerations and purpose

Intercostal nerve blockade is relatively easy to achieve in deeply sedated or anesthetized patients. The ribs themselves serve as bony landmarks for performing this regional anesthetic block and, unless the patient is significantly overweight, are easily palpated. Intercostal nerve blockade can also be performed in surgery, when direct visualization of the target nerves is possible during thoracotomy while the patient still has an open chest. However, as preemptive local anesthesia administered before the surgical insult commences can offer further benefits to the patient, and as the landmarks used for a percutaneous approach to the block are readily palpable in the majority of

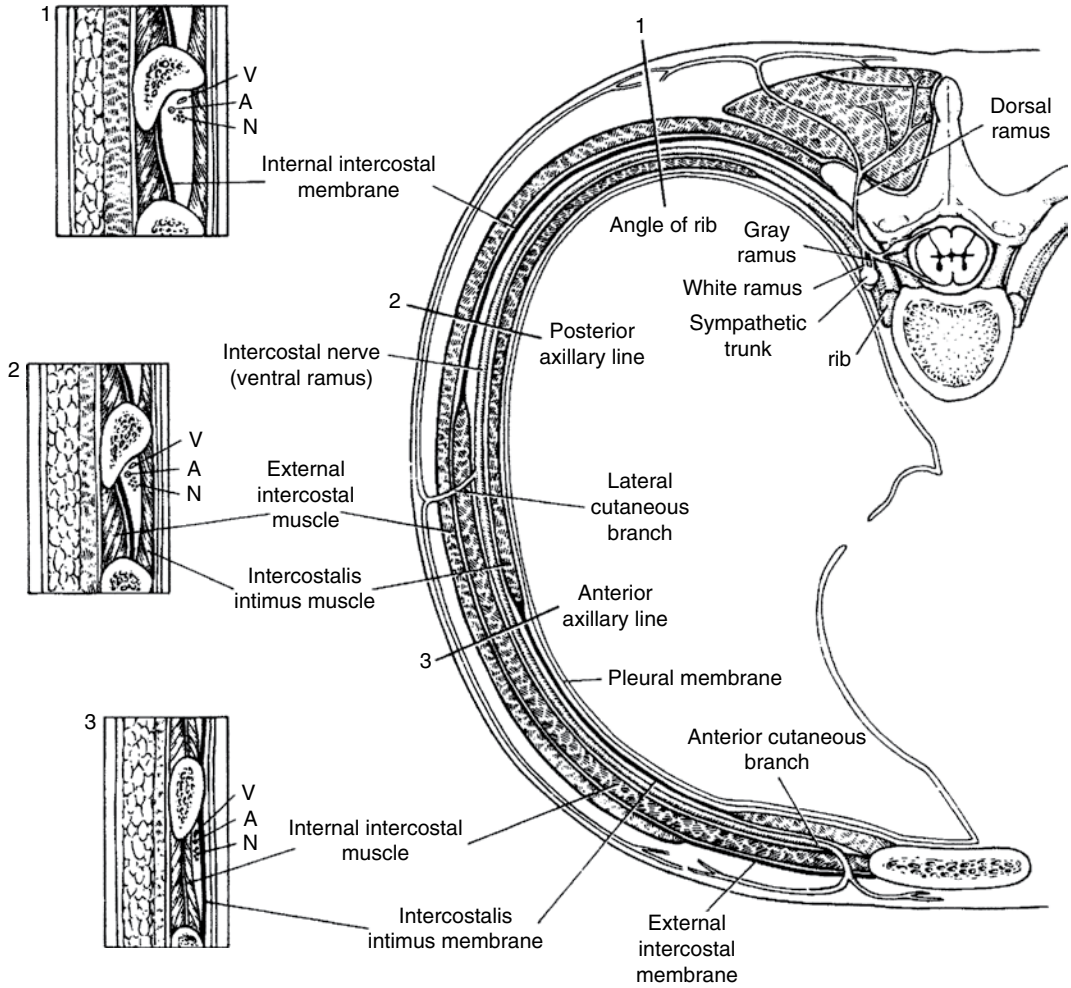


Figure 12.2 The anatomy of the intercostal space. From Dravid and Paul 2007a. Used with permission.

patients, preoperative blockade should be attempted in most patients before the surgical approach is made.

Each intercostal nerve lies immediately caudal to its associated rib (Figure 12.2), so as long as the rib can be palpated and approached with a needle, this block can be performed blindly or with the use of nerve stimulation. Ideally, the rib should be approached by a needle placed as dorsally as possible to effectively block as much of the associated dermatome as possible. It is important to remember the close association of intercostal vessels with the intercostal nerves (Figure 12.3). As with all local and regional blocks, it is extremely important to aspirate before injecting local anesthetic in order to verify absence of vascular puncture.

Using intercostal nerve blocks, several investigators have been able to document beneficial effects for dogs undergoing thoracic surgeries. In canine thoracotomy patients, selective intercostal nerve blocks offer the possibility of improved postoperative ventilation through analgesia without the risk of centrally mediated respiratory depression that can occur with the use of high doses of systemically administered opioids. Following lateral thoracotomy, healthy dogs that received morphine and oxymorphone showed signs of hypoventilation, with significant elevations in $PaCO_2$ and respiratory

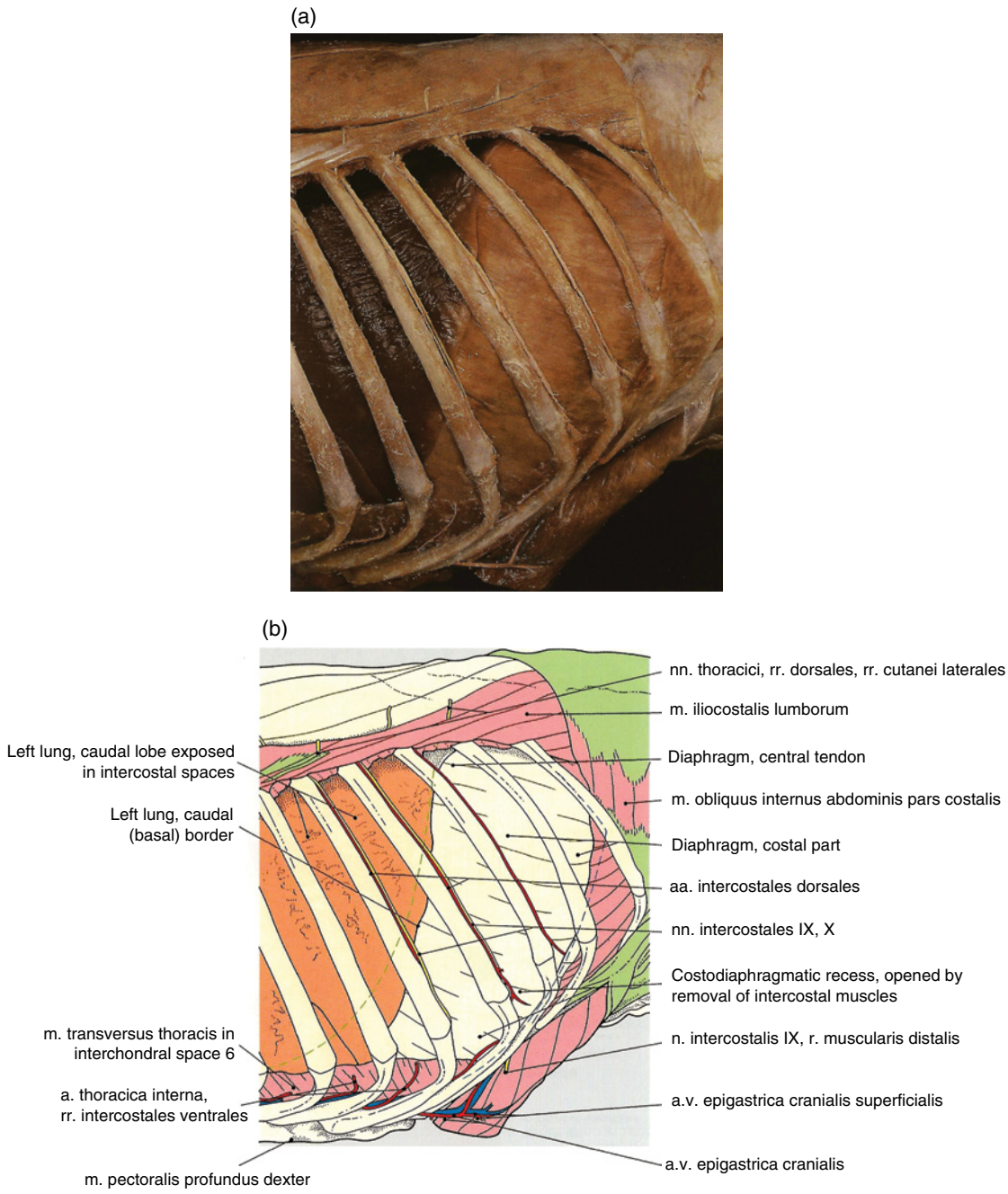


Figure 12.3 (a), (b) Caudal ribs, costal arch, intercostal arteries and nerves of a dog: left lateral view. Intercostal arteries and nerves in intercostal spaces 9, 10, and 11 are displayed after removal of the endothoracic fascia. From Done et al. 2009. Used with permission.

acidosis for up to 90 minutes following extubation (Berg and Orton 1986). Further, the opioid treatment groups experienced a significant decrease in PaO_2 as compared with control groups. Dogs that received intercostal blockade with 0.5 mL of 0.5% bupivacaine at each intercostal site did not demonstrate these alterations in respiratory variables; arterial blood gas tensions, tidal volume, and minute ventilation remained similar to control animals. Regardless of the analgesic technique used, all dogs receiving opioids or intercostal blocks had quiet and pain-free recoveries compared with control dogs where no analgesia was provided for postoperative pain control. In that study, dogs were only monitored for three hours postoperatively, so no conclusions could be drawn in terms of overall duration of effect of the different treatments. The investigators recommended the use of intercostal blocks as an alternative to systemically administered opioids for treating pain after lateral thoracotomy because they are technically easy to perform and provide comparable analgesia to the "gold-standard" of opioids, while avoiding the potential for opioid-related central respiratory depressive effects.

In a later study involving healthy dogs, intercostal blocks using bupivacaine were shown to have a detectable beneficial effect for up to 16 hours following lateral thoracotomy (Flecknell et al. 1991). In that study, a multimodal approach using nalbuphine, a partial opioid agonist, as well as intercostal bupivacaine (total dose 3.5–4.5 mg kg^{-1}) administered across five intercostal spaces was compared with narcotic-only analgesia with nalbuphine. Systemically administered nalbuphine was dosed at regular intervals in both treatment groups. Similar to the previous studies, the intercostal blocks and nalbuphine were found to have comparable analgesic effects, but there were no significant changes in $PaCO_2$ in this particular study and all dogs appeared to breathe normally during observation. However, the authors did observe an improvement in oxygenation following nalbuphine administration in the opioid-only group that was not observed in the intercostal block group until the 16-hour time point. This led the researchers to conclude that the additional analgesic was unnecessary in combination with the regional block until 16 hours, the presumed duration of the block. It is important to note that the relatively high doses of bupivacaine that were tested in this study are not currently used in clinical canine patients for intercostal blocks.

Intercostal bupivacaine has also been compared with epidural morphine for treatment of postoperative pain following lateral thoracotomy in dogs (Pascoe and Dyson 1993). In that study, analgesia for breakthrough pain was required in eight of 20 dogs in the epidural morphine group but only two of 20 dogs in the intercostal bupivacaine group. There were no differences in blood gas values with respect to $PaCO_2$ and PaO_2, and both parameters were maintained within clinically acceptable ranges. Based on its local anesthetic mechanism of action, intercostal bupivacaine should totally abolish nociceptive input from the tissues being supplied by intercostal nerves, but, because thoracotomies involve multiple anatomic structures (including the thoracic limb musculature), it may not totally abolish all input from the whole surgical site. To improve postoperative analgesia, the authors suggested that intercostal bupivacaine could be combined with other techniques for further enhancing intraoperative and postoperative analgesia.

In human surgical patients, intercostal blocks with bupivacaine have been shown to significantly reduce postoperative pain scores compared with intercostal saline or no intercostal local anesthetics when administered as either single blocks, repeat blocks, or as continuous infusions. In people, the use of local anesthesia as repeat blocks or infusions has also been shown to significantly reduce supplementary analgesic requirements (Joshi et al. 2008). The technique of a continuous extrapleural infusion of local anesthetic for intercostal nerve blockade has been described in the human literature (Sullivan et al. 1995). This has the same effect as an intercostal block, exposing the intercostal nerves to local anesthetic, but can provide more continuous or long-term analgesia without additional injections in the postoperative period. Meta-analysis has demonstrated that this technique results in analgesia that is similar to a thoracic epidural and superior to systemic narcotics, with an extremely low incidence (<1%) of local anesthetic toxicity (Detterbeck 2005). A study comparing extrapleural infusion of bupivacaine with intravenous pethidine, an opioid agonist, found an overall increase in pain scores for patients not receiving the block for the first 72 hours following surgery.

Although no studies have been reported in cats, the use of intercostal blocks for prevention of surgical pain from thoracotomy has been used extensively in clinical practice for years. Using the same principles used for dogs, this local anesthetic technique can be incorporated into the anesthetic and analgesic management of feline patients. It is important to note that because of the sensitivity of feline patients to local anesthetics, as well as small patient size, it is important to carefully calculate local anesthetic doses and to dilute the drugs as needed to ensure adequate injectate volumes in these small patients.

Indications

Intercostal nerve blocks can be used to provide analgesia for the lateral thoracic wall and its associated structures. These blocks are useful for providing short-term analgesia as a component of balanced anesthesia for major surgical procedures or for postoperative analgesia following surgery. They can also be used in awake patients to provide analgesia for injuries unrelated to surgery (e.g. single rib fractures, flail chest); however, patients may object to the performance of multiple injections and may move abruptly, increasing the risk of inadvertent pleural, vascular, or pulmonary puncture. As with many local and regional anesthetic techniques, it is important to choose patients carefully based upon presentation and disposition, and to incorporate judicious use of sedation as appropriate.

Single injection blocks will typically last up to 12 hours, depending on the local anesthetic used. As described above, potential for continuous intercostal nerve block exists by using an indwelling perineural catheter or wound soaker catheter placed along an intercostal thoracotomy incision (see Chapter 8 for more detail on the use of this technique). In these situations, longer-term analgesia can be provided by intermittent injections or through continuous local anesthetic infusions using a pump.

Local anesthetics used

The long-acting local anesthetic bupivacaine is most commonly used for intercostal blocks in dogs and cats, and is the most studied local anesthetic for use with these blocks in dogs. Other local anesthetics (lidocaine, mepivacaine, ropivacaine) can also be used to provide anesthesia of varying duration of effect depending on the drug used. Intercostal blocks are most often achieved by blocking four to five consecutive nerves with 0.5 mL bupivacaine (0.5%) per site in patients smaller than 10 kg, and 0.5–2 mL bupivacaine (0.5%) per site in patients greater than 10 kg (Berg and Orton 1986, Flecknell et al. 1991, Thompson and Johnson 1991, Pascoe and Dyson 1993). Single injection intercostal blockade with bupivacaine is expected to provide analgesia for up to 12 hours following the injection. The addition of epinephrine to the local anesthetic has not been shown to prolong the duration of blockade but may increase the allowable local anesthetic dosage due to a decrease in systemic absorption (Kopacz and Thompson 1998; Hadzic 2007).

Distribution of local anesthesia and analgesia

Intercostal nerve blocks are effective for providing regional anesthesia to the lateral chest wall and its associated bony and soft tissue structures. Local anesthetic drugs are administered adjacent to the intercostal nerves behind each rib, and provide sensory and motor blockade to the associated dermatomes. To be effective for pain relief, at least three consecutive nerves should be blocked (Thompson and Johnson 1991). In practice, the nerve that serves the intended intercostal space for the incision is blocked, along with up to two nerves cranially and two nerves caudally. In the case of rib fractures or flail chest, the nerve immediately caudal to the affected rib is blocked.

Equipment

- Clippers;
- sterile gloves;
- 1.5 inch spinal needle;
- syringe for local anesthetic;
- bupivacaine (0.5%); and
- solutions for aseptic preparation of skin.

Although hypodermic needles are commonly used in practice, they do potentially pose more risk for causing trauma due to their long bevel and sharp edges when compared with spinal needles. Caution should be exercised so as not to overly traumatize tissues by redirecting the needle repeatedly while it is in the patient. Small gauge (22–24-gauge) needles should be used whenever possible.

A nerve stimulator and small gauge insulated needle can also be used for performing intercostal nerve blocks. Visible and palpable muscle twitches are easily elicited when the tip of the insulated needle is in close proximity to the intercostal nerve, confirming needle tip placement prior to local anesthetic injection.

Intercostal block – standard technique

- The patient is placed in lateral recumbency, with the operative side of the thorax positioned up (Figure 12.4).
- Initially without using sterile technique, the nondominant hand grasps the thoracic limb and the scapula is advanced cranially to allow the anesthetist to palpate and identify the first rib. The thirteenth rib can alternatively be identified as the caudal aspect of the costal arch. The dorsal spinous processes of the thoracic vertebra should also be palpated (when possible based on body condition) to identify dorsal midline. If these landmarks cannot be palpated, the patient may be too overweight for the blind approach of the intercostal block technique to be used safely. Use of nerve stimulation may be indicated for these patients.
- Once these bony landmarks are identified, the lateral thorax is clipped as necessary for the planned surgical procedure and aseptically prepared. The skin should be prepared for injection across several ribs near the dorsal midline, including at least two to three ribs on either side of the anticipated site of the surgical incision (usually this is required for the surgical procedure regardless of the planned analgesic technique).
- The anesthetist should sterilely glove and prepare a short bevel (1.5 inch) spinal needle (Figure 12.5). A hypodermic needle can also potentially be

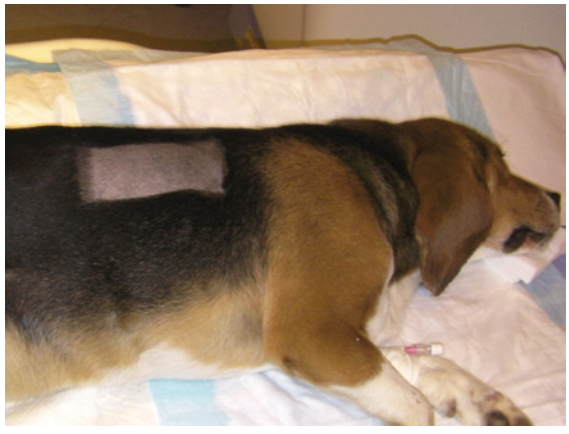


Figure 12.4 Photograph of a dog positioned in left lateral recumbency. The lateral thorax has been clipped in preparation for demonstration of intercostal blockade.

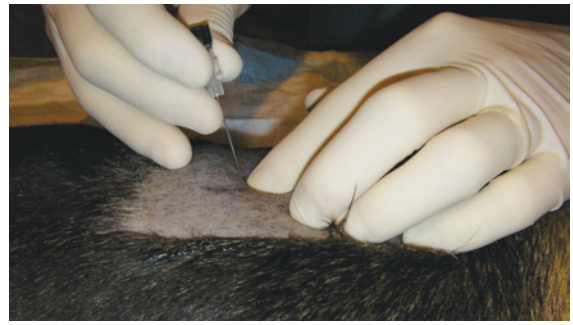


Figure 12.5 Photograph of intercostal blockade in a dog. A 22-gauge spinal needle is being used to perform the block. The nondominant hand is used to palpate the rib immediately cranial to the nerve to be blocked, and the needle is advanced slowly through the skin until it contacts the rib.

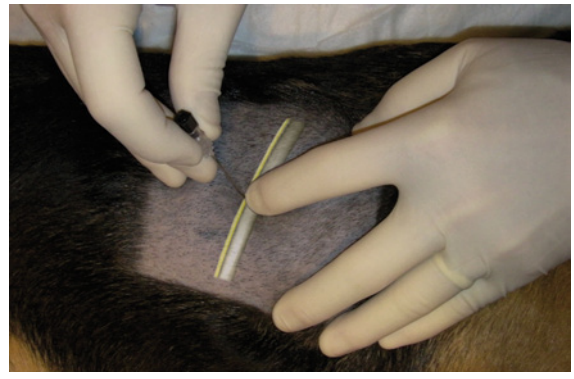


Figure 12.6 Image of intercostal blockade in a dog. The needle should be "walked off" the caudal aspect of the rib (illustrated in white) in an attempt to deposit the local anesthetic in the area of the intercostal nerve (illustrated in yellow).

used, but its sharp long bevel does not allow the operator to appreciate when different tissue planes are penetrated and can cause more damage to the underlying lung if the parietal pleura is inadvertently penetrated during needle approach if the rib is not contacted first.

- The rib immediately craniad to the anticipated incision is palpated as far dorsally as possible so that its intercostal nerve can be targeted as proximally as possible.
- The needle is initially advanced through the skin onto the lateral aspect of the rib.
- The needle tip is then gently "walked off" the rib caudally until it can be advanced medially immediately caudal to the rib (Figures 12.6 and 12.7). Caution should be used not to advance the tip of the needle beyond the depth of the rib. The needle should not penetrate the parietal pleura and enter the pleural space.

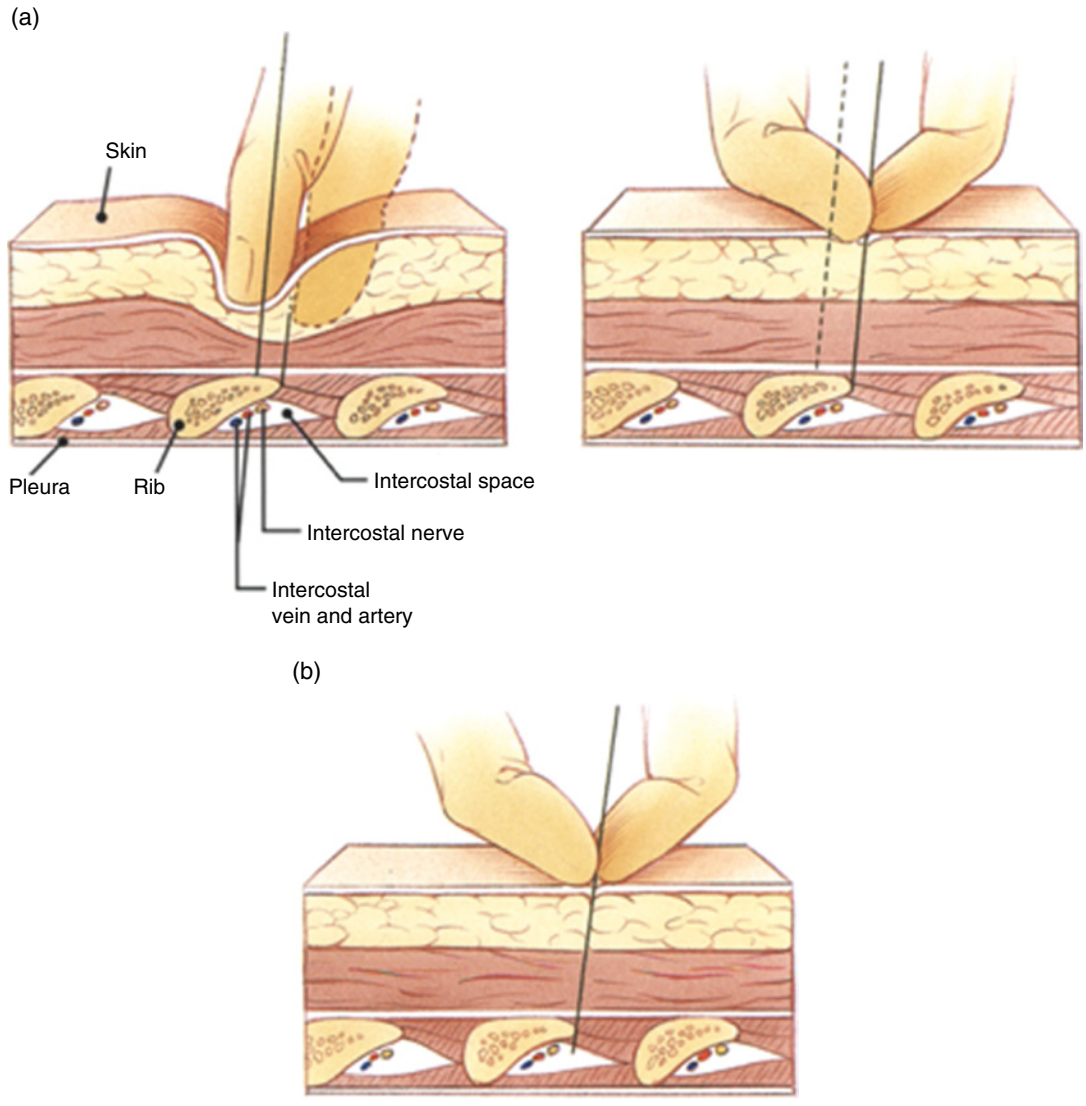


Figure 12.7 (a) and (b) "Walking off" the rib caudally until the tip of the needle enters the intercostal space. From Stromskag and Klevin 1998. Used with permission.

- The stylet is removed and the needle hub is inspected for blood. Immediately before attaching the drug-containing syringe to the needle, air is aspirated into the syringe to form an air bubble above the local anesthetic solution adjacent to the plunger. The syringe is then attached to the hub of the needle.
- The anesthetist should now use the syringe to aspirate, ensuring that the needle tip is not placed intravascularly in an intercostal artery or vein (blood would be aspirated) or that the needle tip is placed in the pleural space (air would be aspirated).
- A small volume of local anesthetic (0.5–1 mL) is then slowly injected through the needle at the single site on the caudal aspect of the rib to perform the block. The small air bubble in the syringe above the local anesthetic solution should not compress more than 50% of its starting volume during injection of the local anesthetic solution. If resistance to injection is being experienced, the air bubble will compress, giving the anesthetist a visual as well as tactile indicator of resistance to injection. If this occurs, the needle should be repositioned and the injection reattempted. Following injection of the local anesthetic, the syringe and needle are withdrawn together as one unit.
- This technique is repeated for the two ribs cranial and the two ribs caudal to the incision in order to successfully block the other dermatomes that will potentially be involved in the surgical field (Figure 12.8).

This technique can also be used with an insulated needle and a peripheral nerve stimulator (Figure 12.13). A low current of 0.5 mA is used, at 1 or 2 Hz and 0.1 ms stimulus duration. When the needle is walked off the caudal aspect of the rib, twitches will be observed along the entire intercostal space as the nerve is stimulated and the intercostal muscles are stimulated to contract. As described above, the syringe should first be aspirated for blood or air followed by injection of the local anesthetic. The twitches will immediately be abolished if the local anesthetic is correctly deposited adjacent to the target intercostal nerve. Although nerve stimulation can be used to identify the target intercostal nerves in any patient, its use is particularly helpful in overweight animals when ribs are not easily palpated and blind approaches would carry more potential risk to the patient (inadvertent penetration of the pleural space, pneumothorax, intravascular injection) as the anesthetist blindly attempts to place the needle without the assistance of palpable landmarks.

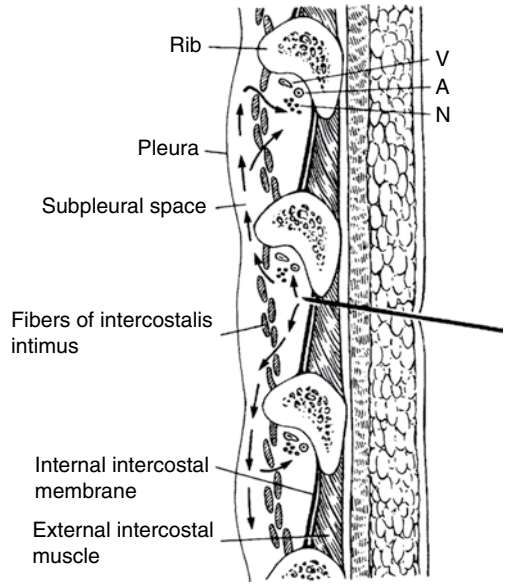


Figure 12.8 The paths taken by fluid injected into the intercostal space. From Dravid and Paul 2007a. Used with permission.

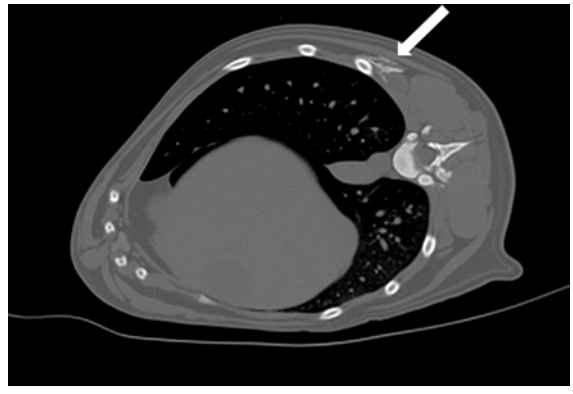


Figure 12.9 Axial computed tomographic (CT) image of a dog in lateral recumbency. An intercostal block has been performed using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The white arrow demonstrates contrast enhancement (hyperattenuation) caudal to the rib in the region of the intercostal space.

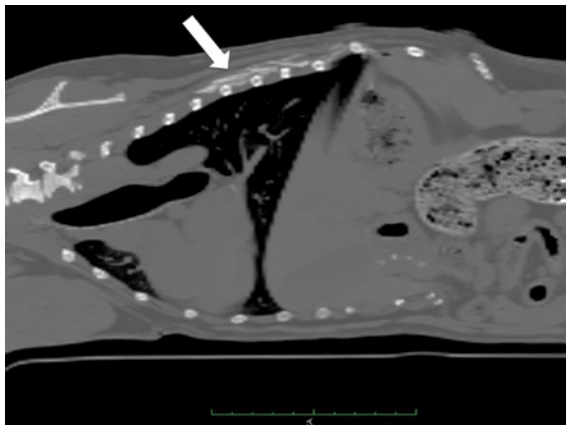


Figure 12.10 Parasagittal multiplanar reformatting from a computed tomographic (CT) scan of a dog. Intercostal blocks have been performed across several successive intercostal spaces using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The white arrow demonstrates contrast enhancement (hyperattenuation) between the ribs in the intercostal spaces.

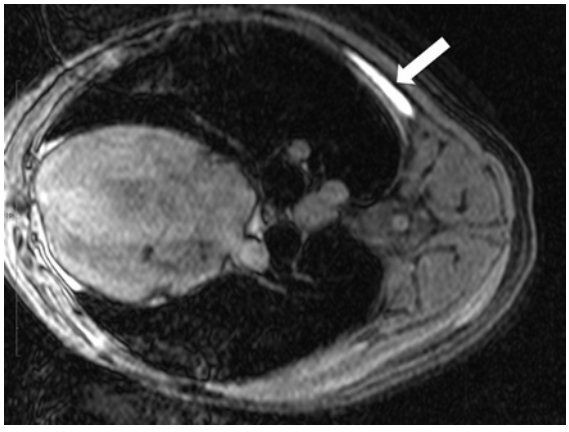


Figure 12.11 Axial magnetic resonance image (MRI) of a dog in lateral recumbency. An intercostal block has been performed using lidocaine and gadolinium contrast medium (gadobutrol 1.0 mmol L^{-1} at 100:1 dilution). The injected solution can be seen spreading along the intercostal space (white arrow).

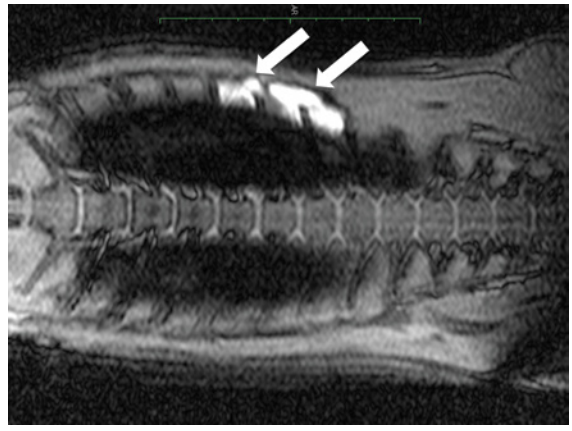


Figure 12.12 Dorsal plane magnetic resonance image (MRI) of a dog in lateral recumbency. Intercostal blocks have been performed across several successive intercostal spaces using lidocaine and gadolinium contrast medium (gadobutrol 1.0 mmol L^{-1} at 100:1 dilution). The injected solution can be seen between the ribs in the intercostal spaces (white arrows).

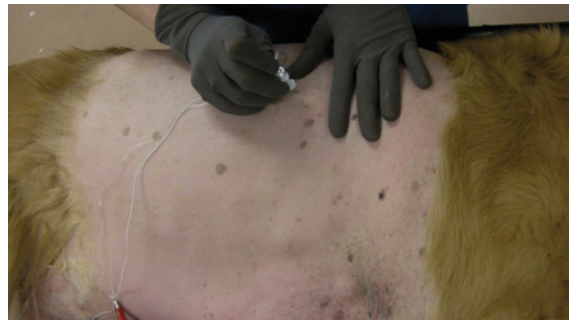


Figure 12.13 An intercostal block being performed in a large dog. The dog is positioned in lateral recumbency and a nerve stimulator and insulated needle is being used to search for the target nerves to assist with performing the block.

Potential complications

Intercostal blocks are relatively easy to perform and, when administered correctly, carry minimal risk to the patient. Although absorption of local anesthetic from the intercostal space is rapid, systemic toxicity of local anesthetics should be of little concern as long as proper dosing and injection technique is used. A review of the human literature of this technique did not reveal any incidents of local anesthetic toxicity (Detterbeck 2005). Inadvertent vascular puncture due to the close proximity of intercostal nerves to the intercostal vessels is possible, and is usually detected when the syringe is aspirated. It is also possible to inadvertently advance the needle into the thoracic cavity, and this can usually be detected on aspiration of air into the needle. If the pleural space is entered, an insignificant pneumothorax can result when the stylet is initially withdrawn from the needle. Although the incidence of pneumothorax in veterinary patients is not reported, human literature

reports an overall incidence of 0.07% (Detterbeck 2005). If interpleural needle placement is not detected, the small volume of local anesthetic solution destined for an intercostal block will instead be deposited interpleurally and, as a result, will ultimately be ineffective for the desired analgesia. A case report of concern describes an intercostal block performed with proper technique at sites between T3 and T7 resulting in temporary total spinal anesthesia in a human patient (Chaudhri et al. 2009). Inadvertent injection into a dural cuff extending beyond the intervertebral foramen was the proposed explanation for this unexpected result. This rare complication has been reported previously in human patients but has not been reported in veterinary medicine (Benumof and Semenza 1975; Sury and Bingham 1986).

Interpleural regional analgesia in dog and cat

General considerations and purpose

Interpleural analgesia was first described in people the early 1980s, and is now recognized as a major analgesic technique for people and animals. Interpleural administration of local anesthetic solutions is useful for providing postoperative pain relief following incision through thoracic dermatomes, post-traumatic thoracic pain, and can even be used for treating chronic pain disorders of the cranial abdomen, including pancreatitis (Dravid and Paul 2007b). In dogs, interpleural administration of local anesthetics provides good analgesia, improves the patient's ventilation, and, when an indwelling catheter is placed into the pleural space, allows a convenient method for repeated dosing of analgesics over time (Thompson and Johnson 1991; Conzemius et al. 1994; Stobie et al. 1995).

Using this technique, local anesthetic solution is injected into the pleural space between the parietal and visceral pleurae in the thoracic cavity. An indwelling catheter can be placed percutaneously and secured between the visceral and parietal pleural and injected with local anesthetic solution as needed for analgesia, or a single dose can be delivered with a needle or cannula. Once it is in the pleural space, the local anesthetic will be distributed with the normal movement of the lungs that occurs with ventilation and patient movement. Based on the effects of gravity, it will typically pool in a dependent location in the interpleural space so the anesthetist needs to take this consideration into account when managing the patient's body position following administration of the local anesthetic (Figure 12.14). If not taken into account, the

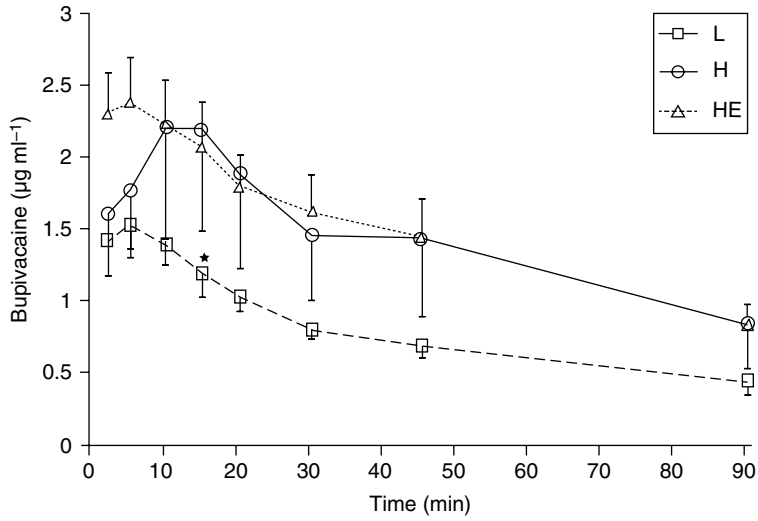


Figure 12.14 Arterial bupivacaine concentrations in halothane-anesthetized dogs after interpleural injection of bupivacaine. Values expressed as mean ± SE. n = 6, except HE at 90 minutes (n = 5). *Significantly different from H at 15 minutes. Significance set at 0.05 level by Fisher's Protected LSD. LSD = 0.95. S = saline, L = bupivacaine 1.5 mg kg^{-1}, H = bupivacaine 3.0 mg kg^{-1}, and HE = bupivacaine 3.0 mg kg^{-1} with epinephrine 5 µg mL^{-1}. From Kushner et al. 1995. Used with permission.

local anesthetic solution may be dispersed to an area of the interpleural space that is unrelated to the target nerves, resulting in failure of the analgesic technique.

When tested in a laboratory setting, this local anesthetic technique decreases the amplitude and increases the latency of evoked potentials transmitted along the affected intercostal nerves. Predictably, when larger volumes of local anesthetic are administered into the interpleural space, the resulting intercostal blockade is more widespread and is more pronounced (VadeBoncouer et al. 1990). However, the large surface area of the pleura can potentially result in rapid absorption of the administered local anesthetic solution and high plasma levels of the local anesthetic can result, potentially leading to local anesthetic systemic toxicity (Kushner et al. 1995) (Figure 12.15). In clinical practice, large volumes of local anesthetic are not necessary to produce a desired analgesic response. The toxic dose of the local anesthetic to be used should first be calculated (e.g. 4 mg kg^{-1} bupivacaine in the dog) and can be avoided before any drug is administered into the pleural space.

It was initially thought that interpleural analgesia might result from diffusion of the local anesthetic across the dorsal parietal pleura into the epidural space. However, studies have been performed in dogs and have conclusively shown that the analgesic effects of interpleurally administered local anesthetics are not the result of central or spinal blockade (VadeBoncouer et al. 1990). When administered into the pleural space, bupivacaine does not produce neural blockade of spinal cord structures and normal spinal cord action potentials are maintained following local anesthetic administration by this route. Blockade of the thoracic spinal cord does not occur and should not be a concern for the anesthetist who plans to use this technique.

As bupivacaine is readily available to veterinarians and has the longest duration of action, it has been the most frequently studied local anesthetic used for interpleural administration (Thompson and Johnson 1991; Conzemius et al. 1994). Bupivacaine administered by this route as a single injection has been shown to provide measureable analgesia for up to 24 hours. When compared with the use of systemically administered opioids for providing analgesia to patients following thoracic procedures, interpleural bupivacaine has been shown to provide better pain relief with minimal side effects. In one study that evaluated the use of 1.5 mg kg^{-1} bupivacaine administered

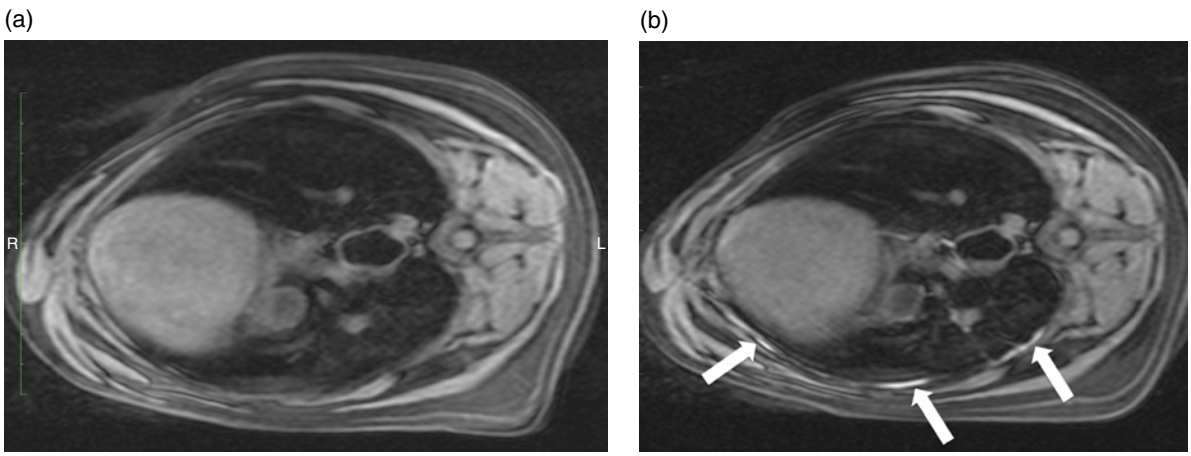


Figure 12.15 (a) Axial magnetic resonance image (MRI) image of a dog's thorax in right lateral recumbency. (b) Axial magnetic resonance image (MRI) image of the same dog in right lateral recumbency following interpleural administration of contrast solution. An interpleural injection of lidocaine and gadolinium (gadobutrol 1.0 mmol L^{-1} at 100:1 dilution) into the right pleural space has been performed. Following administration of the solution, the dog was placed into right lateral recumbency for 10 minutes prior to imaging. The injected solution can be seen spreading along the dependent areas of the pleural space (white arrows).

interpleurally to dogs following intercostal thoracotomy, postoperative blood gas evaluations were superior in dogs treated with interpleural bupivacaine (Thompson and Johnson 1991). These dogs had minor decreases in PaO_2 (that were not considered to be clinically significant) and no significant changes in pH, $PaCO_2$, or BE. Overall, fewer blood gas alterations occurred in the interpleural bupivacaine group than in the systemic morphine group. In terms of analgesic efficacy, the interpleural bupivacaine was found to be comparable to systemically administered morphine or selective intercostal nerve blocks; however, a major benefit of interpleural administration was the relative ease of providing repeated dosing to awake patients through the indwelling interpleural catheter.

Studies of interpleural bupivacaine in human patients echo the efficacy that has been documented in these veterinary studies. Intermittent and continuous administrations of interpleural bupivacaine were compared with the sole administration of fentanyl on a patient-controlled pump (Demmy et al. 2009). Several patients in a fentanyl-only group reported inadequate pain control and the overall fentanyl consumption was significantly greater in this group as compared with those treated with interpleural bupivacaine. Another study of human patients compared several interpleural treatments with a fentanyl-only group and the results showed significantly greater fentanyl consumption in the fentanyl-only group (Karakaya et al. 2004). Interestingly, patients in the interpleural saline group experienced some degree of analgesia as well. The authors hypothesized that the infused injectate could have reduced rubbing between visceral and parietal pleura, resulting in reduced pain during patient movement.

When compared with systemic opioids, interpleural local anesthesia has several documented benefits. In a study of 26 clinical canine patients that were presented for intercostal thoracotomy, $1.5\,mg\,kg^{-1}$ interpleural bupivacaine was administered every four hours via an indwelling chest tube (Conzemius et al. 1994). Dogs were placed operative side down for 10 minutes after the bupivacaine was administered. Another group of dogs received buprenorphine administered IV every six hours. Dogs that received the interpleural bupivacaine had no postoperative increases in heart rate and respiratory rate, and had lower pain scores at each time point up to 24 hours. They also had higher PaO_2 and SaO_2 up to six hours postoperatively but there were no differences in pH or $PaCO_2$ between groups. The authors concluded that both analgesic methods provided effective pain relief, but that dogs receiving interpleural bupivacaine were consistently less painful and this technique was superior for its effects on maintaining normal respiratory function.

A study in pigs showed only slight changes in blood pressure and systemic vascular resistance following interpleural administration of $2\,mg\,kg^{-1}$ bupivacaine with epinephrine (Stromskag et al. 1990). Two studies have evaluated the cardiovascular effects and safety of interpleurally administered bupivacaine in dogs. Kushner et al. (1995) investigated two doses ($1.5\,mg\,kg^{-1}$ and $3\,mg\,kg^{-1}$) of bupivacaine, with and without epinephrine, using saline as a control. Dogs were maintained in dorsal recumbency during their study. No differences in $ETCO_2$, PaO_2, or pH were detected between groups, and mean values for cardiovascular parameters were maintained within clinically acceptable ranges in all dogs in the low dose group. However, two of the six dogs in the high dose bupivacaine group ($3\,mg\,kg^{-1}$) developed clinically significant hypotension following treatment. One of these dogs had respiratory arrest that necessitated positive-pressure ventilation. No arrhythmias or signs of local anesthetic systemic toxicity occurred in any of the dogs. As one might anticipate, the measured plasma levels of bupivacaine were lower in the $1.5\,mg\,kg^{-1}$ group than in the $3\,mg\,kg^{-1}$ group, but all plasma levels were below reported toxic levels in all of the dogs in this particular study (Figure 12.15). The authors concluded that $1.5\,mg\,kg^{-1}$ bupivacaine could be safely administered interpleurally and would not be expected to produce undesirable hemodynamic effects in dogs.

In 2006, Bernard et al. reported the results of a study that investigated the cardiovascular effects of interpleural bupivacaine ($1.5\,mg\,kg^{-1}$) combined with lidocaine ($1.5\,mg\,kg^{-1}$) administered to patients with or without an open

pericardium. They found that cardiac rhythm and cardiac output were unaffected by local anesthetic treatment, and that cardiovascular effects were similar regardless of whether drugs were administered interpleurally or directly into the pericardial space under direct visualization during thoracotomy. This also suggests that interpleural injection is safe in postoperative pericardectomy patients.

Two studies have investigated the effects of interpleural bupivacaine on respiratory mechanics and blood gases in healthy dogs following intercostal and median sternotomy thoracotomy (Stobie et al. 1995; Dhokarikar et al. 1996). In both studies, the local anesthetic technique ($1.5\,mg\,kg^{-1}$ 0.5% bupivacaine) was compared with either systemically administered morphine ($1.0\,mg\,kg^{-1}$ IM) or interpleurally administered morphine ($1.0\,mg\,kg^{-1}$ diluted in 20 mL saline). Significant changes in pulmonary function were observed in all dogs following their lateral thoracotomy procedures. All dogs had some degree of hypoventilation, respiratory acidosis and elevations in their alveolar:arterial (A-a) oxygen gradients following discontinuation of anesthesia. These alterations reflect the changes that are associated with atelectasis, decreased functional residual capacity, accumulation of airway secretions, and collapse/closure of small airways that occur with general anesthesia and thoracotomy, even in otherwise healthy research dogs. The authors concluded that more profound changes might occur in patients with underlying clinical disease or in those patients undergoing actual cardiac or pulmonary procedures. However, despite the generalized changes that occurred in all of their study dogs, PaO_2 levels were highest in dogs in the interpleural bupivacaine group (Stobie et al. 1995). The interpleural bupivacaine dogs also showed evidence of improved analgesia when compared with the systemic morphine group, as they had a longer inspiratory phase in their respiratory cycle, an earlier return to their preoperative inspiratory patterns, and an earlier return to baseline work-of-breathing measurements. The interpleural bupivacaine dogs were subjectively more comfortable, had more quiet recoveries, and were more alert than the morphine-treated dogs. In addition to providing better analgesia, the interpleural bupivacaine also had a longer duration of effect after a single injection and was still effective 12 hours after surgery, long after the systemically administered morphine levels were undetectable (after six hours). The authors concluded that although all three techniques provided adequate pain relief in the early postoperative period, the interpleural bupivacaine had a longer duration of action, was associated with fewer blood gas alterations, and resulted in an earlier return to normal pulmonary function in dogs following intercostal thoracotomy. The interpleural administration of morphine did not appear to offer any benefits beyond that of systemic administration and no real benefit for interpleural morphine could be found through this study.

In their median sternotomy study, the investigators found fewer differences between the different experimental treatment groups (Dhokarikar et al. 1996). The treatments of IM morphine, interpleural morphine, or interpleural bupivacaine all resulted in similar effects on pulmonary function, blood gases, and pain. They suggest that median sternotomy may be a more painful procedure and that their doses of interpleural local anesthetic ($1.5\,mg\,kg^{-1}$ 0.5% bupivacaine) may have been inadequate for the procedure. In addition, the bupivacaine was administered through a chest tube in the left hemithorax, and the dogs were initially positioned in dorsal recumbency after administration, so the study does not reflect the technique that many veterinarians currently employ in a clinical setting whereby the patient is immediately placed in sternal recumbency to pool the local anesthetic along the incision. Although the beneficial effects of using interpleural local anesthesia in this particular median sternotomy study were not as conclusive as the authors hoped they would be, interpleural bupivacaine remains an important option for providing analgesia to patients in a clinical setting following median sternotomy.

Indications

At currently recommended doses of bupivacaine ($1.5\,mg\,kg^{-1}$), interpleural regional analgesia is a

relatively safe and highly effective method of providing thoracic pain relief to patients and should be high on the list for any practitioner dealing with these types of patients. Advantages over intercostal nerve block techniques include ease of administration, the ability to redose easily, and the ability to provide analgesia following median sternotomy. Despite affecting sites of major innervation to the respiratory system such as intercostal nerves, phrenic nerve, and diaphragm, both interpleural and intercostal techniques have minimal detrimental effects on ventilation or cardiovascular parameters (Berg and Orton 1986; Flecknell et al. 1991; Thompson and Johnson 1991; Conzemius et al. 1994; Stobie et al. 1995; Dhokarikar et al. 1996; Detterbeck 2005; Bernard et al. 2006).

A local anesthetic will be less effective for analgesia if a pleural effusion dilutes it or the drug becomes bound to proteins in the effusion. For these reasons, it is important to aspirate effusions from the thoracic cavity prior to local anesthetic injection if an indwelling chest tube is in use. Flushing the chest tube or interpleural catheter with saline should be limited so as to not further dilute the local anesthetic in the interpleural space. Interpleural local anesthesia is typically not recommended if the patient is producing a pleural effusion greater than 1–2 mL kg^{-1} day^{-1}. Alternative analgesia is required in these patients, such as intercostal blocks, epidural morphine, or use of systemically administered analgesics.

Local anesthetics used

The long-acting local anesthetic bupivacaine is most commonly used for interpleural anesthesia in dogs and cats, and is the most studied local anesthetic for use with these techniques. Other local anesthetics (lidocaine, mepivacaine, ropivacaine) can also be used to provide anesthesia of varying duration of effect depending on the drug used. Bupivacaine is typically recommended to be used at a total dose of 1.5–2 mg kg^{-1}, and can be administered into the interpleural space every 8–12 hours.

Distribution of local anesthesia and analgesia

Multiple studies in dogs have shown that interpleurally administered local anesthetics have their mechanism of action from gravity-dependent, multidermatomal blockade of intercostal nerves. When the local anesthetic pools in the dependent parts of the pleural space, it diffuses across the parietal pleura to block the underlying intercostal nerves that course through the area. Human cadavers injected with dye in the interpleural space and left in the supine position for 30 minutes revealed diffuse staining of the chest walls, lung, diaphragm (with a tendency towards pooling in the most dependent area), and the paravertebral region (McKenzie and Mathe 1996). Although the injectate is widely distributed within the thoracic cavity, the distribution of the nerve blockade corresponds largely to the lowermost part of pleural space where pooling of the local anesthetic solution occurs (Riegler et al. 1989; VadeBoncouer et al. 1990). This highlights the need for appropriate patient positioning following injection of the local anesthetic (Figure 12.14).

As explained above, distribution of interpleural bupivacaine nerve block is gravity-dependent. Positioning of the patient following interpleural administration of a local anesthetic during recovery is very important, especially if a catheter is being used. The patient should be positioned in lateral (operative side down) or dorsal recumbency to allow the local anesthetic to pool near the intercostal incision and its associated intercostal nerves. Following median sternotomy, patients should be positioned in sternal recumbency. As the analgesic effect of interpleural local anesthesia is created by movement and pooling of the local anesthetic rather than individual blockade of distinct nerves, nerve block created by interpleural bupivacaine has been shown to be more widespread than the blockade produced by selective intercostal nerve blocks (Thompson and Johnson 1991). Many people believe that interpleural local anesthesia is easier to perform than intercostal nerve blockade and, as there is no risk of inadvertently "missing" a nerve in the operative field, use interpleural local anesthesia as their preferred method of analgesia

for thoracotomy and other painful procedures involving the thorax.

Equipment

- Clippers;
- sterile gloves;
- over-the-needle catheter (14–20G, 2 inch) or other indwelling catheter or chest tube;
- syringe for local anesthetic;
- bupivacaine (0.25–0.5%); and
- solutions for aseptic preparation of skin.

Interpleural analgesia (single injection) – standard technique

- The patient is placed in lateral recumbency. The patient can be awake, sedated, or anesthetized (Figure 12.4).
- A volume of 0.5% bupivacaine should be drawn into a syringe at a calculated dose of 1.5 mg kg^{-1} based on the patient's lean/ideal body weight.
- Initially without using sterile technique, the anesthetist should palpate the lateral thorax to identify the seventh through tenth intercostal spaces.
- Once these spaces are identified, the lateral thorax is clipped between the sixth and tenth intercostal spaces and the skin is aseptically prepared.
- The anesthetist puts on a pair of sterile gloves and uses an over-the-needle catheter (or other appropriate needle or cannula) to perform the block (Figure 12.16a). A syringe with 2–3 mL of saline is attached to the hub of the needle stylet. The needle is initially advanced onto the lateral aspect of the seventh or eighth rib at its midpoint. It is then gently "walked off" the cranial border of the rib until it can be advanced through the intercostal muscles between the ribs. Walking it off the cranial border minimizes the risk of advancing the catheter through the region immediately caudal to the rib that contains the intercostal nerve, artery, and vein, and reduces the chance of damaging these important structures.
- After slowly advancing the needle and catheter through the intercostal space, the pleura will be penetrated (often with a palpable "pop"). The catheter is then gently advanced off the needle stylet into the interpleural space. The catheter is softer than a needle and carries less risk of causing trauma to the underlying lung (Figure 12.16b).
- The needle stylet should be withdrawn from the catheter, and the saline-filled syringe attached to the catheter hub. If the catheter is correctly located in the interpleural space, the column of saline in the syringe will slowly decrease in volume as it is aspirated by the negative interpleural pressure (Figure 12.16c).
- After confirming that the catheter is positioned in the interpleural space, the saline syringe is disconnected from the catheter and the preloaded syringe with local anesthetic is attached.
- This syringe is first aspirated and evaluated for presence of blood to ensure that the needle tip is not placed intravascularly.
- The calculated volume of local anesthetic (1.5 mg kg^{-1} of 0.25–0.5% bupivacaine) is then slowly (over 1–2 minutes) injected through the catheter into the pleural space (Figure 12.16d).
- Following injection of the local anesthetic, the catheter is withdrawn and the patient is positioned such that the operative side is down, allowing the local anesthetic to pool and block the underlying intercostal nerves. Depending on the local anesthetic used, the patient should be maintained in this recumbency for at least 10 (lidocaine) to 20 minutes (bupivacaine) for the full analgesic effect of the drug to be appreciated.
- For 10–15 minutes following administration of the local anesthetic into the pleural space, the patient should be closely monitored for possible complications resulting from systemic absorption of the drug itself or from an error in performing the technique.

Alternatively, an indwelling catheter or chest tube can be placed into the pleural space at the completion of surgery. In this instance, it should be well secured to the patient to prevent inadvertent dislocation as the patient recovers from

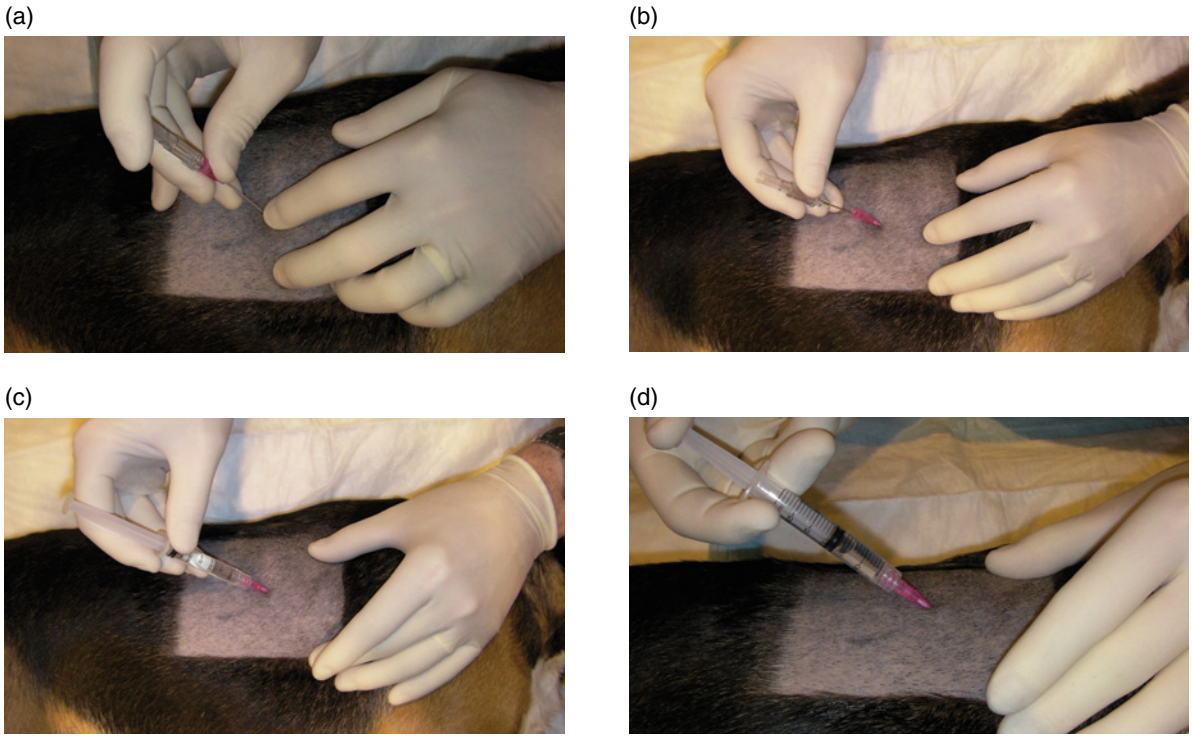


Figure 12.16 (a) Photograph of interpleural blockade using an over-the-needle catheter in a dog. A 20-gauge catheter is being used to perform the block. Initially, the needle stylet/catheter is advanced slowly through the skin until it contacts the rib. After the rib is identified, the unit is "walked off" the cranial aspect of the rib and slowly advanced through the intercostal muscles and parietal pleura into the pleural space. (b) Once the needle enters the pleural space, the catheter is advanced off the needle stylet into the pleural space between the lung and the chest wall. (c) The needle stylet is removed from the catheter and a syringe is attached. Without applying manual pressure to the plunger, a small amount of fluid may be aspirated into the pleural space due to negative pressure, confirming proper placement of the catheter. (d) Once correct placement of the catheter is confirmed, the local anesthetic solution is slowly injected into the pleural space. Following administration of the solution, the patient should be placed into a position that will allow the local anesthetic to "pool" in the area of the target nerves.

anesthesia. Using an indwelling catheter or chest tube offers the additional benefit of being able to provide additional doses of local anesthetic over an extended period of several days as necessary (Figure 12.17).

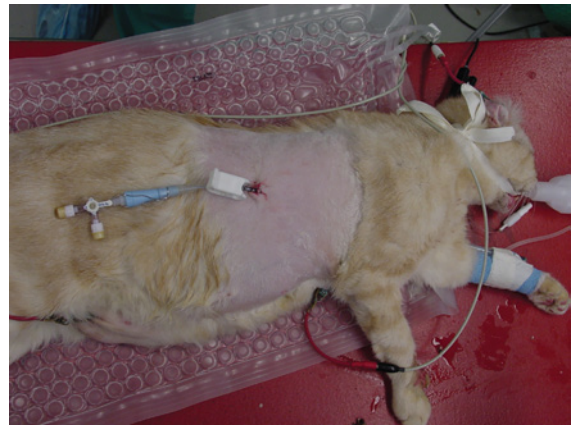


Figure 12.17 Photograph of a cat with an indwelling chest tube in place. Photograph by J.A. Flanders.

Potential complications

Pneumothorax

In people, the most common complication of interpleural injections is pneumothorax, with a reported incidence of 2% (Stromskag et al. 1990; Dravid and Paul 2007b). An insignificant pneumothorax develops in every patient as a small volume of air is initially aspirated into the pleural space due to

negative intrathoracic pressure while the interpleural catheter is placed and capped. This small volume of air will be slowly absorbed and is not considered to be of clinical significance. Lung trauma is rarely encountered unless the anesthetist is overly aggressive in placing the needle or catheter, or unless there is underlying pathology of the lung. Restricting patient movement through adequate restraint and/or sedation, and use of flexible catheters or Touhy needles rather than stiff and sharp-tipped hypodermic needles can minimize the risk of pneumothorax. Although rare, tension pneumothorax should be monitored for, and accumulated interpleural air can be aspirated through the indwelling catheter as necessary. All patients should be carefully observed following placement of an interpleural catheter both before and after drug administration.

Catheter dislocation

Catheter dislocation can occur whenever an indwelling catheter is placed at any site in the body. After correctly positioning the catheter in the pleural space, it should be secured to the patient by means of adhesive patches, tissue glue, suture, and/or bandages. Subcutaneous tunneling of interpleural catheters can been used as a further means to reduce the likelihood of dislodgment or air inadvertently entering the interpleural space around the catheter. The use of a c-clamp or other similar device may reduce the possibility of air entrainment following inadvertent dislodgment of the catheter or the chest tube end pieces.

Local anesthetic systemic toxicity

Rapid absorption of the local anesthetic from the pleural space has the potential to cause systemic toxicity that manifests as cardiovascular collapse and neurologic signs (see Chapter 4 for more information). In most cases, the dose of local anesthetic drug that is tolerated by the patient without manifesting as toxicity depends more on the rate of administration than on the total dose—even a "low" dose of local anesthetic can potentially cause clinical signs of toxicity if it is injected intravascularly or absorbed systemically too quickly. Lower doses that are infused rapidly by the intravenous route produce symptoms of toxicity at lower venous concentrations of local anesthetic than higher doses that are administered more slowly (Scott 1975). Dogs receiving a total cumulative IV dose of $5\,mg\,kg^{-1}$ bupivacaine over 90 minutes may develop seizure activity (Liu et al. 1982, 1983). Using bupivacaine at $1.5\,mg\,kg^{-1}$ interpleurally in dogs has been shown to have minimal adverse systemic effects, and should be administered slowly through a needle or catheter over 1–2 minutes to minimize the chances for complications (Kushner et al. 1995; Bernard et al. 2006). Although there are no reports of cardiac toxicity with modest doses of interpleural bupivacaine, the potential cardiotoxicity of intravenously injected bupivacaine is of important note. Patient treatment orders that call for interpleural local anesthetics should be made especially clear in order to avoid accidental intravenous administration.

Diaphragmatic paralysis

Bilateral interpleural catheters have been used in people to provide analgesia for major thoracoabdominal procedures and to improve postoperative pulmonary function. However, even though interpleural administration of local anesthetics provides excellent postoperative analgesia for surgical procedures, care should be taken as phrenic nerve paresis or paralysis can occur with interpleural blockade. The phrenic nerve lies under the thin layer of mediastinal pleura and is the only motor nerve to the diaphragm in the dog. Despite the apparently excellent safety profile of this block, the close proximity to important neural structures such as the phrenic nerve, recurrent laryngeal nerve, and sympathetic trunk demands that the practitioner consider the patient's underlying condition, and carefully plan and execute the analgesic technique.

In a study that used electromyography to evaluate diaphragmatic function following approximately $1.5\,mg\,kg^{-1}$ interpleural bupivacaine boluses, seven out of nine dogs experienced some degree of loss of diaphragmatic function on the side of the injection (Kowalski et al. 1992). In that study, no attempt was made to direct the drug near the phrenic nerves. Dogs that received bilateral blockade demonstrated paradoxical respirations and generated negative intraabdominal pressures on inspiration, indicating loss of diaphragmatic function. Factors that would explain the

predisposition to diaphragmatic dysfunction in only some of the dogs could not be established. The authors concluded that animals with underlying phrenic nerve and diaphragmatic dysfunction might be especially susceptible to the respiratory complications of interpleural local anesthesia. For these reasons, veterinary patients with underlying diseases that result in an increased risk of cardiovascular and respiratory complications may be better treated with alternative methods of pain relief such as intercostal blocks or systemic opioids.

Pain on injection

Local anesthetics are commercially available as water-soluble salts, usually as hydrochlorides. This acidity increases the stability of the solution in terms of shelf life, but decreases the pH to less than 6.5. Awake or lightly sedated patients may show initial signs of discomfort when the local anesthetic is initially injected into the pleural space and, although this pain is short-lived, can be disconcerting to those who observe it (Thompson and Johnson 1991; Conzemius et al. 1994).

Other complications

Other reported but rare complications related to interpleural blockade with local anesthetics include Horner's syndrome, infection, pleural effusion, and catheter problems such as coiling, kinking, or rupture (Stromskag et al. 1990; Thompson and Johnson 1991; Bernard et al. 2006).

New techniques from human medicine

Thoracic paravertebral blockade

A paravertebral nerve block involves conduction block of the spinal nerve within the paravertebral space. It was first described in human patients in 1905 as a method to provide abdominal analgesia (Karmakar 2001). Dense sensory, motor, and sympathetic block can be achieved from injection of local anesthetic at this location. In human anesthesia, thoracic paravertebral blockade following single-shot or continuous infusion of local anesthetics is gaining popularity and is now widely used in adults, children, and neonates for surgical analgesia.

Thoracic paravertebral blocks are used to provide analgesia for procedures of the chest and upper abdomen, and have been widely used and reported for a number of surgical procedures either as an adjunct to, or a replacement for, general anesthesia in people. Using this technique, a local anesthetic is deposited adjacent to where the rib articulates with the vertebra at the location where a spinal nerve leaves its associated foramen (Figure 12.18). In people, there is a potential space at this location that contains the intercostal (spinal) nerve, the dorsal ramus, the rami communicantes, and the sympathetic chain. Anatomically, the intervertebral foramina, vertebral bodies and discs, pleura, transverse processes, costotransverse ligaments, and intercostal spaces border the paravertebral space. The thoracic paravertebral space is continuous with the intercostal space laterally, epidural space medially, and the contralateral paravertebral space via the perivertebral fascia (Karmakar 2001). It is important to note that as the dura mater may extend into the medial aspect of paravertebral space, there can be a connection with the epidural space and the potential for epidural spread of local anesthetic following performance of this block. As a result, patients need to be monitored closely after the block is administered, similar to when a thoracic epidural has been used (Norum and Breivik 2011). A study of thoracic paravertebral injection in human cadavers found a 40% incidence of epidural spread, all confined to one vertebral segment (Cowie et al. 2010).

Placement of local anesthetic within the thoracic paravertebral space produces unilateral somatic and sympathetic block suitable for procedures of the lateral chest and abdomen (Davies et al. 2006). Bilateral thoracic paravertebral blockade can also be used for midline and bilateral procedures. Theoretically, use of bilateral blocks carries a greater risk of hypotension due to sympathetic blockade, a greater potential for local anesthetic toxicity due to the larger volume of drug solution required, and a higher potential for pneumothorax due to an increased number of injections. However, a review of studies in people that utilized bilateral thoracic paravertebral blockade found overall complication rates to be low and of acceptable risk, and the authors advocated the use of bilateral paravertebral blocks in appropriate cases (Richardson et al. 2011).

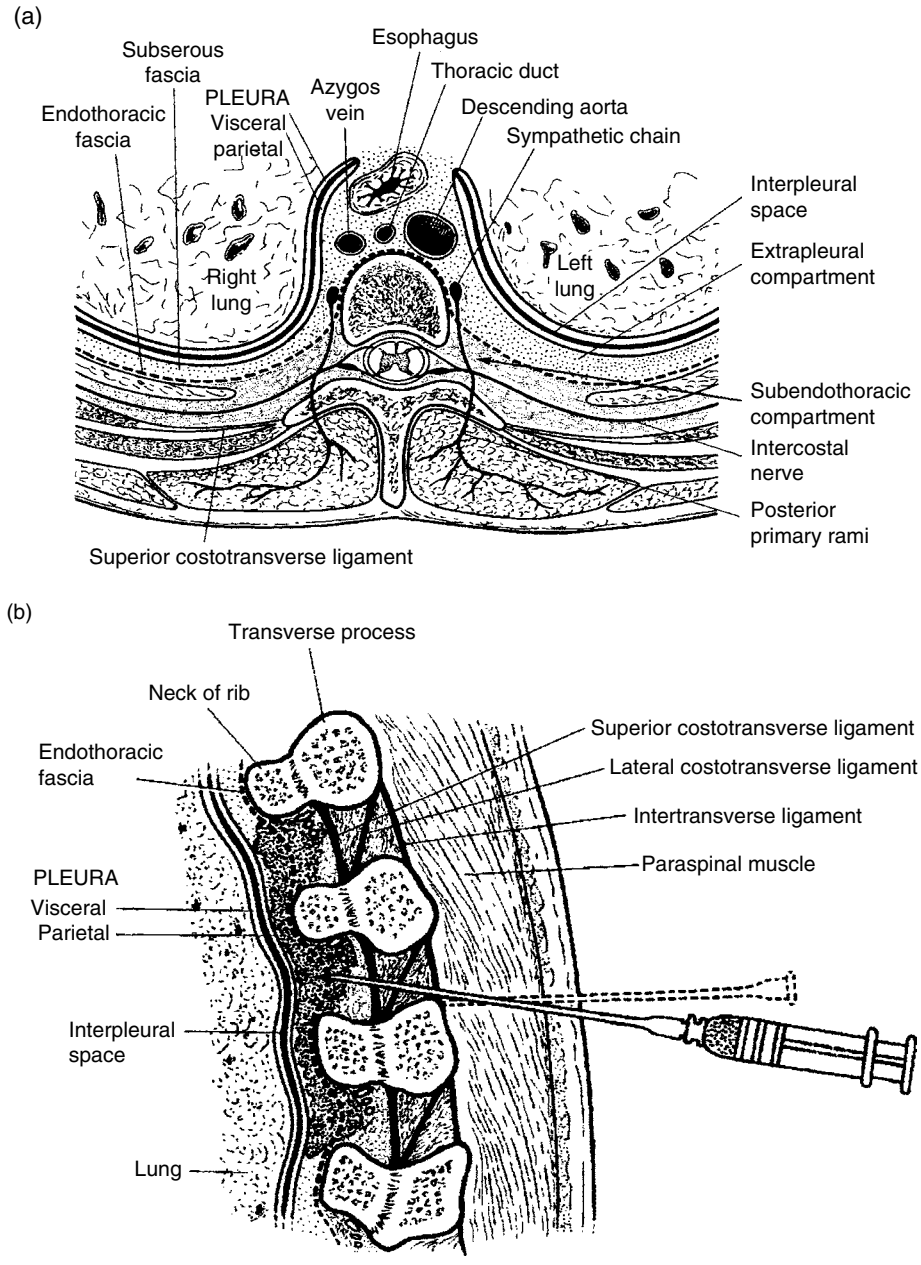


Figure 12.18 (a) Anatomy of the thoracic paravertebral space in people. (b) Sagittal section through the thoracic paravertebral space in people, showing a needle that has been advanced above the transverse process. From Karmakar 2001. Used with permission.

In general, three techniques for performing the block in human medicine are described: the loss-of-resistance technique, the predetermined distance technique, and ultrasound-guided injection (Hadzic 2007). Using blind techniques, it has been reported that the thoracic paravertebral space can be appreciated with a palpable "click" when the superior costotransverse ligament is traversed

following posterior approach by a blunt needle, and local anesthetic drug can be injected with minimal uncertainty of location. Nerve stimulation can also be used to assist with localization of the needle tip.

Compared with thoracic epidural analgesia with local anesthetics, thoracic paravertebral blockade in people results in comparable or superior analgesia following thoracotomy, better preservation of pulmonary function and hemodynamic responses, and also has the advantage of being useful in situations where thoracic epidural may be contraindicated, such as anticoagulant therapy (Coveney et al. 1998; Richardson et al. 1999; Davies et al. 2006; Joshi et al. 2008; Scarci et al. 2010; Pintaric et al. 2011). Like epidurals, thoracic paravertebral blockade may lower a patient's opioid needs, resulting in fewer negative side effects of systemically administered opioids such as urinary retention, nausea, and vomiting. There also appears to be greater suppression of sympathetic responses to surgery when thoracic paravertebral blockade is compared with epidural anesthesia alone. Paravertebral blocks completely abolish somatosensory evoked potentials (a measure of the nervous system's response to stimuli) at the level of blockade (Richardson et al. 1998). This particular feature appears to be unique to paravertebral blocks, and is not shared with epidural blocks.

Recently, a large systematic review looked at 74 randomized studies of human thoracotomy pain that compared the use of different regional anesthetic techniques with the use of systemic opioid analgesia or with each other (Joshi et al. 2008). This review found that the most consistently effective analgesia for thoracic pain was provided by a thoracic epidural technique combining a local anesthetic with an opioid administered by continuous infusion. However, based on the analyzed evidence, thoracic paravertebral blockade with a local anesthetic that was administered as a bolus followed by a continuous infusion for two to three days was also beneficial and would be recommended. The analgesia from the paravertebral technique was found to be comparable to thoracic epidural analgesia (when a local anesthetic was used alone), but was associated with fewer side effects such as pulmonary complications, hypotension, nausea, and urinary retention. The authors also concluded that, if thoracic epidural or paravertebral analgesia were not feasible for any reason, intercostal nerve blocks would be recommended based on reduced pain and analgesic use compared with systemic opioids in most procedure-specific studies. Investigators have also shown that following elective thoracotomy, use of thoracic paravertebral blockade can be further improved by the addition of a continuous incisional block using a subcutaneous catheter that is placed into the surgical wound at the time of surgery. When this catheter is infused with local anesthetic, analgesia is improved over that obtained by use of thoracic paravertebral block alone (Garutti et al. 2009).

One study in people documented a 12% failure rate in sensory block in patients receiving a thoracic paravertebral block (Cheema et al. 2003). Unfortunately, the onset of the block was slow when 0.15–0.3 $mL\,kg^{-1}$ of 0.5% bupivacaine was used, and the block required up to 40 minutes for full effect. There was no correlation between block distribution, injectate volume, and local anesthetic mass. In addition, these authors found a high level of variability in local anesthetic spread. Although there was blockade of three to four segments following a single injection, the spread was unpredictable and varied between individual patients. They concluded that a single injection thoracic paravertebral block produces a safe but unpredictable block. This conclusion was recently echoed by a human cadaveric study, which found that the spread of injectate following thoracic paravertebral injection was highly variable and that epidural spread is possible (present in 40% of cadavers injected) and may contribute significantly to analgesia in clinical patients (Cowie et al. 2010).

Complications in people are uncommon. Failure rates range between 6.1% and 10% (Karmakar 2001; Naja and Lonnqvist 2001). Complications that have been reported include inadvertent vascular puncture (6.8%), hypotension (4%), hematoma (2.4%), pain at site of skin puncture (1.3%), signs of epidural or intrathecal spread (1%), pleural puncture (0.8%), and pneumothorax (0.5%). Rare complications include blockade of the ipsilateral brachial plexus with an associated Horner's syndrome and have been reported to be due to cranial and/or lateral spread of injectate to areas such as the stellate ganglion, preganglionic fibers, or alternate pathways such as the Kuntz nerve (Tenicela and Pollan 1990; Coveney et al. 1998; Renes et al. 2011). A single case of hemidiaphragmatic paresis has been reported following injection at the level of T2–T3 and was thought to be due to

spread of injectate to the phrenic nerve at the level of the subclavian artery and vein (Renes et al. 2011). The use of a bilateral paravertebral technique has been found to approximately double the likelihood of inadvertent vascular puncture and to cause an eight-fold increase in pleural puncture and pneumothorax when compared with unilateral blocks (Naja and Lonnqvist 2001). However, a 2011 review of the literature that evaluated bilateral paravertebral blockade found a more modest to absent increase in risk and recommended the use of bilateral blockade as an alternative to thoracic epidural for midline procedures (Richardson et al. 2011). The overall complication rates of unilateral and bilateral thoracic paravertebral blocks are low and considered acceptable. As with any regional anesthetic technique, it is important to monitor patients closely for untoward effects of the block. The incidence of potential complications following thoracic paravertebral blockade in animals is not yet reported.

Although there is a growing body of evidence to support use of thoracic paravertebral blocks in people, no studies have been published to date that investigate or report the use of this technique in animals. This technique is currently under investigation in dogs and cats and may prove to be a useful alterative to intercostal nerve blocks for providing longer-term thoracic analgesia following thoracotomy. The technique described below should serve only as a guide for performance of this block, and will undoubtedly be adjusted as the block is used and tested in research and clinical situations in animals.

Equipment

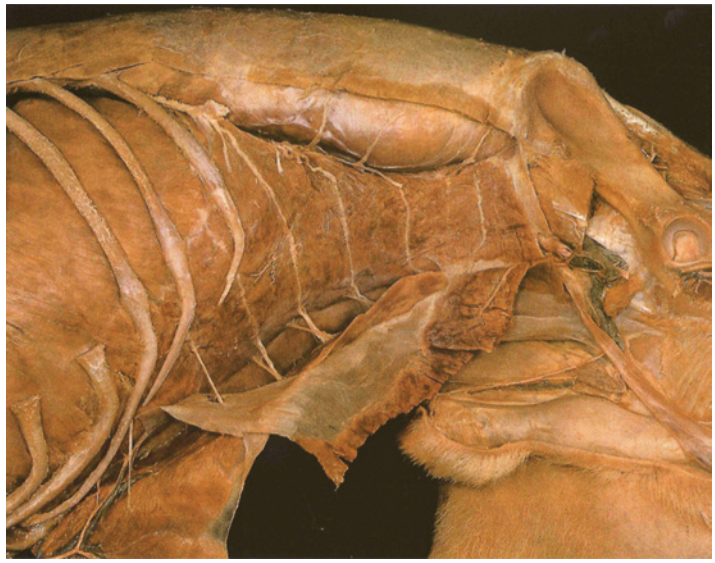
- Clippers;
- sterile gloves;
- syringe for local anesthetic;
- bupivacaine (0.25–0.5%);
- solutions for aseptic preparation of skin;
- peripheral nerve stimulator; and
- insulated Tuohy needle (100 mm 20 G).

Technique

- The patient is placed in sternal recumbency. The patient can be awake, sedated, or anesthetized.
- Clip an area over the patient's dorsal midline over the corresponding vertebra to be blocked. Clip laterally until the heads of the rib can be easily palpated.
- Palpate the major landmarks for the procedure including the relevant spinous processes of the target thoracic vertebrae, and the bodies and the dorsal angles of the corresponding ribs. The puncture site is located in a parasagittal plane relative to the patient's midline.
- Perform an aseptic preparation of the skin overlying the intended puncture sites.
- If the patient is sedated rather than anesthetized, infiltrate the skin and puncture sites with 2% lidocaine to increase patient tolerance to the procedure.
- Set the nerve stimulator to initially deliver a current of 1 mA.
- Insert the stimulating needle perpendicular to the skin in a dorsoventral direction with a slight medial-lateral orientation. If the tip of the needle contacts the vertebral transverse process, the needle should be withdrawn and redirected in a more cranial direction until adequate contraction of the corresponding intercostal muscle is detected.
- The stimulation of the ventral roots of thoracic spinal nerves elicits contraction of the corresponding intercostal muscle. Contraction of dorsally located epaxial muscles can be evoked if the dorsal roots of the thoracic spinal nerves are stimulated, and should not be confused for true intercostal muscle contractions. Contraction of the intercostal muscle may be very subtle; therefore it can be useful to palpate the corresponding intercostal muscle with the nondominant hand while manipulating the stimulating needle with the dominant hand.
- When needle location is confirmed, the calculated volume of local anesthetic (1.5 mg kg^{-1} of 0.25–0.5% bupivacaine for all of the planned sites) is then slowly injected.
- For 10–15 minutes following administration of the local anesthetic into the pleural space, the patient should be closely monitored for possible complications resulting from systemic absorption of the drug, epidural spread, or from an error in performing the technique.

An ultrasound-guided approach to thoracic paravertebral blocks was first reported in 2010 and this technique has gained in popularity (Marhofer et al. 2010; Bondar et al. 2010). Real-time ultrasound guidance offers the advantage of visualizing the boundaries of the paravertebral space. This is

(a)



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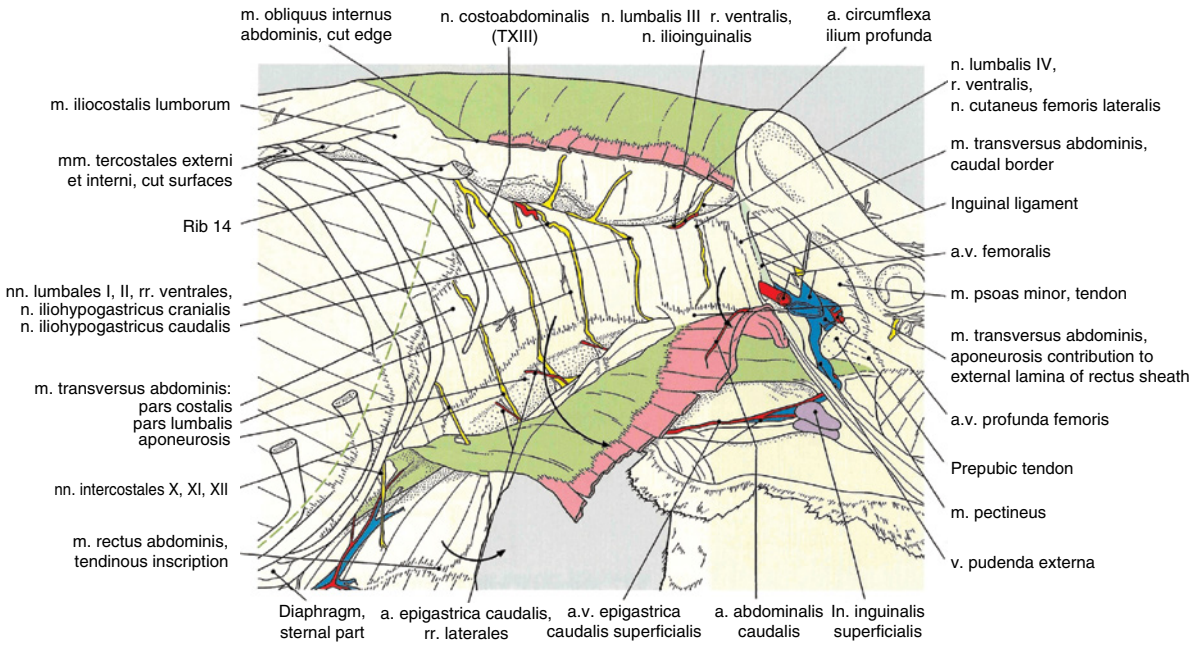


Figure 12.19 (a), (b) Transverse abdominal muscle and nerves of the abdominal wall of a dog: left lateral view. The internal oblique muscle has been cut through longitudinally close to its origin from the thoracolumbar fascia, and from its association with the inguinal ligament. The internal oblique muscle is reflected ventrally. From Done et al. 2009. Used with permission.

especially important as the pleural space can be visualized and avoided. As with all ultrasound-guided regional blocks, the injecting needle and local anesthetic spread can be visualized. Although, to date, no study has proven an improved efficacy for ultrasound-guided techniques, there is a

theoretical improvement in block speed, onset, efficacy, and safety. Due to the large degree of breed and species variability in veterinary medicine, the ultrasound-guided approach to this block holds great promise.

Transversus abdominis plane (TAP) block

The TAP block was originally described for use in people as an alternative method of providing complete sensory analgesia to the lateral and anterior abdominal wall (Rafi 2001). It was further developed and tested by McDonnell and colleagues (McDonnell et al. 2007a, b, 2008) and there are now many published studies and case reports of its use in people that show the TAP block to be an effective alternative to other techniques such as lower thoracic or lumbar epidural, with few side effects (Niraj et al. 2009b; O'Connor and Renfrew 2010). It is now one of the most rapidly expanding regional anesthetic techniques used in people, and it appears to be an important tool in postoperative pain management in human patients undergoing surgery involving the anterior abdominal wall.

Pain experienced by patients undergoing abdominal procedures frequently derives from the abdominal wall incision (McDonnell et al. 2007a, b). Anatomically, the abdominal wall consists of three muscle layers: the external abdominal oblique, the internal abdominal oblique, and the transversus abdominis, as well as their associated fascial sheaths. The segmental ventral branches of the lower thoracic and upper lumbar nerves innervate the skin, muscles, and parietal peritoneum of the ventral abdominal wall. These branches leave their respective intervertebral foramina and course over the vertebral transverse process before piercing the musculature of the lateral abdominal wall to run ventrally through the fascial plane between the internal oblique and transversus abdominis muscles (Figure 12.19). Cadaveric studies in people have shown there to be extensive branching and communication of nerves within the fascial plane (Rozen et al. 2008). The TAP block involves deposition of local anesthetic using either single-shot needle placement or continuous infiltration via catheter placement into the neurofascial plane with local anesthetic, effectively blocking the nerves that supply the anterior abdominal wall that exist within this potential space (Figures 12.20 and 12.21).

The block needs to be performed bilaterally if it is to be effective for providing analgesia across the patient's midline. Two different approaches have been described in the literature depending on the region of interest: the original posterior approach is performed immediately superior to the iliac crest (at the lumbar "triangle of Petit") and is effective for procedures below the umbilicus, whereas the new anterior subcostal approach is effective for procedures above the umbilicus (Barrington et al. 2009; Jankovic et al. 2009) (Figure 12.22). A contrast-based study on injectate spread suggests that the method of injection significantly impacts the pattern of spread and the area of blockade (Carney et al. 2011).

In people, the TAP block has been used to provide dermatomal sensory block of the lower thoracic and upper lumbar abdominal afferent nerves for a variety of abdominal procedures. By 2010, seven randomized, double-blinded clinical trials that investigated the effects of a TAP block on postoperative pain had been reported (McDonnell et al. 2007a; Carney et al. 2008; McDonnell et al. 2008; El-Dawlatly et al. 2009; Niraj et al. 2009c; Belavy et al. 2009; Costello et al. 2009). These studies included a total of 364 patients. The procedures included bowel resection via midline abdominal incision (McDonnell et al. 2007a), Cesarean delivery (McDonnell et al. 2008; Belavy et al. 2009; Costello et al. 2009), abdominal hysterectomy via transverse abdominal incision (Carney et al. 2008), open appendectomy (Niraj et al. 2009a), and laparoscopic cholocystectomy with all four ports below the umbilicus (El-Dawlatly et al. 2009).

In four studies the patients received a general anesthetic in addition to the block (McDonnell et al. 2007a; Carney et al. 2008; El-Dawlatly et al. 2009; Niraj et al. 2009c), whereas patients in the other studies received co-administered spinal anesthesia but no general anesthetic (McDonnell et al. 2008; Costello et al. 2009). In three studies the TAP block was performed bilaterally after induction of anesthesia using the blind technique via the triangle of Petit (McDonnell et al. 2007a; Carney et al. 2008; McDonnell et al. 2008), whereas in the remaining studies an ultrasound-guided TAP block was performed (El-Dawlatly et al. 2009; Niraj et al. 2009c; Belavy et al. 2009; Costello et al. 2009). Local

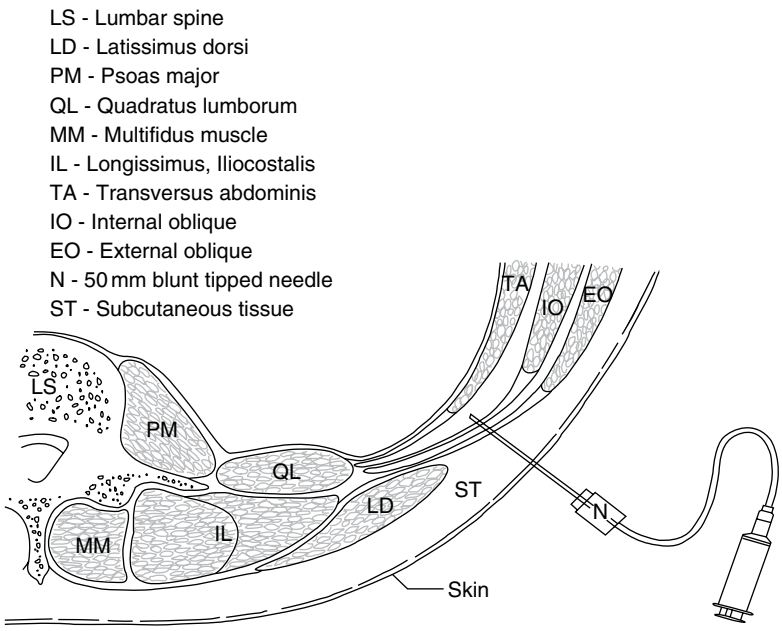


Figure 12.20 Line drawing of a transverse section through the abdominal wall at the level of the lumbar triangle of Petit (TOP) in people. The floor of the triangle is composed, from superficial to deep, of the fascial extensions of external oblique, internal oblique, and transversus abdominis, respectively, and the peritoneum. The needle is inserted through the triangle, using the loss-of-resistance technique. The needle is shown in the transversus abdominis plane, and the fascial layers have separated as a result of the injection of local anesthetic. From McDonnell et al. 2008. Used with permission.

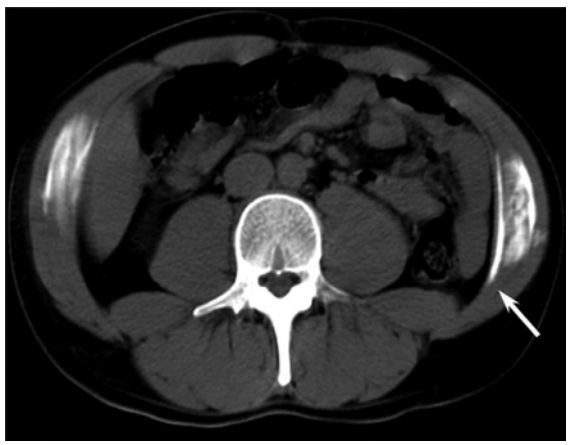


Figure 12.21 Computed tomographic image of the abdominal wall in a person, 20 minutes after the injection of iopamidol contrast. The arrow on the right demonstrates contrast enhancement (high signal) between the internal oblique and transversus abdominis muscles. The contrast is less discrete on the left, as some contrast had penetrated through the more superficial plane between the external and internal oblique muscles along the needle path at the time of injection. From McDonnell et al. 2007b. Used with permission.

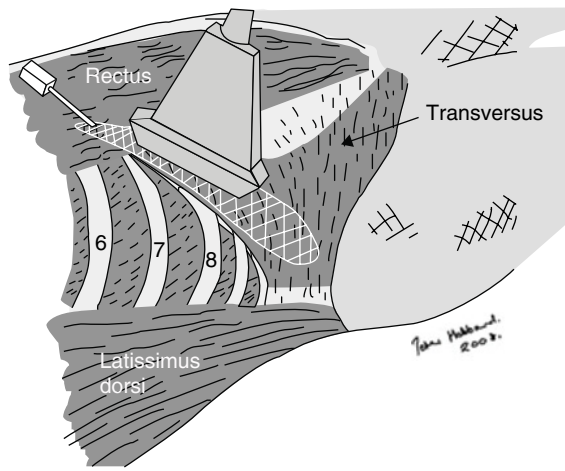


Figure 12.22 Diagram of a transversus abdominis plane (TAP) block being performed in a person. The probe is positioned on the anterior abdominal wall immediately inferior to the costal margin with needle-probe orientation shown. The hatched area under the probe indicates the anticipated spread of injectate following this technique. From Barrington et al. 2009. Used with permission.

anesthetics used included levobupivacaine, bupivacaine, or ropivacaine. In four studies, saline was injected as a placebo in the control group (Carney et al. 2008; McDonnell et al. 2008; Belavy et al. 2009; Costello et al. 2009), whereas in the other three studies no placebo infiltration was performed.

In all but one study, the initial 24-hour postoperative morphine consumption by the patients was significantly reduced in those people receiving a TAP block. In the one study that did not demonstrate a significant effect on postoperative opioid requirements, spinal morphine was administered as part of the multimodal approach to analgesia in all of the patients (including the control group) (Costello et al. 2009). As a result, pain scores were low in all patients so it was difficult to statistically demonstrate analgesic improvement from the TAP block.

A number of published studies have demonstrated the efficacy of this block in human medicine. A 2011 meta-analysis compared a number of randomized controlled trials that assessed use of the TAP block for provision of analgesia for a variety of abdominal procedures. In groups that received the block, a reduction was observed in overall opioid consumption, and an increase was observed in periods of time until patients requested additional analgesia (Siddiqui et al. 2011). A different review of numerous trials found reduced pain scores in four out of six studies and a decrease in morphine consumption in six out of seven studies (Peterson et al. 2010). Placement of indwelling catheters into the TAP neurofascial space has recently been reported, and can be used to provide prolonged analgesia to patients over three to four days (Gucev et al. 2008; Niraj et al. 2009a; Heil et al. 2010).

Overall, in the studies involving bowel surgery, appendectomy, and hysterectomy, pain scores at rest and during mobilization were significantly reduced in patients receiving a TAP block in the early postoperative period (zero to six hours), and continued for up to 24 hours. Patients suffered less postoperative nausea and vomiting (PONV), and sedation was lower in the TAP patients (Peterson et al. 2010). However, a review of the TAP literature suggests that overall evidence for reduced PONV and sedation in patients following this block is weak.

Important information such as the analgesic duration following single-shot and continuous techniques, and the optimal procedure-specific volumes and concentrations of local anesthetics remains to be established. A study of the pharmacokinetics of ropivacaine following TAP block revealed a significantly higher concentration in abdominal injection sites as compared with serum (Latzke et al. 2011). Although the local levels were highly variable, this suggests a topical mode of action rather than a systemic effect. A preliminary study that investigated the use of lidocaine for bilateral TAP blocks showed serum concentrations within or just above the therapeutic range for the anti-arrhythmic effects of lidocaine in people (Kato et al. 2009). Whether or not there is also a systemic component to the analgesia observed in patients receiving TAP blocks in addition to the local analgesic effects of the local anesthetics administered into the neurofascial sheath is not currently known. However, a systemic component to the analgesic effect is speculated based on the efficacy of the block with obstetric and gynecologic procedures such as Cesarean section and hysterectomy. Both of these surgical procedures have a significant component of visceral pain in addition to abdominal wall pain; a block solely providing coverage to the abdominal wall would not be expected to have a significant analgesic effect (Peterson et al. 2010).

Use in animals

Due to the variability in body wall thickness of the different dog and cat breeds, the blind technique of performing the TAP block in small animals is not recommended at this time. The ultrasound-guided technique allows for direct visualization of the different layers of the body wall, increasing the chances of block success while decreasing chances of peritoneal puncture (Figure 12.23). There is a single report of using a TAP block for provision of analgesia in a live animal. In that case report, the authors administered a TAP block using bupivacaine to a Canadian lynx for additional analgesia to facilitate an exploratory laparotomy (Schroeder et al. 2010). The authors confirmed correct placement of the local anesthetic between the relevant fascial planes using ultrasound visualization. They reported that the

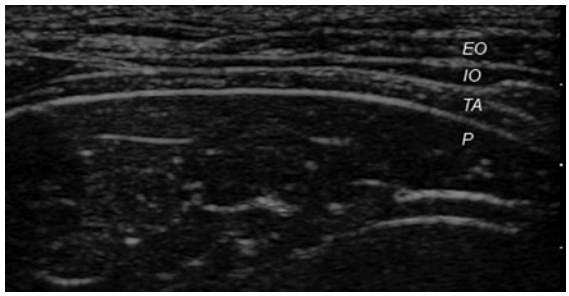
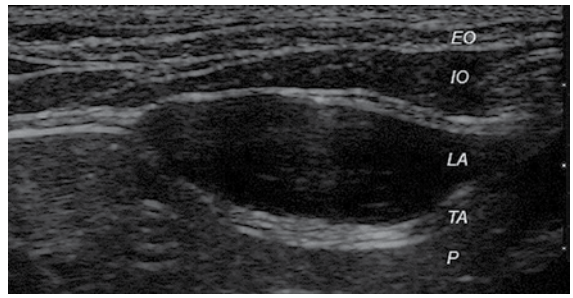


Figure 12.23 Ultrasonographic image obtained in a live dog demonstrating layers of abdominal wall. Small dots on the right of image indicate 1 cm depth markers. EO, external abdominal oblique; IO, internal abdominal oblique; TA, transversus abdominis; P, peritoneal cavity. From Schroeder et al. 2011. Used with permission.

feline had minimal responses to surgical stimulation, and recovered smoothly following the procedure with perceived analgesia of eight to ten hours duration. Although this report represents the experience of using a TAP block in only a single patient, it does lend support for further research to be completed to assess the utility of using this technique in animals.

Since the initial case report in a lynx, two cadaveric studies of the block using medium-sized dogs suggest the significant utility of this block. Following injection under ultrasound-guidance, the spread of injectate in the canine cadavers was largely comparable to that of human cadavers (Tran et al. 2009; Schroeder et al. 2011; Bruggink et al. 2011) (Figure 12.24). As adequate coverage of the ventral nerve roots of T12–L2 was demonstrated following injection, one would expect this block to provide adequate coverage for most canine abdominal wall procedures. Randomized controlled trials in dogs as well as other species need to be undertaken before further conclusions can be drawn.

(a)



(b)

Figure 12.24 (a) Ultrasonographic image obtained in a live patient post-injection of local anesthetic solution (5 mL of 0.125% bupivacaine) into the fascial plane overlying the transversus abdominis. Small dots on right of image indicate 1 cm depth markers. EO, external abdominal oblique; IO, internal abdominal oblique; LA, local anesthetic; TA, transversus abdominis; P, peritoneal cavity. (b) Dissection of the lateral abdominal wall showing T12–L3 spread of methylene blue solution following ultrasound-guided TAP block in a cadaver. From Schroeder et al. 2011. Used with permission.

Equipment

- Ultrasound machine with 13–6 MHz linear array probe;
- clippers;
- skin preparation solution;
- sterile gloves;
- syringe for local anesthetic;
- extension set;
- 20 G Tuohy or spinal needle; and
- bupivacaine (0.5%) diluted accordingly to a final volume of 2 mL kg^{-1}.

Ultrasound-guided technique

- The patient is placed in lateral recumbency with the side to be blocked uppermost.

- Clip a generous amount of the lateral body wall to allow for adequate visualization with the ultrasound probe. The area of interest is found midway between the caudal aspect of the last rib and iliac crest, at the level of the patient's axilla.
- The skin overlying the anticipated puncture site is aseptically prepared for needle insertion.
- To allow for greater flexibility of movement during performance of the block, the needle should be attached to the syringe via an extension set.
- Using a 13–6 MHz linear array probe in a transverse orientation, the lateral body wall (approximately 3–7 cm dorsal to the patient's ventral midline depending on patient size) midway between the caudal aspect of the last rib and the iliac crest is imaged. A clear image of the three muscle layers of the abdominal wall should be obtained prior to needle insertion (Figure 12.23).
- Using an in-plane needling approach (to allow for real-time visualization of the needle's position), the needle is advanced through the external and internal abdominal oblique muscles and into the fascial plane overlying the transversus abdominis muscle.
- The syringe should be used to aspirate for blood. Following negative aspiration, a small (0.5–1 mL) test dose of the local anesthetic is injected into the potential space between the transversus abdominis and the internal abdominal oblique muscles. The use of ultrasound allows for direct visualization of local anesthetic spread within the desired facial plane (Figure 12.24a). If not observed to be in the correct location, the needle is repositioned and the test injection is repeated as necessary.
- Once the needle is confirmed to be in the correct location within the fascial plane, the remainder of local anesthetic solution is injected up to a total volume of 1 mL kg^{-1}.
- Following performance of the TAP block on one side, the patient is turned over into the other lateral recumbency and the procedure is repeated using an additional 1 mL kg^{-1} of the diluted local anesthetic solution.

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13 The Pelvic Limb

Luis Campoy and Stephan Mahler

Overview

The pelvic limb is innervated by two nervous plexuses (lumbar and sacral) that should both be partly or entirely blocked in order to provide surgical anesthesia and analgesia to the entire pelvic limb. Femoral and sciatic nerve blocks are considered to be of an intermediate level of difficulty, and are minimally invasive, selective, and associated with a low rate of complications. However, psoas compartment and dorsal/transgluteal sciatic nerve blocks are deeper blocks that are more challenging to perform and their success rates are largely linked to the clinician's experience.

Like the majority of regional anesthetic techniques, good anatomic knowledge is required to increase the success rate and to minimize complications. Single injection nerve blocks are the most frequently used techniques. The placement and continued use of a perineural catheter for a continuous peripheral nerve block (CPNB) is difficult to achieve in small animals due to the lack of patient cooperation as early catheter displacement may occur once patients become ambulatory.

General considerations

Femoral and sciatic nerve blocks are considered intermediate level and are easy to master; landmarks are consistent and reliable in most dogs and, with sufficient practice, these techniques are associated with a good success rates. For anesthesia of the entire pelvic limb (including the hemipelvis), the blocks should additionally include the lateral femoral cutaneous nerve (L3–L4 in the majority of dogs), and the caudal cutaneous femoral nerve (sacral plexus, S1 mainly; some dogs would have some contribution from L7 and S2).

Sedation/anesthesia requirements

To prepare the patient for the procedure, an intravenous catheter should be placed. For sedation, a combination of either intravenous fentanyl 2–5 $\mu g\,kg^{-1}$ or dexmedetomidine (0.5–1 $\mu g\,kg^{-1}$) and propofol 2–4 $mg\,kg^{-1}$ can be administered. Note that the higher doses may be required when electrolocation is used by itself (as higher current outputs are used), compared with a combined ultrasound/electrolocation-guided technique.

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Supplemental oxygen should be supplied to the patient in order to minimize hypoxemia caused by drug-induced ventilatory depression. The use of monitoring devices during the procedure is also highly recommended. Additionally, local infiltration at the puncture site with a local anesthetic such as lidocaine 2% may be necessary if the patient is sedated rather than anesthetized.

Animal positioning

Patient positioning is an important aspect of the procedure as nerves are flexible structures whose location can vary somewhat depending on the position of the limb. Standardized positioning helps to ensure a good quality block and potentially minimizes complications.

Special considerations for electrolocation techniques

- Before injecting the local anesthetic solution, it is important to verify that the needle is not positioned either intravascularly or intraneurally. Negative blood aspiration should be observed. Additionally, the current output of the nerve stimulator should be decreased to 0.2 mA and absence of obvious motor stimulation should be verified. Then the intensity should be increased to 0.4 mA to re-establish the twitch, and the first 1 mL of local anesthetic should be injected. This should cause the motor response to cease, as the injectate displaces the nerve away from the needle (Raj Test). Bear in mind, however, that a local anesthetic solution can also dissipate the current by acting as an electrolyte (Tsui and Kropelin 2005). It is also imperative to ensure that no resistance is encountered during the injection. Intraneural injections are associated with high injection pressures (>20 psi, 138 kPa) (Kapur et al. 2007). If resistance to injection is experienced, the needle should be repositioned before further local anesthetic is injected.
- During and after the block, watch for potential adverse effects in the patient such as tachycardia, hypotension, arrhythmias, muscle twitches, tremors, or seizures. These might suggest local anesthetic systemic toxicity, necessitating immediate treatment.

Special considerations for ultrasound-guided techniques

- During injection, watch for fluid to begin spreading around the nerve. The anesthetic solution will appear as a hypoechoic circumferential ring around the nerve, known as the "doughnut sign," ruling out intravascular needle placement (Robards et al. 2008). While injecting, the position of the needle can be slightly modified to improve diffusion of the solution around the nerve.
- For an adequately imaged ultrasound-guided nerve block, a positive motor response to nerve stimulation does not actually increase the success rate of the block. If an adequate image is obtained, these blocks are usually effective, even in the absence of a motor response (Beach et al. 2006).
- Provided the needle is perfectly in plane with the transducer, as the local anesthetic is being injected, you should be able to see its dispersion around the nerve. If not, it may indicate an intravascular injection (even in the absence of blood aspiration) as the pressure applied by the transducer may occlude venous structures making aspiration negative (Robards et al. 2008).

Indications

A wide range of surgical procedures can be performed after pelvic limb nerve blocks, including fracture repairs and articular procedures (femoral head osteotomies, knee arthroscopy, anterior cruciate ligament repair, tibial plateau leveling osteotomy (TPLO), tibial tuberosity advancement (TTA), foot and ankle surgery, etc.). A sciatic nerve block alone is sufficient to perform surgery of the foot and the hock (Singelyn et al. 1991). The sciatic nerve can be blocked in the popliteal area (caudal approach), which avoids unnecessarily proximal motor blockade of the biceps femoris, semitendinosus and semimembranosus muscles. If the surgical procedure involves the tibia or the stifle, the femoral nerve should also be included in the block technique (Patel et al. 1986; Farny et al. 1994; Lintner et al. 1996; Goranson et al. 1997).

Contraindications/precautions

Some contraindications are absolute:

- neuropathies
- skin infection at the puncture site
- bleeding disorder or high risk of bleeding
- known adverse reactions to a local anesthetic

Other situations may increase the risks or complicate the procedure and constitute relative contraindications:

- sepsis
- fracture or edema that changes the anatomic landmarks
- deep nerve blocks (lumbar plexus block) are particularly difficult to carry out in obese animals (loss of anatomic landmarks, loss of ultrasonographic contrast)

Choice of local anesthetics and adjuncts

In general, a combination of bupivacaine 0.5% and dexmedetomidine ($0.5\,\mu g\,mL^{-1}$) is most commonly used by the authors to provide surgical anesthesia. Ropivacaine 0.75% in combination with dexmedetomidine ($0.5\,\mu g\,mL^{-1}$) is also used with similar results.

Psoas compartment (lumbar plexus) block in the dog

The psoas compartment block is considered an advanced level technique, mainly because of the depth of the needle placement and the sensitive anatomy. This block has relatively higher potential for complications and should only be practiced after appropriate training. Used in combination with a sacral plexus or sciatic nerve block, it should provide anesthesia to the entire pelvic limb.

Functional and clinical anatomy

The lumbar plexus originates in the lumbar spine (L3–L6) and is located within the iliopsoas muscle compartment. This muscle originates on the transverse processes of L2 and L3 and attaches along the ventral and lateral surfaces of the L4 through L7 lumbar vertebrae (Figure 13.1). The lumbar plexus is formed by the ilioinguinal, lateral femoral cutaneous, genitofemoral, femoral, and obturator nerves.

This compartment is limited ventrally by the aponeurosal continuation of the fascia iliaca, thus producing a true sheath that allows for diffusion of local anesthetics around the nerves. As soon as the roots of the lumbar plexus emerge from the intervertebral foramina, they become embedded in the iliopsoas muscle. The femoral nerve arises from the

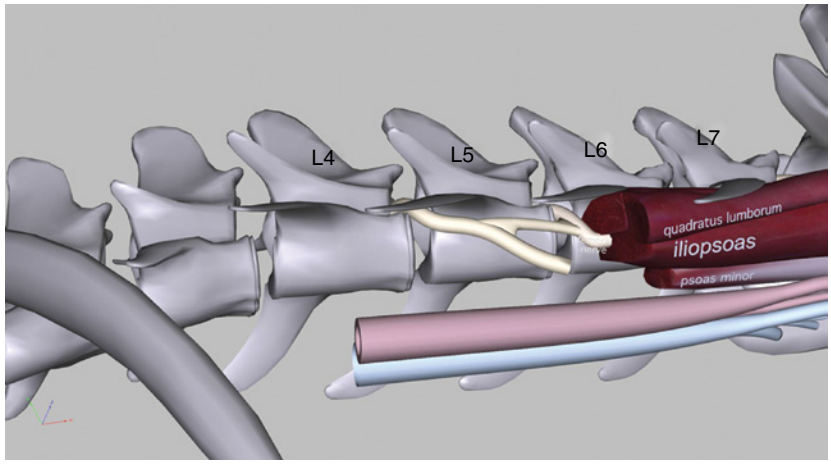


Figure 13.1 Tridimensional animation of the lumbar area of a dog. The L4, L5, and L6 spinal nerves contribute branches to form the femoral nerve. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

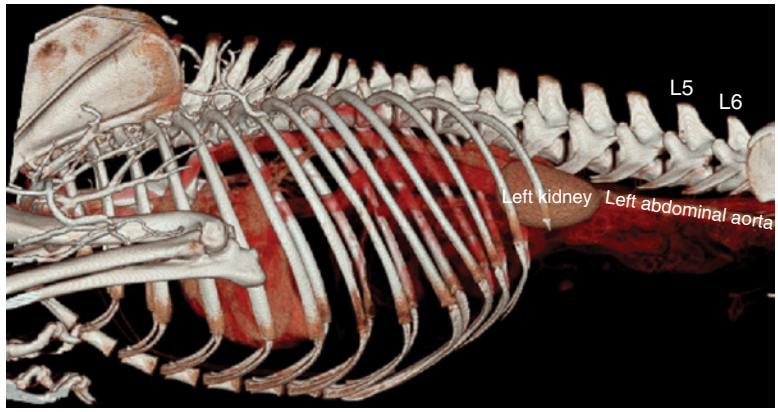


Figure 13.2 Left lateral view of a computerized tomography reconstruction of a dog's trunk. Note the vertebral bodies of L5 and L6, landmarks for a psoas compartment block.

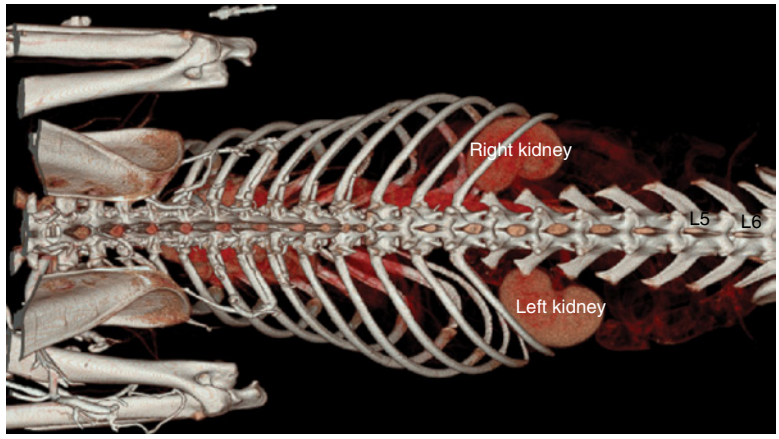


Figure 13.3 Dorsal view of a computerized tomography reconstruction of a dog's trunk. Note the vertebral bodies of L5 and L6, landmarks for a psoas compartment block.

cranial part of the lumbar plexus (L4–L6), courses through the psoas major muscle, and then exits through the femoral canal to the quadriceps femoris muscle. The femoral nerve is accompanied by the external iliac artery and vein.

The left kidney extends from approximately L1 to L3, whereas the right kidney is located a half to one intervertebral spaces more cranial (T13 to L2), although their positions (particularly the left kidney) vary with posture and respiration (Figure 13.2). The medial edge of the kidneys is located approximately 1 cm from the mid dorsal line in a medium size dog (Figure 13.3). The dorsal aspect of their adipose capsule is related to the quadratus lumborum, psoas, and transversus abdominis muscles.

The abdominal aorta is slightly displaced to the left by the caudal vena cava. The abdominal aorta and vena cava run along in the groove formed by the right and the left portions of the iliopsoas muscle. At the level of L7, the abdominal aorta bifurcates into the right and the left internal iliac and middle sacral arteries; similarly, the abdominal vena cava bifurcates into the common right and left iliac veins.

Distribution of local anesthesia and analgesia

- Anesthesia of the hemipelvis, femur, femorotibial joint (partial), skin of the dorsomedial tarsus and first digit.

- In one study (Farny et al. 1994) using a combination of psoas compartment and sciatic nerve blocks for lower limb anesthesia in people, complete sensory blockade was obtained in 40 out of 45 patients (89%).
- The cutaneous area over the greater trochanter and hip may not be effectively blocked when using a single injection technique as described in this chapter. This block often misses the lateral femoral cutaneous nerve (originates in L4 with some contributions from L3 and L5) and the caudal femoral cutaneous nerve (from the sacral plexus, S1–S2).

Nerve stimulation-guided psoas compartment block

Several authors have described slight variations of the same technique. Portela et al. (2012) described a pre-iliac approach to the femoral nerve while still within the lumbar plexus domain.

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small dogs, 20-gauge, 100 mm for medium/large dogs);
- sterile gloves;
- syringes and needles; and
- local anesthetic ± adjuvant.

Standard technique (Campoy et al. 2008)

Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost.
- Clip the area over the dorsal spinous and transverse processes from L4 to L7.

Anatomic landmarks

- Dorsal spinous processes of L5–L6 and the transverse process of L5 (Figure 13.4), ventral border of the psoas major muscle.
- The puncture site is located parasagittaly (as to clear the vertebral body of L5) to the spinous process of L5.

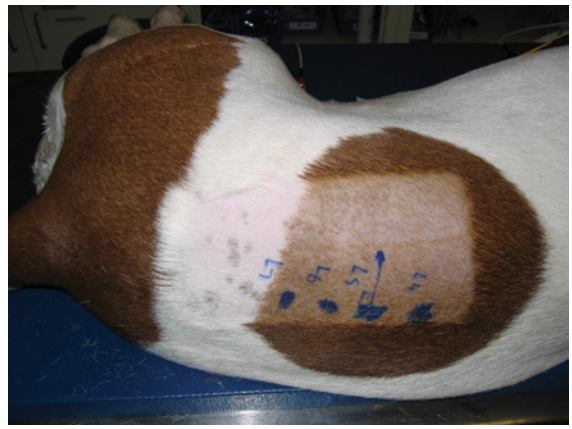


Figure 13.4 Psoas compartment (lumbar plexus) block in a dog. The dog is positioned in lateral recumbency. The needle is advanced in a parasagittal plane at the level of L5, and should not contact the vertebral body or transverse process of L5 as it is advanced into the psoas muscle.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Pre-measure depth using the ventral border of the iliopsoas muscle as a reference.
- The stimulating needle should be advanced with a strictly sagittal orientation with the nerve stimulator set initially to deliver a current of 1.5 mA.
- In the event of contact with the transverse process of L5, the needle should be "walked off" in a caudal direction so as to pass behind the transverse process until contractions of the quadriceps muscle (anterior motion of the femur, extension of stifle) show that the needle is in direct vicinity of the L5 lumbar plexus root.
- Decrease the current gradually to 0.8–1 mA in 0.2 mA increments, until the same response can be elicited, repositioning needle if necessary (injecting at lower currents may increase the incidence of epidural migration (Farny et al. 1994).

Clinical tips

- Recommended volume to be injected: 0.4 mL kg^{-1} (Campoy et al. 2008). The psoas muscle is relatively loosely compacted, therefore reasonably large volumes are required to fill this space (Figure 13.5).
- The authors commonly use bupivacaine 0.5% combined with dexmedetomidine (0.5 µg mL^{-1}). his provides approximately six to eight hours

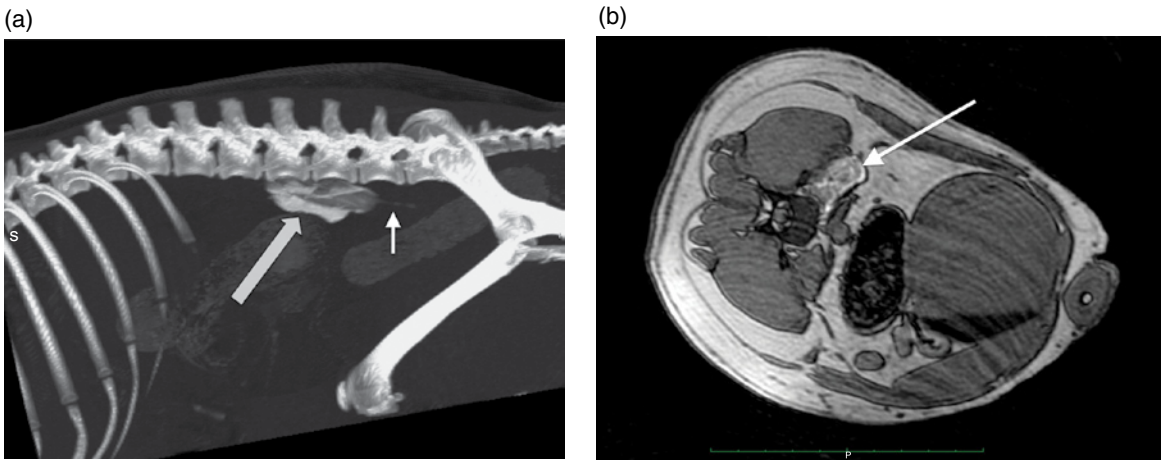


Figure 13.5 (a) 3-D reconstructed computed tomographic (CT) image of a dog. A psoas block has been performed using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The large arrow demonstrates contrast enhancement (hyperattenuation) within the psoas muscle. The small arrow shows contrast enhancement tracking along the femoral nerve as it exits the psoas muscle and courses caudally towards the limb. (b) Axial magnetic resonance image (MRI) of a dog in right lateral recumbency. A psoas block has been performed using lidocaine and gadolinium contrast medium (gadobutrol 1.0 mmol L^{-1} at 100:1 dilution). The injected solution can be seen within the psoas muscle compartment (white arrow).

of blockade. Alternatively, ropivacaine 0.75% combined with dexmedetomidine (0.5 µg mL^{-1}) can be used with similar results.

- Higher volumes result in more solid, complete, and faster blockade, but may have a higher risk of toxicity.
- As an alternative, the lumbar plexus nerve roots can be approached and blocked individually from L4 to L6 (0.2 mL kg^{-1} divided into three injection points) (Portela et al. 2008).

Lateral pre-iliac technique (Portela et al. 2012)

Patient positioning

- Position the patient in lateral recumbency with the site to be blocked located uppermost and the leg in a neutral position.
- Clip the lateral and middle-dorsal aspect of the lumbosacral and gluteal regions.

Anatomic landmarks

- A line should be drawn from the spinous process of L6, perpendicular to the spine in a dorsoventral direction (Figure 13.6).

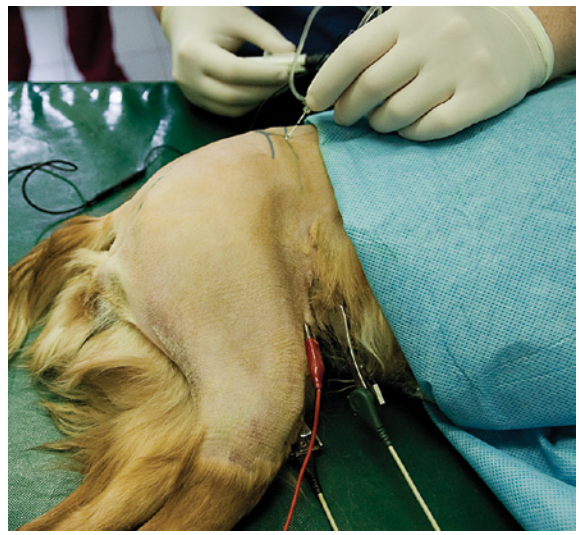


Figure 13.6 Note landmarks on the pre-iliac region. The puncture site is located at the intersection of a line running in a dorsoventral direction at the level of L6 and a second line running parallel to the spine originated at the most cranial point of the iliac crest. Photograph by D.A. Portela.

- A second line should be drawn from the most cranial aspect of the iliac crest parallel to the spine until it intersects the first line.

- The puncture site is located at the intersection of these two lines.

Step-by-step procedure
- Perform a final sterile preparation of the puncture site.
- Advance the insulated needle in a caudomedial direction with an inclination of 30–45° angle through the iliocostalis lumborum muscle with the nerve stimulator set initially to deliver a current of 1 mA.
- Once the tip of the needle is within the appropriate range of the femoral nerve, contractions of the quadriceps muscle will result in stifle extension.

Clinical tips
- Recommended volume to be injected: 0.1 mL kg^{-1}.
- With this approach the obturator nerve may also be blocked.
- Contractions of the *iliocostalis lumborum*, *sartorious*, *gracillis* or *pectineum* muscles should not considered to be positive end points.

Potential complications
- The possibility of epidural migration of the local anesthetic may be reduced when compared to a traditional psoas compartment block (Portela et al. 2012).
- There are no vascular structures in close proximity to the nerve, therefore the risk of vascular puncture is reduced.

Combined ultrasonography (US)/electrolocation-guided psoas compartment block

The major advantage of the ultrasound-guided psoas compartment block is that it allows the operator to estimate the depth of the lumbar plexus prior to needle insertion. This evaluation is to prevent deep needle insertions with subsequent peritoneal cavity injection leading to possible vena cava, aorta, or kidney lacerations.

Equipment
- Low frequency ultrasound transducer (<7 MHz) with sterile sleeve where indicated;
- peripheral nerve stimulator;
- insulated Tuohy needles (22–18-gauge, 50–100 mm) are preferred for deep blocks because they are more readily observed ultrasonographically and they are easier to direct under ultrasound guidance;
- sterile gloves;
- syringes and needles;
- isopropyl alcohol; and
- local anesthetic ± adjuvant.

Standard technique

Patient positioning
- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost.
- Clip the dorsal area (from L4 to L7).

Anatomic landmarks (ultrasound anatomy)
The iliopsoas muscle is easily visualized using ultrasound (Figure 13.7). The iliopsoas muscle can be seen by first identifying the sacrum and then gliding the transducer cranially, counting along from L7 to L5. This initial scanning allows the operator to identify the transverse processes and vertebral bodies of L7 to L5, acquire longitudinal and transverse images of the psoas compartment, and determine the distance from the skin to the iliopsoas muscle (Cannon and Puchalski 2008).

Step-by-step procedure
- Perform a final sterile preparation of the puncture site.
- Glide, rotate, and tilt the transducer until the iliopsoas muscle in its short axis can be seen.
- Set the peripheral nerve locator to deliver a 0.4 mA current output at 1–2 Hz.
- Insert the needle from medial to lateral with an in-plane approach. This approach helps to minimize injection into the dural sleeves that extend laterally beyond the neural foramina.
- Advance the needle towards the iliopsoas muscle, keeping the needle tip in the field of ultrasound view at all times.
- Watch for the characteristic contractions of the quadriceps femoris muscle, resulting in stifle extension.
- On injection of the local anesthetic solution, diffusion of the fluid within the psoas muscle confirms proper position of the needle tip.

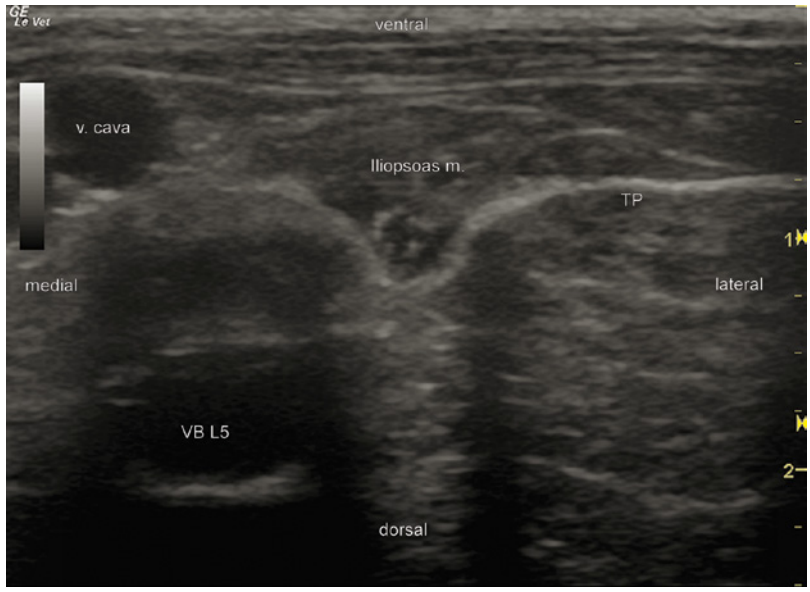


Figure 13.7 Ultrasound image at the level of L5.

Clinical tips

- Lumbar and then quadratus muscle twitches may be firstly seen as the needle is advanced towards the psoas major muscle due to direct muscle stimulation.
- Recommended volume to be injected: 0.4 mL kg^{-1} (Campoy et al. 2008). The psoas muscle is relatively loosely compacted, therefore reasonably large volumes are required to fill this space.
- Higher volumes result in more solid, complete, and faster blockade, but may have a higher risk of toxicity.

Continuous psoas compartment block

Unlike many other locations, the psoas compartment offers the advantage of being an area surrounded by dense connective tissue, allowing an indwelling catheter to be firmly held in place by muscles. Furthermore, movements of the pelvic limb contribute less to displacement of the catheter than if the catheter was placed adjacent to the femoral nerve in the femoral triangle.

Equipment

- Same equipment as previously described including low frequency US transducer and peripheral nerve stimulator.
- Dedicated set for continuous peripheral nerve block including a 20–21-gauge, 400–500 mm catheter.

Placement and securing of CPNB catheters

- Using ultrasound, the needle is inserted at a perpendicular angle and advanced until a quadriceps twitch is obtained at a current output of 0.5–1.0 mA.
- The catheter is advanced a few centimeters past the tip of the needle.
- While the needle is being withdrawn, the catheter is carefully advanced in order to minimize catheter displacement.
- An aspiration test for blood or cerebrospinal fluid (CSF) should be performed.
- The catheter can be then tunneled subcutaneously a few centimeters to secure it in place.
- A transparent light dressing can be placed to cover the catheter site.

Drug choice and infusion rates of local anesthetics

- A continuous infusion of local anesthetic via a peripheral nerve catheter may be ideal to provide continuous long-term postoperative analgesia.

- A bolus of local anesthetic (0.3–0.4 mL kg^{-1}) should be administered, followed by continuous infusion. The infusion rate can be set to deliver 0.05 mL kg^{-1} h^{-1}.
- Drugs commonly used by the authors include:
  - bupivacaine 0.12–0.25% combined with dexmedetomidine (0.5 µg mL^{-1} of solution); or
  - ropivacaine 0.2% combined with dexmedetomidine (0.5 µg mL^{-1} of solution).

Monitoring of the continuous psoas compartment block

Monitor the patient for signs of local anesthetic systemic toxicity or epidural spread (bilateral motor deficits).

Potential complications and how to avoid them

Table 13.1 Potential complications (adapted from New York School of Regional Anesthesia, accessed at http://www.nysora.com/techniques/lumbar_plexus_block/).

Complication	How to avoid
Hematoma	Deep needle insertion should be avoided (vena cava, aorta)
Local anesthetic toxicity	Due to inadvertent intravascular injection during needle manipulation Careful and frequent aspiration should be exerted during the injection Avoid injecting the local anesthetic quickly Large volumes of long-acting anesthetic should be reconsidered in geriatrics or patients with hepatic dysfunction
Nerve injury	The risk of nerve injury after lumbar plexus block is low Never inject when high pressure on injection is encountered Use a peripheral nerve locator
Hemodynamic consequences	Lumbar plexus blockade results in unilateral sympathetic blockade Spread of the local anesthetic to the epidural space may result in hypotension Every patient receiving a lumbar plexus block should be monitored to the same extent as patients receiving epidural anesthesia

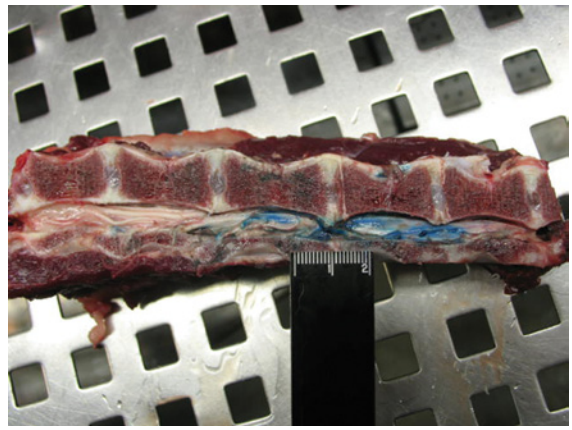


Figure 13.8 Photograph of the lumbar area of a canine cadaver demonstrating epidural migration of methylene blue between lumbar vertebrae 5 and 6 following performance of a psoas compartment block using 0.4 mL kg^{-1} of dye solution.

There is a potential risk of epidural migration of the injectate and subsequent bilateral nerve blockade following psoas compartment blocks (Figure 13.8). Farny et al. (1994) reported an incidence of 9% in people. Our experience shows a comparable incidence of 6% (Campoy et al. 2008). Using a threshold current of 1 mA and turning the patient over on to the blocked side (blocked side down) immediately after blockade have been postulated to reduce the incidence of this complication.

Other potential complications

- Abdominal vena cava puncture
- Aortic puncture
- Viscus puncture may also be possible
- Catheter displacement mainly occurs as the patient becomes ambulatory and can be minimized with tunneling
- Although Capdevila et al. (2005) reported positive cultures in 28% of patients with perineural catheters in which no prophylactic antibiotics had been administered, the incidence of true infections was very low (0.07%). Contamination is frequently the result of colonization of the skin at the catheter insertion site and subsequent contamination of the catheter tip on removal of the catheter (Capdevila et al. 2005). The incidence of contamination is not known when prophylactic antibiotics are used, as is often the case with orthopedic surgery, but it would be expected to be lower. Appropriate aseptic techniques should

be used while any indwelling catheter is in place, and the catheter should be removed if any signs of infection are present.

Femoral nerve block

The femoral nerve block is considered an intermediate level technique that is easy to master. This block can be applied to a wide range of surgical procedures, and it is commonly used in combination with a sciatic nerve block to achieve anesthesia of the pelvic limb (distal to mid femur).

Functional and clinical anatomy

The femoral nerve arises from the cranial portion of the lumbar plexus and is formed by the ventral branches of the L4, L5, and L6 spinal nerves. As it continues distally, it follows a course through the center of the iliopsoas muscle. At the distal end of the iliopsoas muscle, the femoral nerve exits the muscle and courses across the femoral triangle (Figure 13.9). At this level, it gives rise to the cutaneous and muscular branches of the saphenous nerve that supply the sartorious muscle. The femoral triangle is delimited by

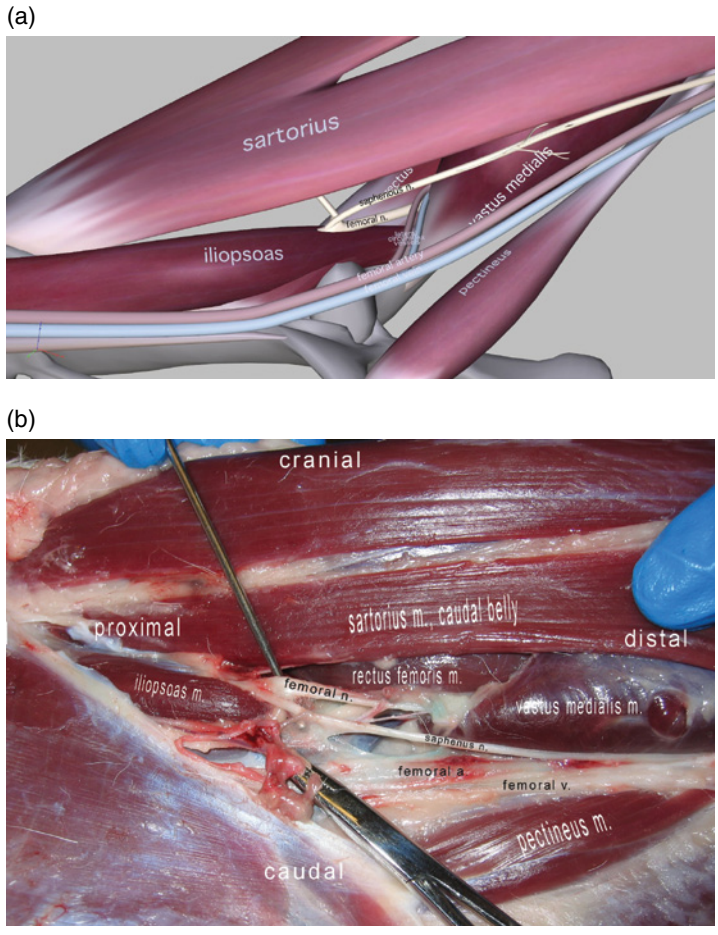


Figure 13.9 (a) Tridimensional animation of the left femoral triangle from a ventral position. The image demonstrates that the triangle is delimited by the iliopsoas muscle proximally, the pectineus muscle caudally, and the sartorius muscle cranially. Within the triangle, the femoral nerve is located cranial to the femoral artery and vein. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu. (b) Dissection of the femoral triangle of the left pelvic limb of a dog cadaver. The caudal belly of the sartorius muscle has been displaced cranially to allow for visualization of the femoral nerve. Note the relationship of the femoral vessels, the femoral nerve, and the rectus femoris muscle.

the iliopsoas muscle proximally, the pectineus muscle caudally, and the sartorius muscle cranially. Within the triangle, the femoral nerve is located cranial to the femoral artery and vein, running deep to the caudal belly of the sartorius muscle. The lateral circumflex vessels originate from the femoral artery and vein. They cross the femoral triangle in a craniocaudal direction, disappearing between the vastus medialis and rectus femoris muscles. The femoral nerve then continues distally, entering the quadriceps muscle between the vastus medialis and rectus femoris.

Innervation of the stifle (Figure 13.10)

The medial articular nerve (MAN) arises from the saphenous nerve (SN). Occasionally, it receives supplementary fibers from the obturator and/or femoral nerves. The MAN supplies the medial, posterior, and anterior aspects of the stifle, and may send branches to the anterior attachment of the posterior cruciate ligament. The posterior articular nerve (PAN) arises from two separate branches: PAN-1 (directly from the tibial nerve) and PAN-2 (from a muscular branch of the tibial nerve). The PAN supplies the posterior and posteromedial aspects of the stifle joint. The lateral articular nerve (LAN) arises from the common peroneal nerve (CP). It serves the lateral collateral ligament (LCL) and the lateral portion of the stifle joint capsule.

Distribution of local anesthesia and analgesia

Anesthesia of the femur (mid diaphysis to distal), femorotibial joint (medial aspect of the femorotibial joint capsule), femorotibial intra-articular structures, skin of the dorsomedial tarsus and first digit.

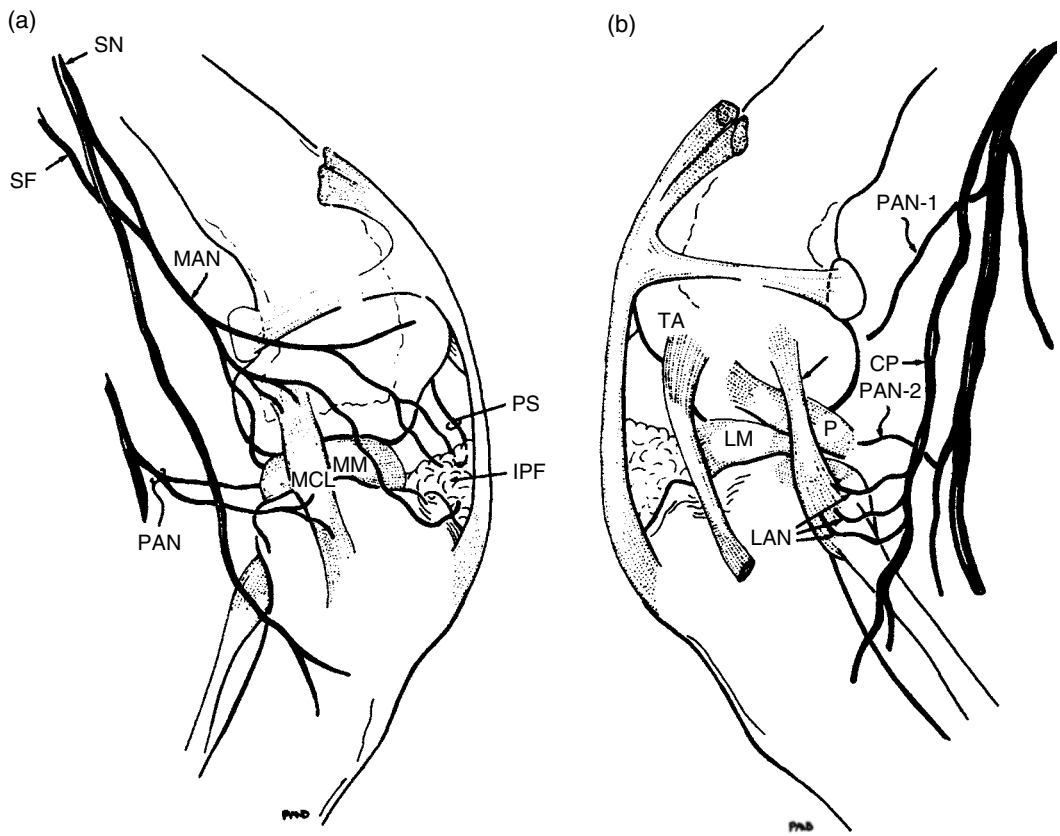


Figure 13.10 (a) Innervation of the stifle, medial view. (b) Innervation of the stifle, lateral view. From O'Connor and Woodbury 1982. Used with permission.

Nerve stimulation-guided femoral nerve block

This technique has been described using two different approaches and variations (Campoy 2006; Mahler and Adogwa 2008; Portela et al. 2012).

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge, 50 mm);
- sterile gloves;
- syringes/needles; and
- local anesthetic ± adjuvant.

Campoy technique (Campoy 2006)

Patient positioning (Figure 13.11)

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost, abducted 90°, and extended caudally.
- Clip the inguinal area.

Anatomic landmarks (Figure 13.12)

- The femoral triangle is delimited by the pectineus muscle caudally, the sartorius muscle cranially, and the iliopsoas proximally.
- Locate the femoral artery by palpating the femoral pulse.
- The femoral nerve is located cranial to the femoral artery.

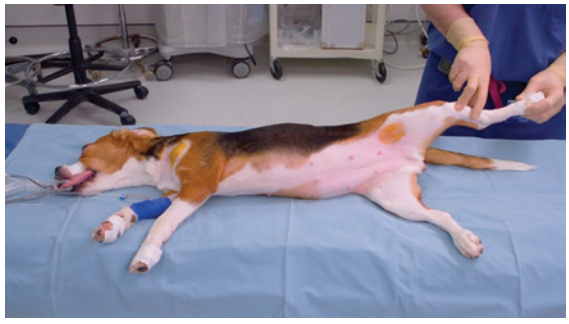


Figure 13.11 A dog positioned for femoral nerve block. The patient should be placed into lateral recumbency with the limb to be blocked positioned uppermost, abducted 90°, and extended caudally. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

- The puncture site is located within the femoral triangle, cranial to the femoral artery.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Insert the stimulating needle cranial to the femoral artery and advance it towards the iliopsoas muscle, maintaining a 20–30° angle with the nerve stimulator set initially to deliver a current of 1 mA (Figure 13.13).
- The femoral nerve is located directly medial to the caudal belly of the sartorius muscle.

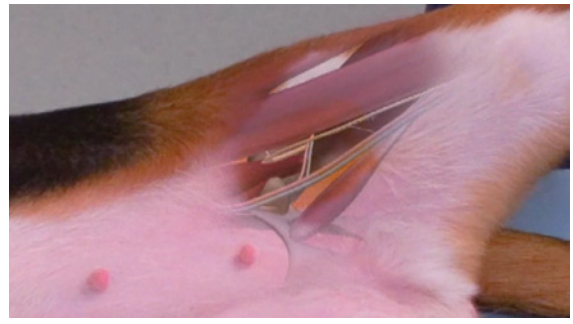


Figure 13.12 The femoral triangle is delimited by the pectineus muscle caudally, the sartorius muscle cranially, and the iliopsoas proximally. The femoral nerve is located cranial to the femoral artery and vein. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

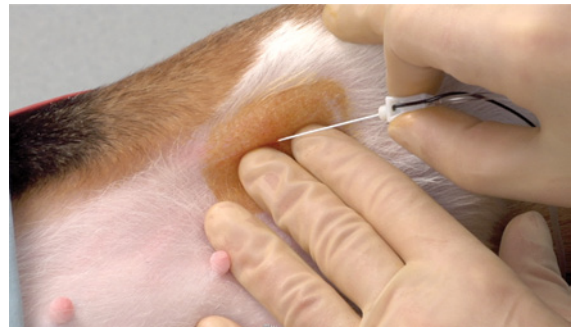


Figure 13.13 Performance of a left-sided femoral nerve block in a dog using a standard technique (Campoy). The stimulating needle is inserted cranial to the femoral artery and advanced towards the iliopsoas muscle, maintaining a 20–30° angle to the skin. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

- Once the tip of the needle is within the appropriate range of the femoral nerve, contractions of the quadriceps muscle will result in stifle extension.
- Decrease the current gradually to 0.4 mA (threshold current) in 0.2 mA increments, until the same response can be elicited, repositioning needle if necessary.

Clinical tips

- Recommended volume to be injected: 0.1 mL kg^{-1} (Figure 13.14).
- The authors commonly use bupivacaine 0.5% combined with dexmedetomidine (0.5 µg mL^{-1}). This provides approximately 14 (6–24) hours [median (min–max)] until analgesia may be needed after cruciate surgery (Campoy et al. 2012). Alternatively, ropivacaine 0.75% combined with dexmedetomidine (0.5 µg mL^{-1}) can be used with similar results.
- No reliable anatomic landmarks could be identified to gauge the depth to which the needle should be inserted. However, a distinct "pop" can be felt once the needle has punctured the dense, superficial fascia iliaca overlying the nerve.
- In a mid-sized breed, such as a Labrador Retriever, the femoral nerve is located approximately 0.5–1 cm under the skin.
- The femoral nerve lies fairly superficial in the femoral triangle and should be approached carefully to avoid deep needle insertions. The operator should try to leave the needle untouched while appreciating the muscular contractions. Release digital pressure on the needle to avoid the needle being pressed against the femoral nerve through the fascia iliaca, confirming that the fascia has indeed been punctured and that the tip of the needle is in close contact with the nerve.
- The lateral circumflex vessels cross the femoral triangle in a craniocaudal direction. If these small vessels are inadvertently penetrated during the procedure, a small hematoma can form. This hematoma may not be obvious externally, but the amount of blood may be enough to dissipate the current, causing the loss of a twitch. Under these circumstances, if aspiration is negative for blood and the injection of a small amount of local anesthetic does not result in signs of intravascular injection, one can inject the remainder of the anesthetic.
- Contractions of the sartorius muscle should not be considered an acceptable end point. It could be that the tip of the needle is located too superficially and the sartorius muscle is being stimulated directly. In this case, the needle should be advanced further. A second possibility may be that a branch of the femoral nerve that supplies this muscle is being stimulated. In this case, the needle also needs to be repositioned until better twitches are seen.

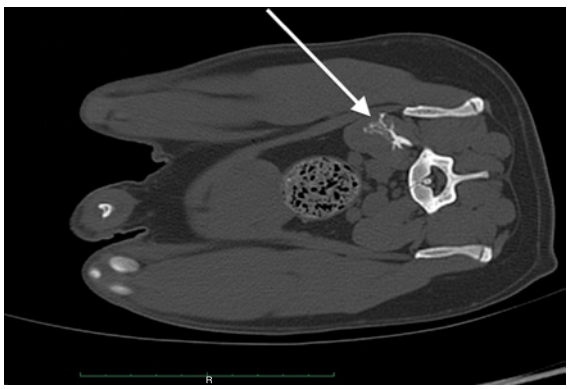


Figure 13.14 Computed tomographic (CT) image of a dog. A femoral nerve block has been performed using lidocaine and iohexol 240 mg iodine mL^{-1} (10:1 dilution). The arrow indicates the location of contrast enhancement.

Clinical pearls

- In some cases, the saphenous nerve leaves the principal femoral nerve trunk proximally to the puncture site, therefore, it is possible that the cutaneous branch may not be anesthetized.
- Ben-David et al. (2004) showed that a sciatic nerve block is necessary in order to achieve complete analgesia following total knee arthroplasty. However, Allen et al. (1998) reported that the addition of a sciatic nerve block did not further improve analgesic efficacy in procedures involving the knee joint in humans. Weber et al. (2002) reported that 67% of patients who have had preoperative femoral blocks required the addition of sciatic blocks postoperatively.
- In the authors' opinions, the need for an additional sciatic nerve block has to do with the level of irritation/trauma that the common

peroneal nerve undergoes during surgery. Preoperatively, as there is no way to predict this, it is our recommendation to always perform a combined sciatic/femoral nerve block for surgical procedures involving the stifle.

Mahler technique (Mahler and Adogwa 2008)

Patient positioning

- Access to the right femoral nerve is obtained with the dog in lateral recumbency with the leg to be blocked downmost.

Anatomic landmarks

The femoral artery is palpated in the femoral triangle as proximal as possible. The puncture site is located just cranial to the femoral artery, with the needle directed slightly caudally.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Insert the stimulating needle cranial to the femoral artery and advance it towards the iliopsoas muscle, maintaining a 20–30° angle with the nerve stimulator set initially to deliver a current of 1 mA.
- The femoral nerve is located directly medial to the caudal belly of the sartorius muscle.
- Once the tip of the needle is within the appropriate range of the femoral nerve, contractions of the quadriceps muscle will result in stifle extension.
- Decrease the current gradually to 0.4 mA (threshold current) in 0.2 mA increments, until the same response can be elicited, repositioning needle if necessary.
- Recommended volume to be injected: 0.1 mL kg^{-1}.

Combined US/electrolocation-guided femoral nerve block

Several authors have described slightly different variations of this block (Costa-Farre et al. 2011; Campoy et al. 2010; Echeverry et al. 2010, 2011; Shilo et al. 2010). Costa-Farre et al. (2011) used the same patient positioning as described by Campoy et al. (2010); however, those authors used an out-of-plane technique. Echeverry et al. (2010) and Shilo et al. (2010) positioned their patients with the leg to be blocked downmost and in-plane technique was used in those studies. Recently, Echeverry et al. (2011) described a suprainguinal approach.

Equipment

- High frequency transducer (9–15 MHz) with sterile sleeve when indicated;
- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small dogs, 20-gauge 100 mm for medium/large dogs);
- sterile gloves;
- syringes/needles;
- isopropyl alcohol; and
- local anesthetic ± adjuvant.

Femoral triangle approach (Campoy et al. 2010)

Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost, at a 90° angle, and extended caudally.
- Clip scanning area and puncture site.

Anatomic landmarks (ultrasound anatomy) With the transducer placed over the femoral triangle, perpendicular to the course of the femoral artery, a short axis view of the femoral vessels and the nerve is obtained (Figure 13.15). The femoral artery can be visualized in the near field. The artery is a round, hypoechoic, pulsatile structure. The femoral vein is rarely seen adjacent to the artery, as it is usually compressed by the pressure that is being exerted by the ultrasound transducer. The femoral nerve is located cranial and deep to the femoral artery, and it is visible as a nodular hyperechoic structure directly beneath the thin caudal belly of the sartorius muscle. The rectus femoris muscle can be seen cranial to the nerve. The fascia iliaca sometimes appears as a hyperechoic line, superficial to the femoral nerve. The puncture site is located in the proximal and cranial aspect of the thigh (cranial belly of the sartorius muscle) in-plane with the transducer.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Glide, rotate, and tilt the transducer until the large pulsatile femoral artery in its short axis can be seen (Figure 13.15).

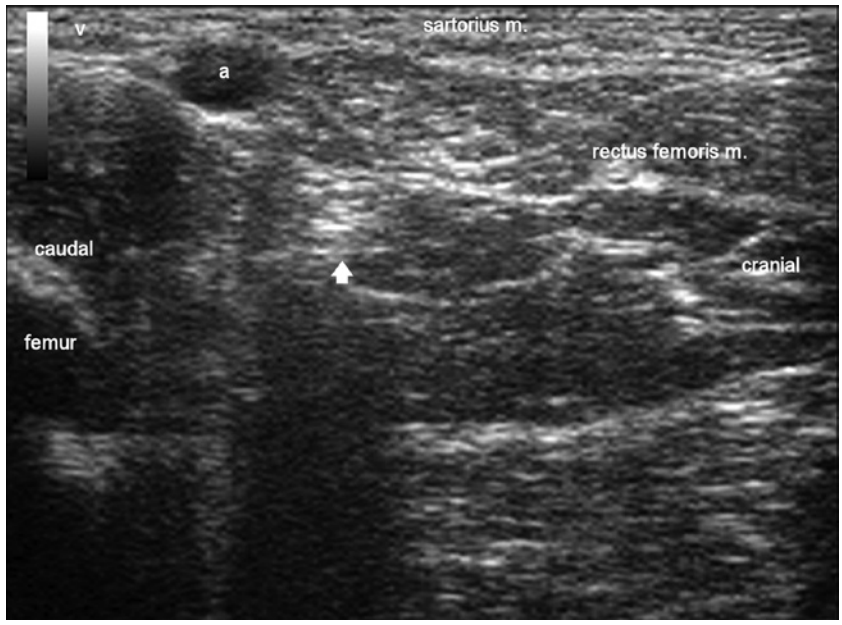


Figure 13.15 Ultrasonographic cross-section (short axis) view of the right femoral triangle of a dog. (a: femoral artery, v: femoral vein, arrowhead: femoral nerve).

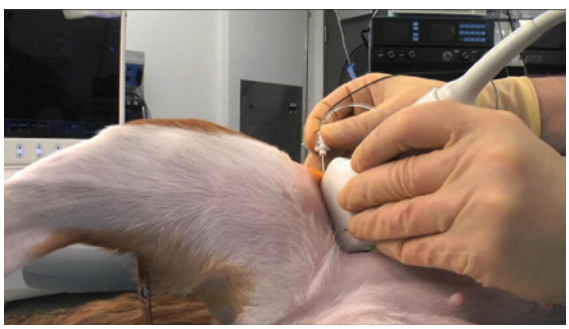


Figure 13.16 Performance of a right-sided femoral nerve block in a dog. The ultrasound transducer is positioned to visualize the femoral triangle in short axis in the inguinal area, and the stimulating needle is advanced in-plane through the sartorius and rectus femoris muscles towards the femoral nerve. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

- Set the peripheral nerve locator to deliver a 0.4 mA current output at 1 or 2 Hz.
- Insert the stimulating needle through the sartorius and rectus femoris muscles (Figure 13.16).
- Advance the needle towards the femoral nerve, keeping the needle tip in the field of ultrasound view at all times.
- Watch for the characteristic contractions of the quadriceps femoris muscle, resulting in stifle extension.

Clinical tips

- Recommended volume to be injected: 0.1 mL kg^{-1} (Costa-Farre et al. 2011; Campoy et al. 2010; Shilo et al. 2010). However, the final injection volume should be assessed by monitoring the ultrasound image—if local anesthetic is observed to surround the nerve with less than the calculated volume, the full volume does not need to be administered.
- For an adequately imaged ultrasound-guided nerve block, a positive motor response to nerve stimulation does not actually increase the success rate of the block. If an adequate image is obtained, these blocks are usually effective, even in the absence of a motor response (Beach et al. 2006).
- Should the needle not be perfectly in plane with the transducer, it may lead to misinterpretation of the exact location of the needle tip.

Potential complications The main potential complication associated with the femoral nerve block is the potential risk of puncturing the femoral artery, vein, or the nerve itself.

Table 13.2 Potential complications. (adapted from New York School of Regional Anesthesia, accessed at http://www.nysora.com/peripheral_nerve_blocks/nerve_stimulator_techniques/3100-Femoral-Nerve-Block.html).

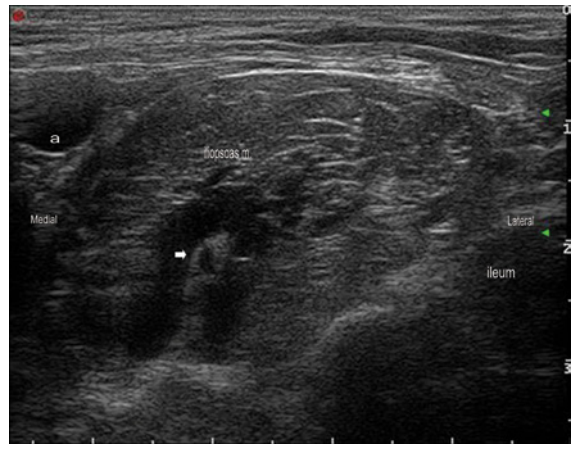
Potential complications	How to avoid
Hematoma	Avoid multiple needle insertions If the femoral artery or vein are inadvertently punctured and a hematoma develops, apply firm compression for a minimum of five minutes or until clotting occurs
Local anesthetic toxicity	Avoid inadvertent intravascular injection with frequent aspiration of the syringe during the injection. If ultrasound-guided technique is used, verify the spread of local anesthetic around the nerve ("doughnut sign") Always look for signs of toxicity during and after injection such as tachycardia, hypotension, arrhythmias, muscle twitches, tremors, or seizures Large volumes of long-acting anesthetic should be avoided in geriatric patients or patients with hepatic dysfunction
Nerve injury	Local anesthetic should never be injected when resistance is encountered during the injection Check for absence of overt muscular twitch at a current output less than 0.2 mA (this is of special importance when using only the electrolocation technique) Perform a Raj test to help rule out intraneural injections Local anesthetic should never be injected when a patient overtly reacts during the injection (if patient is sedated rather than anesthetized) Use of peripheral nerve locator and/or ultrasound significantly minimizes the risk of nerve injury

Ventral suprainguinal approach (Echeverry et al. 2010, 2011)

Patient positioning

- Position the patient in dorsal recumbency with leg to be blocked moderately extended.

(a)



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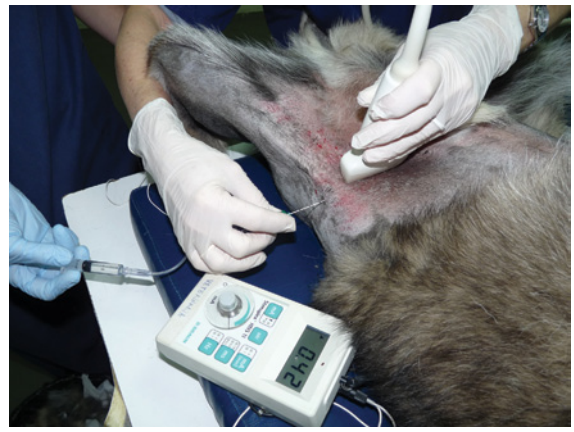


Figure 13.17 (a) Ultrasonographic cross-section (short axis) view of the femoral triangle. (a: external iliac artery, arrowhead: femoral nerve). (b) Performance of a femoral nerve block using a ventral suprainguinal approach in a dog (left leg). Under ultrasound-guidance, the stimulating needle is advanced from a lateral position towards the femoral artery. Image and photograph by A. Agut and E. Belda.

Anatomic landmarks (ultrasound anatomy) (Figure 13.17a)

Step-by-step technique

- The transducer is initially positioned perpendicular to midline, slightly cranial to the inguinal nipple.
- From this point, the transducer is glided laterally until the femoral nerve is identified in its short axis.

- The transducer is then glided in a cranial direction, following the femoral nerve.
- The stimulating needle is advanced from a lateral position using an in-plane technique to approach the femoral nerve (Figure 13.17b).

Clinical tips

- Recommended volume to be injected is 0.1 mL kg^{-1}; however, the final injection volume should be assessed by monitoring the ultrasound image.

Sciatic nerve block

This procedure is considered an intermediate level technique. This block will result in anesthesia of the stifle (partial) and the structures distal to it. Used in combination with a femoral nerve block, anesthesia of the entire pelvic limb (distal to mid femur) can be achieved.

Functional and clinical anatomy

The sciatic nerve is formed by the ventral branches of the L6, L7, and S1 spinal nerves. The nerve passes between the middle and deep gluteal muscles (gluteus medius and gluteus profundus muscles) and exits the pelvis through the greater sciatic notch. On leaving the pelvic region, the sciatic nerve lies between the superficial gluteal muscle laterally and the gemelli and quadratus femoris muscles medially (Figure 13.18a). The sciatic nerve descends between the greater trochanter and the ischiatic tuberosity. In this region, the sciatic nerve gives rise to the muscular branches that supply the caudal thigh muscles (Figure 13.18b). The caudal gluteal artery and vein lie caudal to these nerve branches. Immediately distal to the greater trochanter and ischiatic tuberosity, the sciatic nerve lies between the biceps femoris muscle laterally and the semimembranosus muscle caudal and medially. The sciatic nerve then divides into its two branches, the tibial nerve medially and the common peroneal nerve laterally. The location of this division is variable and can occur anywhere from the level of the hip joint to just proximal to the stifle joint.

Distribution of local anesthesia and analgesia

The caudal approach to the sciatic nerve results in anesthesia of the caudolateral aspect of the stifle (including part of the joint capsule and intra-articular structures), tibia, tarsus, metatarsus (dorsal/peroneal component and plantar/tibial component), and digits (except first digit and proximal aspect of second digit). The lateral approach to the sciatic nerve also results in the block of the muscular branch and, in turn, the ischiotibial muscles (semitendinosus, semimembranosus, and biceps femoris muscles).

The dorsal (transgluteal) approach allows for blockade of the ischiotibial muscles and probably some of the sensory branches of the coxofemoral joint. A paravertebral (paralumbar and parasacral) approach (L7–S2) results in anesthesia of the ischiotrochanteric muscles (internal obturator, gemelli, quadratus femoris muscles) and the gluteal muscles.

It should be noted that as the coxofemoral joint is innervated by the femoral nerve, for complete anesthesia, in addition to a parasacral approach to the sacral plexus, a psoas compartment block may be necessary for surgeries such as a femoral head osteotomy (FHO).

Nerve stimulation-guided sciatic nerve blocks

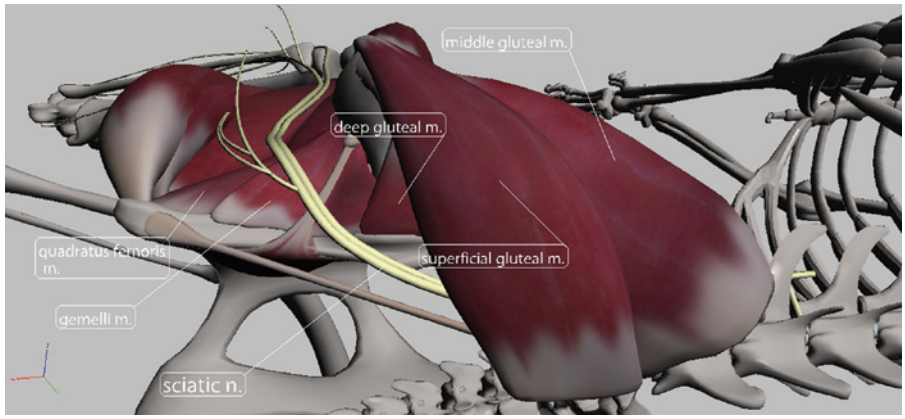
Several authors have described the blockade of the sciatic nerve (Campoy et al. 2008; Mahler and Adogwa 2008; Portela et al. 2010).

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- peripheral nerve stimulator;
- insulated needle (22-gauge, 50 mm);
- sterile gloves;
- syringes and needles; and
- local anesthetic ± adjuvant.

(a)



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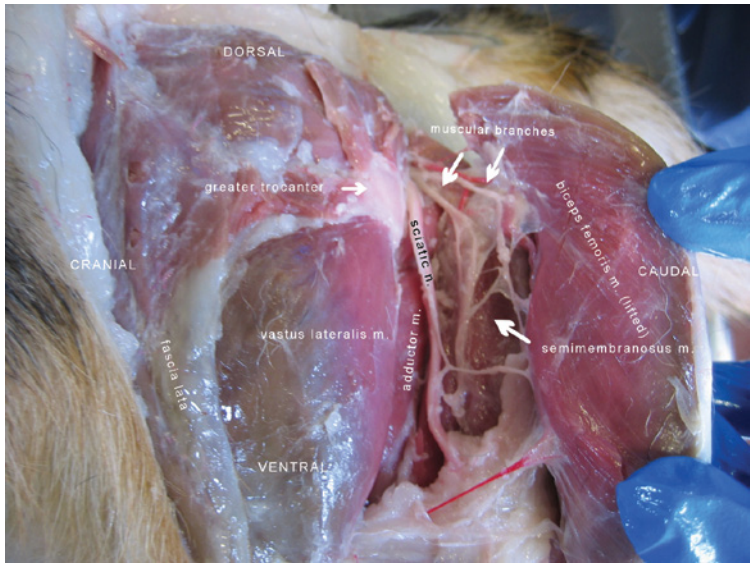


Figure 13.18 (a) Tridimensional animation of the sciatic nerve of a dog. The sciatic nerve passes between the middle and deep gluteal muscles and exits the pelvis through the greater sciatic notch. On leaving the pelvic region, the sciatic nerve lies between the superficial gluteal muscle laterally and the gemelli and quadratus femoris muscles medially. The sciatic nerve descends between the greater trochanter and the ischiatic tuberosity. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu. (b) Dissection of lateral thigh of a canine cadaver showing the sciatic nerve. The biceps femoris muscle has been transected and reflected caudally to allow for easier visualization of the sciatic nerve and its surrounding structures.

Lateral approach technique (Campoy et al. 2008)

Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost and extended in a natural position.
- Clip the area between the greater trochanter and ischiatic tuberosity.

Anatomic landmarks

- Identify the greater trochanter (GT) and ischiatic tuberosity (IT).
- Draw a line between these two points (GT-IT line) (Figure 13.19).

Figure 13.19 GT-IT line. If the length of this line is divided into thirds, the puncture site is located at a point between the cranial and middle thirds. From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

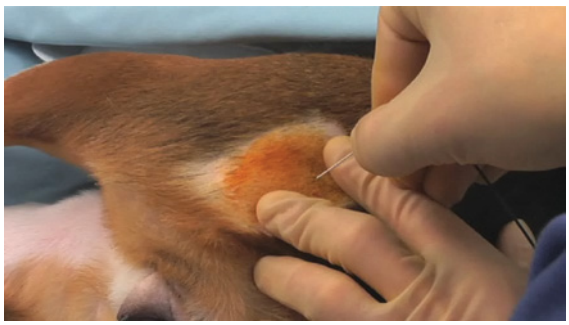


Figure 13.20 Performance of a sciatic nerve block in a dog using the lateral approach. The index and middle fingers of the nondominant hand are used to palpate the greater trochanter and ischiatic tuberosity. The puncture site is located one-third of the distance from the greater trochanter (GT) to the ischiatic tuberosity (IT). From: L. Campoy, Peripheral Nerve Blocks in the Dog. Available through Partners in Animal Health, Cornell University, Ithaca, NY, USA. www.partnersah.vet.cornell.edu.

- The puncture site is located at the point between the cranial and the middle thirds.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- Insert the stimulating needle and advance it in a 45° angle off the skin with the nerve stimulator set initially to deliver a current of 1 mA (Figure 13.20).
- As the needle is advanced, contractions of the biceps femoris muscle may be observed. This is usually associated with direct muscle stimulation as the needle passes through the muscles. These contractions are not the result of true sciatic nerve stimulation. Do not misinterpret these contractions as a positive indicator of sciatic nerve stimulation.
- If at any time the needle contacts bone, withdraw and redirect it.
- Once the tip of the needle is correctly advanced within the appropriate vicinity of the sciatic nerve, a positive contraction response will be elicited. A correct positive response to sciatic nerve stimulation is seen as dorsiflexion or plantar extension of the foot.
- Decrease the current gradually to 0.4 mA (threshold current) in 0.2 mA increments, until the same response can be elicited, repositioning needle if necessary.

Clinical tips

- The recommended volume to be injected is 0.05–0.1 mL kg^{-1} (Campoy et al. 2008) (Figure 13.21).
- The authors commonly use bupivacaine 0.5% combined with dexmedetomidine (0.5 µg mL^{-1}). This provides approximately 14 (6–24) hours [median (min-max)] until analgesia may be needed (Campoy et al. 2012). Alternatively, ropivacaine 0.75% combined with dexmedetomidine (0.5 µg mL^{-1}) can be used with similar results.
- Contractions of the biceps femoris muscle should not be considered an acceptable end point. If the needle tip is still superficial and the

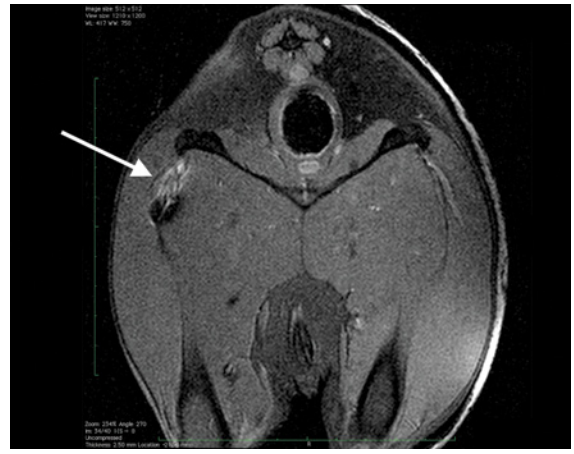


Figure 13.21 Axial magnetic resonance image (MRI) of a dog. A sciatic nerve block has been performed using lidocaine and gadolinium contrast medium (gadobutrol 1.0 mmol L^{-1} at 100:1 dilution). The injected solution (white arrow) can be seen between the greater trochanter and ischiatic tuberosity.

current output is still 1 mA when this response is observed, it is likely that the biceps femoris muscle is being directly stimulated. In this scenario, the needle tip is still too superficial and needs to be further advanced into the tissue.
- Contractions of the semimembranosus or semitendinosus muscles should not be considered an acceptable end point. If stimulation of the hamstrings (semimembranosus muscle, semitendinosus muscle) is observed without foot movement, the needle is most likely located too far caudally. In this situation, the muscular branches of the sciatic nerve, and not the sciatic nerve itself, are being stimulated. Injections in this location miss the main sciatic nerve and will result in block failure.

Transgluteal approach technique (Mahler and Adogwa 2008)

The transgluteal approach to the sciatic nerve is an intermediate level technique that is easy to master and carries a low risk of complications. This block is well suited for those individuals who wish to gain experience with nerve blocks. It should initially be practiced in very lean patients as the relevant landmarks are easier to identify.

Patient positioning
- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost.
- Clip the area from the wing of the ilium to the ischiatic tuberosity up to midline.

Anatomic landmarks
- Landmarks include the dorsal iliac spine, ischiatic tuberosity, lumbar dorsal vertebral processes, and sacrotuberous ligament.
- A line is drawn connecting the dorsal iliac spine and the ischiatic tuberosity. Another line is drawn perpendicular to the first line, crossing it between the mid and caudal thirds. A third line is drawn from the dorsal iliac spine parallel to the long axis of the body, crossing the perpendicular line (Figure 13.22).
- The puncture site is located midway between the two intersections, just cranial to the sacrotuberous ligament (through the superficial gluteal muscle).

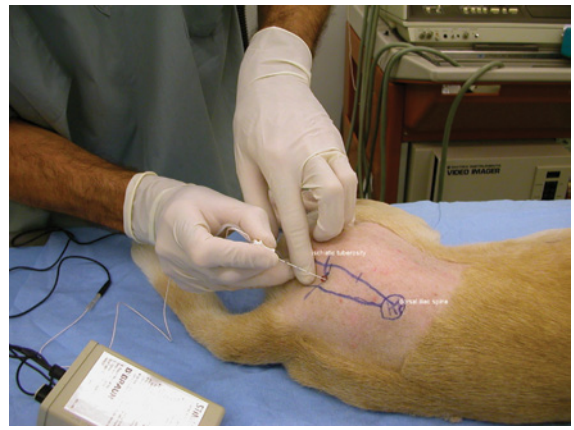


Figure 13.22 Performance of a sciatic nerve block in a dog using the transgluteal approach. A line is drawn connecting the dorsal iliac spine and the ischiatic tuberosity. Another line is drawn perpendicular to the first line, crossing it at its caudal third. A third line is drawn from the dorsal iliac spine parallel to the long axis of the body, crossing the perpendicular line. The puncture site is located midway between the two intersections.

Step-by-step procedure
- Insert the needle in a cranial and ventral direction with the nerve stimulator set initially to deliver a current of 1 mA.
- Contractions of the gluteal muscles are often seen and indicate that the needle tip stimulates the caudal gluteal nerve (superficial gluteal muscle) or the muscle fibers (medial and deep gluteal muscles) directly.
- Continue advancing the needle towards the ischium.
- Once the tip of the needle is within the appropriate vicinity of the sciatic nerve, a positive twitch response will be elicited. Watch for contractions of the biceps femoris, semitendinosus, semimembranosus (extension of the hip joint and abduction of the limb), gastrocnemius (extension of the tarsus), digital flexors, and/or extensor muscles (flexion and extension of the digits).

Clinical tips
- Landmarks are easily identified in most patients; however, adipose tissue over the gluteal area obscures the bony prominences in overweight patients.

- The index finger of the nondominant hand should be placed over the sacrotuberous ligament and the needle inserted just craniolateral to it: this precaution avoids inserting the needle too close to the caudal gluteal vessels with subsequent accidental puncture.

Parasacral approach (Portela et al. 2010)

In this approach the local anesthetic solution is injected at the level of the roots of the sacral plexus involving the sciatic roots, before the sciatic nerve becomes a single large nerve. The sacral plexus provides the roots for the pudendal nerve, the caudal cutaneous femoral nerve, and the gluteal nerves.

Patient positioning

- Position the patient in lateral recumbency with the leg to be blocked uppermost.

Anatomic landmarks (Figure 13.23)

- Spinous processes of L6–L7
- Medial sacral crest
- Cranial dorsal iliac crest
- Ischiatic tuberosity

A line is drawn between the cranial dorsal iliac crest and the ischiatic tuberosity. This line should be divided into three equal parts.

The puncture site is located at the junction of the cranial and middle thirds.

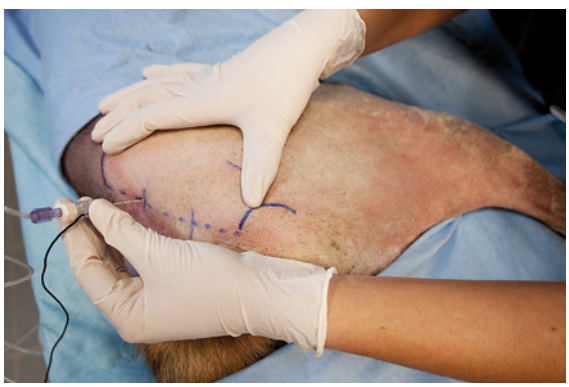


Figure 13.23 Performance of a sciatic nerve block in a dog using the parasacral approach. A line is drawn between the cranial dorsal iliac crest and the ischiatic tuberosity and is divided into three equal parts. The puncture site is located at the junction of the cranial and middle thirds. Photograph by D.A. Portela.

Step-by-step technique

The stimulating needle is advanced until the stimulation of the sciatic nerve roots and contractions of the gastrocnemius muscle or even digital (and/or tarsus) flexion or extension are elicited.

Clinical tips

- Recommended volume to be injected: 0.05 mL kg^{-1}.
- Portela et al. (2010) obtained successful blocks in five out of eight dogs (in the other three dogs only partial blockade was achieved).
- It is possible that a volume of 0.05 mL kg^{-1} was not sufficient to satisfactorily reach the L7, S1, and S3 nerve roots. Therefore it was suggested by those authors that a higher volume might be needed in order to improve the success rate of this paravertebral sciatic approach.

Combined US/electrolocation-guided sciatic nerve block

Several authors have described different approaches to an ultrasound-guided sciatic nerve block (Costa-Farre et al. 2011; Campoy et al. 2010; Echeverry et al. 2010; Shilo et al. 2010). Note that Costa-Farre uses an "out-of plane" needling technique.

Equipment

- High frequency transducer (9–15 MHz) with sterile sleeve when indicated;
- peripheral nerve stimulator;
- insulated needle (22-gauge 50 mm for small dogs, 20-gauge 100 mm for medium/large dogs);
- sterile gloves;
- syringes and needles;
- isopropyl alcohol; and
- local anesthetic ± adjuvant.

Technique (Campoy et al. 2010)

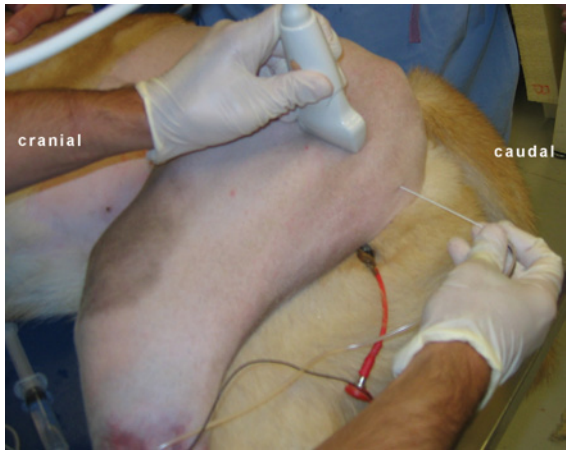
Patient positioning

- Position the patient in lateral recumbency.
- The limb to be blocked should be positioned uppermost and extended in a natural position.
- Clip scanning area and puncture site.

Anatomic landmarks (ultrasound anatomy)

With the transducer oriented in a craniocaudal position over the lateral aspect of the thigh immediately distal to the ischiatic tuberosity, a short axis view of the sciatic nerve is obtained (Figure 13.24). Using this approach, the biceps femoris muscle is lateral (closest to the ultrasound probe) to the sciatic nerve. Deep (medial) to the biceps femoris are the semimembranosus and adductor muscles. The semitendinosus muscle is located caudal to the biceps femoris. The sciatic nerve can be seen as a small double-discoid hyperechoic structure with hypoechoic center, located deep (medial) to the biceps femoris and cranial to the semitendinosus muscle. The needle puncture site is located in the caudal aspect of the thigh immediately distal to the greater trochanter and ischiatic tuberosity, in-plane with the ultrasound transducer.

(a)



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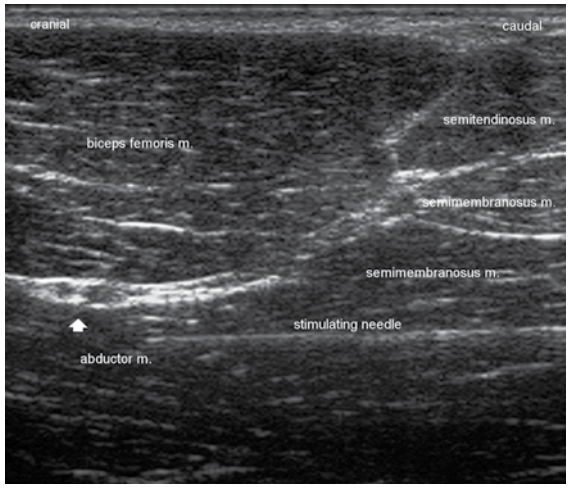

Figure 13.24 (a) With the nondominant hand, place the transducer over the area immediately distal to the greater trochanter and ischiatic tuberosity. Insert the stimulating needle in a caudocranial direction, guiding it through the semimembranosus muscle and medial to the fascia of the biceps femoris muscle towards the sciatic nerve. (b) Ultrasonographic cross-section (short axis) view of the sciatic nerve (arrow head) deep to the biceps femoris muscle.

Step-by-step technique

- Perform a final sterile preparation of the puncture site.
- Place the transducer over the area immediately distal to the greater trochanter and ischiatic tuberosity.
- Glide, rotate, and tilt the transducer until the fascia of the biceps femoris, semimembranosus and semitendinosus muscles can be seen (Figure 13.24b).
- Set the peripheral nerve locator to deliver a 0.4 mA current output at 1 or 2 Hz.
- Insert the stimulating needle in a caudocranial direction, guiding it through the semimembranosus muscle and medial to the fascia of the biceps femoris muscle (Figure 13.24a).
- Advance the needle towards the sciatic nerve, keeping the needle tip in the field of ultrasound view at all times.
- Watch for the characteristic twitch pattern: plantar extension of the foot, corresponding to stimulation of the tibialis nerve component, or dorsiflexion of the foot, corresponding to stimulation of the peroneal nerve component.

Clinical tips

- Recommended volume to be injected: 0.05–0.1 mL kg^{-1} (Costa-Farre et al. 2011; Campoy et al. 2010; Shilo et al. 2010). However, the final injection volume should be assessed by monitoring the ultrasound image.

Technique (Shilo et al. 2010)

Patient positioning

- Position the patient in lateral recumbency with the leg to be blocked uppermost.

Anatomic landmarks (ultrasound anatomy)

- Using this approach, the sciatic nerve is identified at the level of the greater trochanter.
- The nerve is then followed proximally to the point where it crosses the ilium, just caudal to the sacroiliac joint. At this location, the sciatic nerve is visualized in its short axis as an oval, hypoechoic structure with a hyperechoic rim located medial to the ilium and lateral to the caudal gluteal artery (Figure 13.25).
- Depending on the exact plane of the ultrasound transducer, the sciatic nerve may be observed coursing ventral to the medial aspect of the ilium or to lateral aspect of the sacrum (Figure 13.26).

Step-by-step technique

- Perform a final sterile preparation of the puncture site.
- Place the transducer over the area caudal to the sacroiliac joint (Figure 13.26).
- Glide, rotate, and tilt the transducer until a long axis view of the sciatic nerve is obtained.
- Depending on the exact plane of the ultrasound transducer, the sciatic nerve may be observed coursing ventral to the medial aspect of the ilium or to the lateral aspect of the sacrum (Figure 13.25).
- Advance the needle using an in-plane technique.

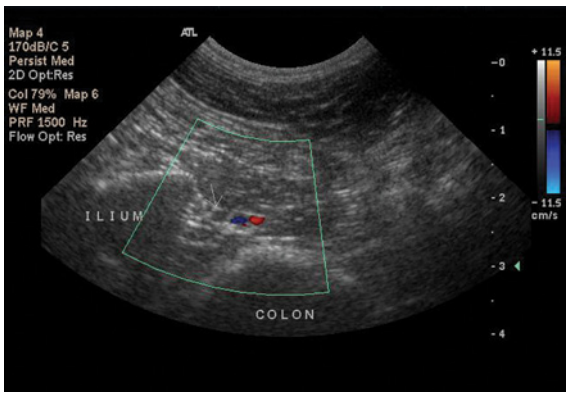

Figure 13.25 Ultrasonographic images with color-flow Doppler in short axis (transverse) plane. Sciatic nerve (arrow) with the caudal gluteal artery (red) and vein (blue) in an 8 kg dog. From Shilo et al. 2010. Used with permission.

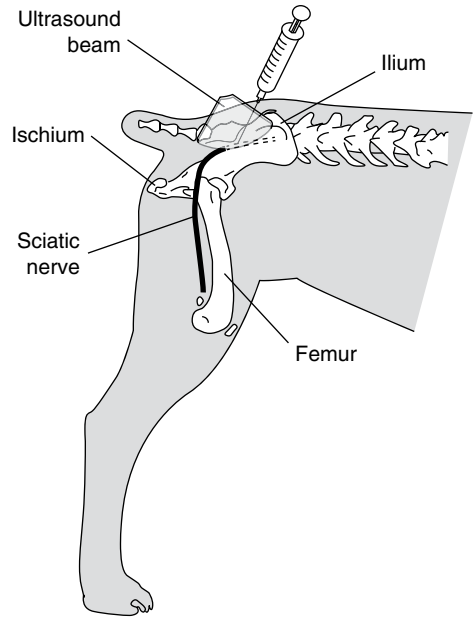

Figure 13.26 Injection technique for ultrasound-guided sciatic nerve block in the dog (right pelvic limb). Note that the nerve is visualized in the long axis and an in-plane technique is used. From Shilo et al. 2010. Used with permission.

- Watch for the characteristic twitch pattern: plantar extension of the foot, corresponding to stimulation of the tibialis nerve component, or dorsiflexion of the foot, corresponding to stimulation of the peroneal nerve component.

Potential complications and how to avoid them

The main potential complication associated with sciatic nerve block is nerve injury resulting in temporary or permanent foot knuckling. Local anesthetic should never be injected when resistance is encountered during the injection. Watch for the doughnut sign indication, perineural dispersion of the local anesthetic solution. Look for signs of nerve swelling or cavitation as the solution is injected. Local anesthetic should never be injected when a patient overtly reacts during the injection (if patient is sedated rather than anesthetized).

Intra-articular analgesia

General considerations

A strategy for providing pain management following joint surgery is the intra-articular (IA) use of local anesthetics. The technique is commonly performed for knee and shoulder arthroscopic procedures in people (Ballieul et al. 2009), even though there is only weak evidence to suggest effective reduction of postoperative pain after IA local anesthesia in human patients undergoing arthroscopic knee surgery (Moiniche et al. 1999). In veterinary medicine, stifle and coxofemoral joint injections are also commonly performed, but potentially any joint can be injected with local anesthetics.

Indications

Indications for IA drug administration include the provision of perioperative analgesia. Additionally, IA injections can be used to provide relief in patients suffering from chronic pain such as advanced osteoarthritis. Intra-articular injection may also be a useful as a diagnostic tool to confirm IA pain when physical examination and diagnostic imaging fail to provide conclusive answers (Van Vynckt et al. 2010).

Choice and dosing of local anesthetics

The drugs most commonly used for diagnostic and therapeutic purposes in human and small animal practice include lidocaine, mepivacaine, bupivacaine, or ropivacaine. When injected preoperatively, the addition of epinephrine (1:100 000) to the local anesthetic solution helps to minimize hemorrhage during the surgical procedure. The addition of buprenorphine (3 µg kg^{-1}) or morphine (0.1 mg kg^{-1}) to the local anesthetic solution will extend the total analgesic duration of the intra-articular block. Intra-articular use of clonidine (Reuben and Connelly 1999) or dexmedetomidine (Al-Metwalli et al. 2008) also enhances analgesia after arthroscopic knee surgery in people. Corticosteroids (i.e. betamethasone and methylprednisolone) and hyaluronic acid are also used as intra-articular therapies in cases of osteoarthritis. Stem cell therapy is currently being investigated as part of the treatment of osteoarthritis (Black et al. 2008).

Toxicity of intra-articular local anesthetics

Recently, attention has been drawn to the possible toxic effects of local anesthetics on chondrocytes. Bogatch et al. (2010) studied the effects of lidocaine and bupivacaine on bovine articular chondrocytes in a suspension culture. Their results suggest potential chemical incompatibility of the drugs producing formation of needle-like crystals in synovial fluid and chondrocyte death. The chondrotoxicity of local anesthetics appears to be dose- and time-dependent. Prolonged intra-articular administration of high concentrations of local anesthetic solutions may result in adverse clinical effects (chondrolysis) (Karpie and Chu 2007). A single IA injection of 0.5% bupivacaine led to reduced chondrocyte density without chondrolysis six months after injection (Chu et al. 2010). In other studies, a single injection of low-concentration bupivacaine appears to be safe (Webb and Ghosh 2009). Incidentally, most clinical case reports of IA complications in people describe chondrolysis following continuous bupivacaine infusions (Anderson et al. 2010). Ropivacaine has been shown to be less chondrotoxic than bupivacaine (Piper and Kim 2008). Evidence relating to the effects of epinephrine and preservative agents found in local anesthetic solutions on intra-articular surfaces has yet to be elucidated (Webb and Ghosh 2009).

Distribution of local anesthesia and analgesia

The IA injection of local anesthetics will provide blockade of intra-articular structures only, and analgesia of extra-articular structures and the skin will not be achieved. Using this technique does not replace the requirement for supplemental analgesics in cases of open surgical procedures; however, it may reduce the dose and interval for administrating supplemental analgesic therapy (Day et al. 1995).

Equipment

A standard regional anesthesia tray is prepared with the following equipment:

- sterile gloves;
- syringes;

- hypodermic (stifle joint) or spinal (hip joint) needles (22–23-gauge); and
- local anesthetic ± adjuvant.

Technique for stifle joint injection

Patient positioning

- Position the patient in dorsal or lateral recumbency.
- A pillow, towel roll, or large sandbag can be placed in the popliteal space to provide stability.
- The stifle joint should be in a flexed position.
- Clip the area between the patella and the tibial tuberosity.
- Perform an initial skin preparation.

Anatomic landmarks

- Patella and tibial tuberosity
- Patellar tendon

Step-by step procedure

- Perform a final sterile preparation of the puncture site.
- Insert the needle lateral to the patellar ligament, half way between the cranial pole of the patella and the tibial tuberosity (Figure 13.27).
- Once the needle has entered the joint, the hub of the needle should be observed for presence of synovial fluid (confirming correct needle position). However, absence of synovial fluid (i.e. mild or no joint effusion) does not necessarily rule out correct needle location. In this case, a 2–3 mL syringe is attached to the needle and 1 mL of local anesthetic is injected.
- The syringe is then removed from the needle. Look for spontaneous backflow of the local anesthetic solution, confirming the correct IA position of the needle (Luc et al. 2006).
- Depending on the size of the patient, 1–6 mL of local anesthetic solution is then injected into the joint. Lack of resistance during injection confirms correct IA position of the needle tip and excludes injection into periarticular soft tissue or fat pad.

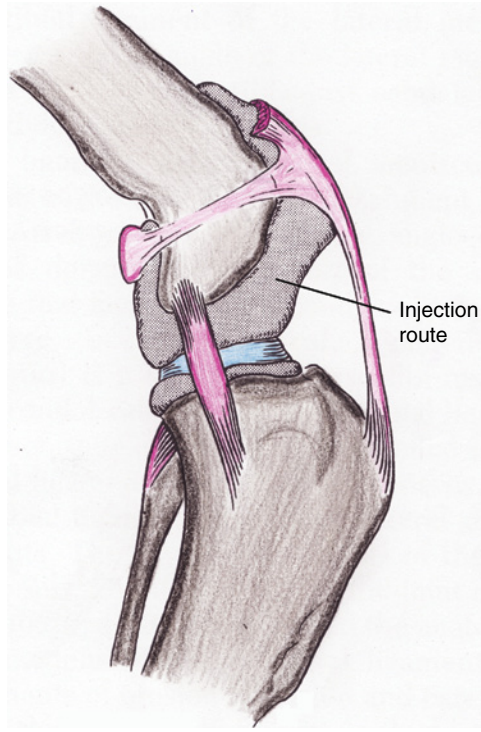

Figure 13.27 Lateral aspect of the right stifle joint showing the position and direction for needle placement during intra-articular injections. The needle is in the midline and would pass between the femoral epicondyles and menisci if inserted to its full depth.

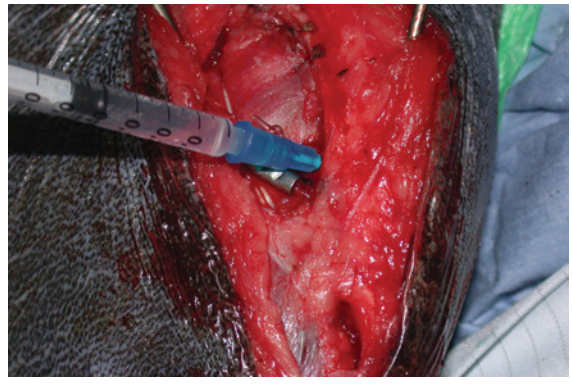

Figure 13.28 Photograph of an intra-articular injection being performed during surgery of the stifle of a dog.

Intra-articular injection can also be performed intraoperatively. Immediately after joint closure, the surgeon inserts the needle into the articular space under direct view (Figure 13.28).

- 1–6 mL of local anesthetic solution is injected into the joint.
- As leakage may occur through the suture line and decrease the total volume of analgesic placed into the joint, an option is to introduce a catheter in the joint during closure of the different layers including fascia, subcutaneous tissue, and skin. After the surgery is finished, the intra-articular injection is performed and the catheter is pulled out of the joint.

Technique for hip joint injection

Patient positioning

- Position the patient in lateral recumbency with the coxofemoral joint to be injected located uppermost.
- Adduct the limb slightly (30° of hip flexion) with the stifle in a neutral position (Saunder et al. 2004).
- Clip the area around the greater trochanter.

Anatomic landmarks

- Greater trochanter.

Step-by-step procedure

- Perform a final sterile preparation of the puncture site.
- The puncture site is located 5 mm cranial and 15 mm proximal to the greater trochanter in a mid-sized dog.
- Once the needle has penetrated the joint, the hub of the needle is observed for evidence of synovial fluid (this would confirm correct needle positioning). However, absence of synovial fluid (i.e. mild or no joint effusion) does not rule out correct needle positioning. In this case, a 2–3 mL syringe is attached to the needle and 1 mL of local anesthetic is injected.
- The syringe is then removed looking for a spontaneous backflow of local anesthetic solution, confirming the correct IA position of the needle (Luc et al. 2006).
- Depending on the size of the patient, 1–6 mL of local anesthetic solution can be injected into the joint. Lack of resistance during injection confirms correct IA position of the needle tip and excludes injection into periarticular soft tissue or fat pad.
- Intraoperative hip joint injection is not satisfactory as hermetic suture of the joint is difficult to achieve.

Complications

- Intra-articular injections are associated with very few complications or adverse reactions.
- The most obvious concern about IA injections is infection. Strict adherence to sterile technique is of utmost importance.
- Serum levels of lidocaine and bupivacaine obtained after local anesthetic IA injection are below toxic levels for both single injection and continuous irrigation (Weiker et al. 1991).
- Failure to inject the drug in the articular cavity.
- Cartilage or IA ligament laceration.

Clinical tips

- One method that has been suggested in order to increase the efficiency of analgesics placed in the stifle joint involves placing a tourniquet above the joint and inflating it to 300 mmHg before the IA injection is performed. The tourniquet should be left on for 10 minutes and then released (Pascoe 2000).

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14 Epidural and Spinal Anesthesia

Pablo E. Otero and Luis Campoy

Overview

The administration of agents with analgesic properties via the epidural or spinal routes has been used for many years to provide highly effective localized anesthesia and analgesia to small animal patients. "Epidural" (extradural) anesthesia involves administration of a local anesthetic (or other drug) into the epidural space (outside the dura), whereas the administration of the drug into the subarachnoid space is known as "spinal," "subarachnoid," or "intrathecal" anesthesia. Drug access to the site of action is largely dependent on the drug's physical and chemical properties and its interaction with the different membranes that cover and protect the nervous tissue. Sound anatomic knowledge and an understanding of the effects of drug selection are essential for the safe implementation of these techniques.

Anatomy of the spine

Dogs and cats have seven cervical vertebrae, 13 thoracic vertebrae, seven lumbar vertebrae, three sacral vertebrae, and up to approximately 20 coccygeal (caudal) vertebrae. The three sacral vertebrae are fused into a single unit to form the sacrum. The cervical, thoracic, and lumbar vertebrae represent approximately 27%, 37%, and 29% of the total spinal length respectively, whereas the sacrum only accounts for 7% of the total spinal length (Fletcher and Kitchell 1966; Evans and Miller 1993).

The vertebral canal extends from the foramen magnum on the back of the skull to the sixth coccygeal vertebra. The canal is elliptical in cross-section, and is wider horizontally than vertically. The supraspinous ligament attaches to the apices of the dorsal spinous processes and extends from the thoracic to the coccygeal segments. The interspinous ligaments connect adjacent spinous processes along their entire height from top to bottom.

The vertebral canal consists of the epidural space and intrathecal structures that include the spinal cord, the meninges, and the cerebrospinal fluid (CSF) (Figures 14.1, 14.2, and 14.3). The dorsal longitudinal ligament is attached to the vertebrae and the intervertebral disks and forms the floor of the vertebral canal. This ligament widens where it is in contact with the intervertebral disks. The roof of the vertebral canal is formed by individual

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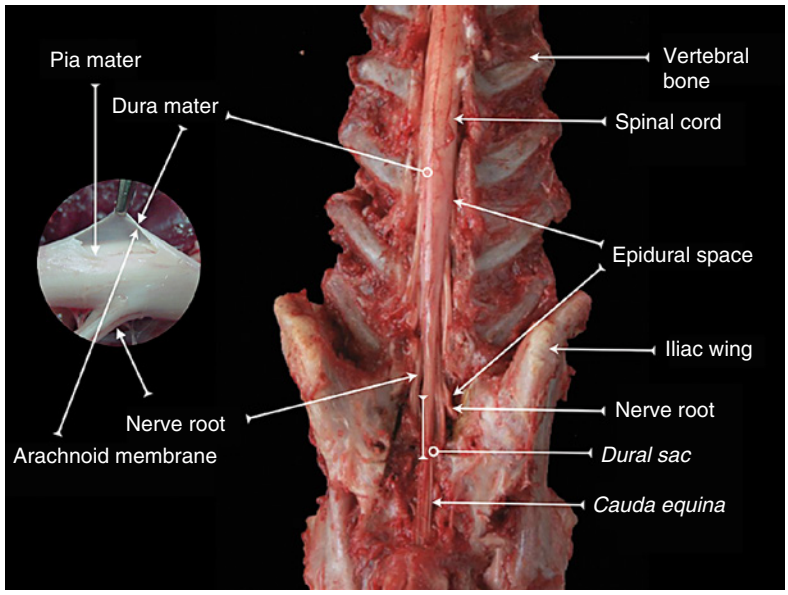

Figure 14.1 Dorsal view (coronal section) of the lumbar spine of a dog.

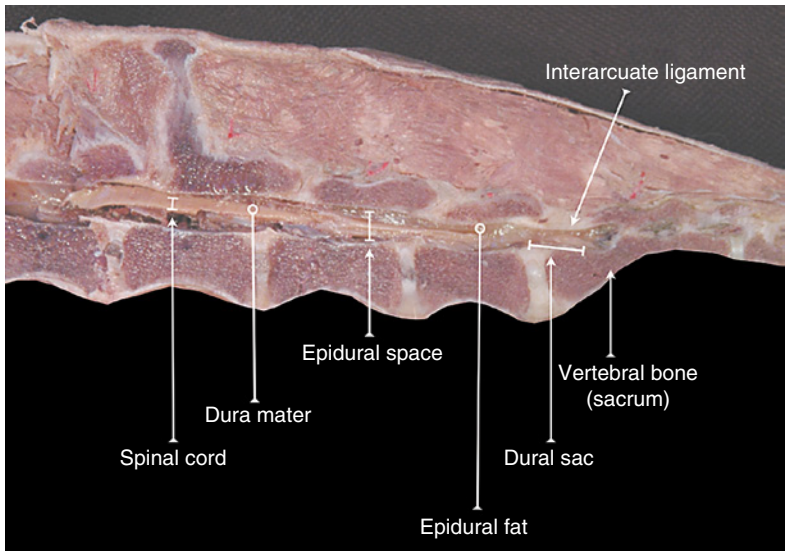

Figure 14.2 Lateral view (sagittal section) of the lumbar spine of a dog.

vertebral laminae and the interarcuate ligament (also referred to as the "ligamentum flavum" or "yellow ligament") which widens at the level of the intervertebral spaces. The sides of the vertebral canal are formed by intervertebral pedicles and foramina.

The spinal cord courses through the vertebral canal from the brain to the caudal lumbar region (Figure 14.4). Caudally, the spinal cord tapers into a conical structure called the conus medullaris. In large breed dogs, the conus medullaris typically extends only as far as the sixth or seventh lumbar

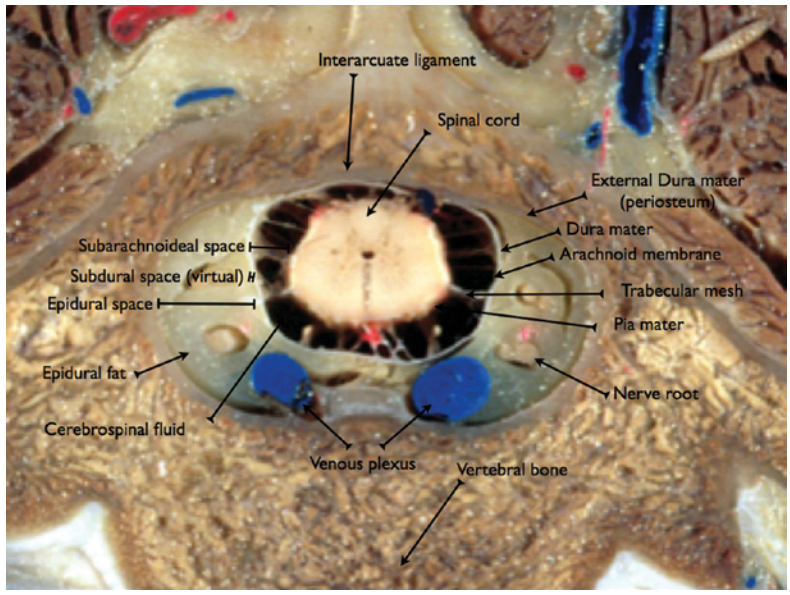

Figure 14.3 Transverse view (axial section) of a dog spine at the level of L5.

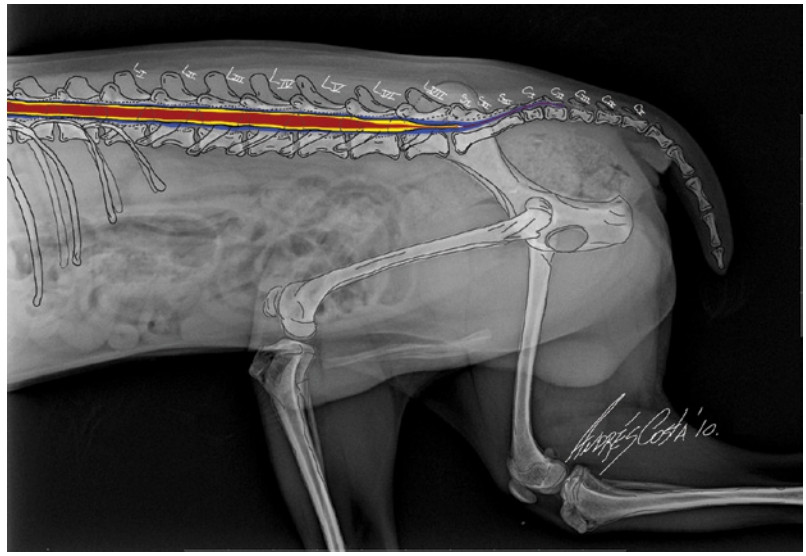

Figure 14.4 Lateral radiograph of a dog in lateral recumbency. The overlay shows the spinal cord (red) with filum terminale, subarachnoid space (yellow) and dura mater (black outline). The epidural space is shown as blue.

vertebrae, whereas in small breed dogs and cats it continues caudally to the level of the lumbosacral space. At birth the spinal cord extends even further caudally, often to the level of the sacrum.

The spinal cord is supplied by three arteries that extend along its entire length. The ventral spinal artery lies along the surface of the ventral fissure of the spinal cord and supplies oxygenated blood to the gray and white matter of the spinal cord. Paired dorsolateral spinal arteries run along each side of the cord near the furrow from which the dorsal roots of the spinal nerves arise. Venous circulation

within the vertebral canal comprises an internal vertebral venous plexus that runs along the floor of the canal, draining blood from the structures inside the vertebral canal (Figure 14.3).

The epidural space and the meninges

The meninges consist of three layers of tissue that surround the brain and spinal cord (Figure 14.1). A main function of the meninges and the CSF contained within them is to protect the central nervous system. The pia mater is the innermost membrane and is firmly attached to the spinal cord itself. The arachnoid membrane is the middle layer and is adhered on its outermost surface to the dura mater. Cerebrospinal fluid is contained within the subarachnoid space that exists between the pia mater and the arachnoid membrane. The subarachnoid space is a trabecular mesh that separates the arachnoid membrane from the pia mater (Figure 14.3). The fluid-filled subarachnoid space extends beyond the last segment of spinal cord and is called the lumbar cistern (Figure 14.4). The dura mater is the outermost layer of tissue and continues caudally past the termination of the spinal cord to form a structure referred to as the dural sac (Figure 14.2). As the dura mater continues even further caudally, it tapers down to form a thin tubular ligament referred to as the filum durae matris spinalis. This structure covers the filum terminale (glial and ependymal cells that originate from the spinal cord) and continues into the second or third coccygeal vertebra (Evans and Miller 1993).

The dura mater (dura mater spinalis) is closely adhered to the arachnoid membrane (Figure 14.1). Together, they form a cylindrical tube with lateral extensions that accompany the spinal nerves as they exit the vertebral canal through their respective intervertebral foramina. Each nerve root (ventral and dorsal branches) that emerges from the spinal cord is initially covered by an extension of the meninges (dura mater and arachnoid membrane) which will blend with connective tissues to form what will later become the sheaths of the peripheral nerves (Evans and Miller 1993).

The dural sac can be inadvertently punctured during performance of epidural anesthesia. In dogs, the dural sac typically ends at the level of L6–L7, whereas in cats it can extend caudally as far as the first sacral segment (Figure 14.4). This is why it is much more common to see a "wet-tap" when performing epidural anesthesia in cats-even a needle that is correctly located at the lumbosacral space can puncture the dural sac, allowing CSF to enter the needle and be detected in the needle hub. This may also occur in small breed dogs and should be a consideration prior to performance of the block. The anesthetist should anticipate the possibility of this event occurring and should have a plan to deal with dural puncture if and when it does occur in some patients.

The cauda equina comprises a bundle of nerve fibers formed by the roots of the sacrum and caudal segments and is located within and caudal to the dural sac, around the filum terminale. In dogs, the cauda equina is located within the epidural space at the level of the sacrum and the tail and comprises spinal nerve roots covered by individual meningeal sheaths (Figure 14.1) (Evans and Miller 1993).

The "epidural space" is the potential space that is located between the dura mater and the wall of the vertebral canal (Figure 14.3). It contains adipose and connective tissues as well as the internal vertebral venous plexus. The epidural space is typically larger at the level of the lumbosacral space as the dural sac tapers off in this area. As the lumbosacral intervertebral space and the epidural space are both largest at this location, epidural anesthesia is typically performed in dogs and cats at this location as it gives the anesthetist the greatest chance of performing a successful block.

Medulla spinalis and nerve roots

Dorsal and ventral rootlets emerge bilaterally from each vertebral segment of the spinal cord. These rootlets bind together to form the dorsal and ventral nerve roots. The dorsal and ventral roots progress towards the intervertebral foramen separately, at which point they merge to form the corresponding spinal nerve. The length of each root, from its source in a specific medullar segment to the exit through the corresponding intervertebral foramen, is variable and depends on the spinal region in which it is located. From T1 caudally, spinal nerves exit the vertebral canal through intervertebral foramina located caudal to the named vertebra (Fletcher and Kitchell 1966). After leaving

the vertebral canal, spinal nerves divide into a dorsal branch, a ventral branch, and a ramus communicans that will join the ganglia of the sympathetic trunk.

Physiology of somatic and autonomic blockade

Somatic blockade

Site of action of local anesthetics

The principal site of action for local anesthetics that are administered by the epidural route is the nerve root (Figures 14.5 and 14.6). The spinal roots become blocked when they are bathed by the local anesthetic solution, as the local anesthetic diffuses along a concentration gradient through the different nerve structures (Liu and Bernards 2002; Bernards et al. 2003a, b).

The pelvic limb is supplied by spinal nerves arising from L3 to S1 (lumbosacral plexus). To obtain segmental blockade that achieves sensory and motor block of the entire pelvic limb, local anesthetics must be administered at a volume that is sufficient to spread up to the level of L3. The abdominal wall and peritoneum are innervated by spinal nerves arising from T11 to L3 (Evans and Miller 1993). Therefore, to obtain complete blockade of the abdominal wall, the local anesthetic solution must be able to spread from the site of injection up to the level of T11. This is an important consideration when considering which drugs to use and at what volume to use them.

Distribution of regional anesthesia and analgesia

The cranial migration of a solution administered in the epidural space is related to the injected volume of local anesthetic solution. Anesthetics administered at the level of the lumbosacral space are distributed in caudal, cranial, and lateral directions within the vertebral canal (Figure 14.6). As one would expect, lumbosacral injection requires proportionately greater volumes of solution in

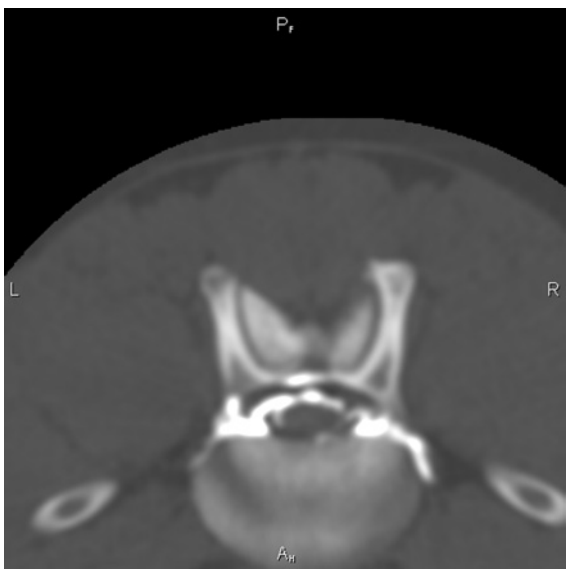

Figure 14.5 Axial computed tomographic (CT) image of the lumbar spine of a dog. An epidural injection of iohexol (240 mg iodine mL^{-1}) has been performed. Note the presence of contrast enhancement (white) bilaterally within the intervertebral foramina and exiting the canal with the spinal nerves.

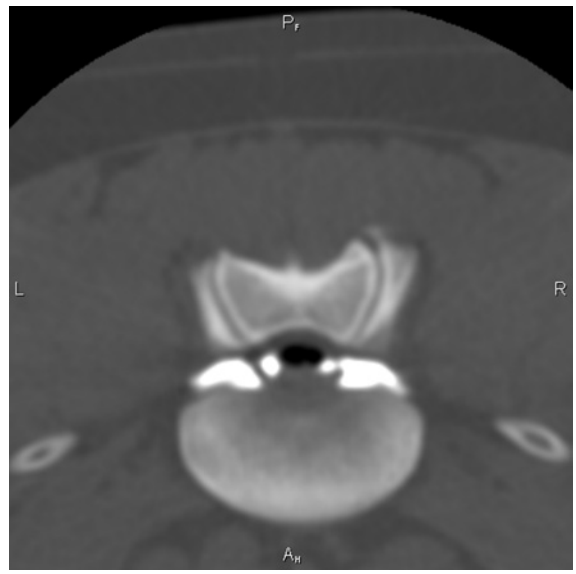

Figure 14.6 Axial computed tomographic (CT) image of the lumbar spine of a dog. An epidural injection of iohexol (240 mg iodine mL^{-1}) has been performed. There is contrast enhancement (white) bilaterally within the intervertebral foramina. The black area dorsal to the spinal cord represents air that was inadvertently injected into the epidural space during administration of the iohexol solution. Every effort should be made to avoid injecting air into the epidural space as it can direct the local anesthetic solution away from its target sites (the spinal nerves).

order to achieve the same level of blockade when compared with injections that are performed at lumbar spaces cranial to L7. This is due to the loss of local anesthetic through the lateral sacral foramina (Burn et al. 1973; Park et al. 1980), and the fact that there is a relatively larger volume of vertebral canal to fill with drug solution. Solutions injected at intervertebral spaces cranial to L7 tend to flow in a predominantly cephalad (cranial) direction (Vas et al 2003; Freire et al. 2010), whereas this may not be the case when the traditional L7–S1 site is used.

There are many factors that can affect the spread of solutions that are administered into the epidural space:

- volume and concentration of drug (Lee et al. 2004a; Duke et al. 2000);
- speed and pressure during injection (Iff et al. 2007);
- site of injection (Visser et al. 2008);
- direction of the needle bevel (Visser et al. 2008);
- position of the animal (Gorgi et al. 2006);
- size and permeability of the intervertebral foramina (Bromage 1962);
- amount of fat in the epidural space (Lee et al. 2004b; Lundblad et al. 2011);
- size of the associated venous and lymphatic plexus (Park et al. 1980);
- age and physical condition (Bromage 1962); and
- baricity and specific gravity of the injected solution.

Volume and concentration

The cranial (cephalad) migration of a solution that is administered in the epidural space increases as the injected volume increases. This observation has been described in several species (Johnson et al. 1996; Lopez et al. 1997; Lee et al. 2004a; Lansdowne et al. 2005; Gorgi et al. 2006; Freire et al. 2010). Once a sufficient volume of drug is used to reach a particular location (dermatome), the intensity and duration of the resulting block depends on the concentration of the local anesthetic that is administered (Gomez de Segura et al. 2009; Duke et al. 2000; Otero et al. 2007). As a result, if the local anesthetic solution is diluted too much with other agents (i.e. opioids, saline), the resulting block will not be as profound. This is often referred to as a "patchy block."

Many studies have compared the effects of equal doses of local anesthetics in solutions with different concentrations. In people, when the same total drug mass is administered epidurally in different concentrations and volumes, it produces a similar degree of sensory blockade (Duggan et al. 1988; Nakayama et al. 2002). This has also been observed in dogs following the epidural administration of various local anesthetics at different concentrations and volumes (Duke et al. 2000; Otero et al. 2007). There appears to be a minimum volume needed to achieve epidural blockade. Below this volume, the concentration of local anesthetic does not appear to have an effect on the degree of nerve blockade. However, once this minimum volume is reached, a greater concentration of local anesthetic will increase the analgesic efficacy and duration of the block. This also holds true when drugs are injected in the CSF, whereby the total drug mass injected determines the extent of the effects.

Speed and pressure of epidural injection

When epidural administration of drugs is performed quickly and with higher injection pressures, the solutions will travel further cranially. Care should be taken to administer the drug solution slowly over 1–2 minutes, and if any resistance to injection is encountered, the injection should be stopped and the needle repositioned. An easy way of determining injection pressure is to aspirate a small air bubble (1–3 mL) into the syringe that contains the injectate. Before connecting the syringe to the needle, the air bubble is made to sit next to the plunger by adjusting the orientation of the syringe (Figure 14.7). Once it is connected to the needle, as the solution is slowly injected, the air bubble should not compress more than 50% of its starting volume. If the bubble does compress, it suggests that resistance to injection is being experienced, and the injection should be stopped. After the drug solution has been completely injected, it is imperative not to inject any of the air that remains in the syringe into the epidural space.

Site of injection

With a given injection volume, the more cranial the site of injection, the further forward the solution will migrate. This needs to be taken into account if injections are not made at the lumbosacral space, from which most recommended drug volumes from the literature are assumed to be administered.

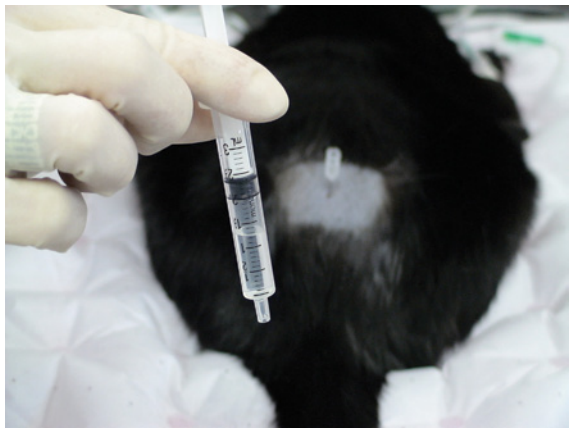

Figure 14.7 A cat has been positioned in sternal recumbency and a spinal needle placed at the lumbosacral intervertebral space. Prior to drug administration, an air bubble has been drawn into the syringe and positioned adjacent to the plunger. Once the syringe is connected to the needle, the air bubble will be used to assess resistance to injection. During injection, if the air bubble undergoes compression, resistance is being detected and the injection should be stopped.

Direction of the needle bevel

The direction of the needle bevel determines, to a minor extent, the direction that the injectate will travel. This is most relevant when a Tuohy needle is used. For example, if the needle bevel is aimed caudally, the injectate will be more directed caudally. This is not usually an issue when regular spinal needles are used.

Position of the animal

If the patient is positioned on a flat surface/table with its head down (also called the "Trendelenburg position"), the injectate will tend to migrate cranially due to the effects of gravity. This observation should be remembered in cases where a calculated volume of local anesthetic is administered, followed by the patient being positioned with the head and front of the body lower than the hind end (e.g. for perineal surgeries). In those patients, the degree of nerve blockade may be greater than anticipated, and the side effects of local anesthetic administration (vasodilation, intercostal nerve blockade) may be greater than expected. This can be easily avoided by decreasing the volume of local anesthetic to be administered.

Amount of fatty tissue in the epidural space

In children, it has been suggested that a difference in the amount of epidural fat may explain why a standardized volume of injectate travels further cranially in neonates and infants than it does in toddlers. A similar effect is thought to occur in animals.

Size of the associated venous and lymphatic plexus

When epidural venous and lymphatic vessels become engorged, the epidural space will be become relatively smaller, and it can be anticipated that a calculated volume of solution will travel further cranially. This is one consideration when performing epidural anesthesia in female patients when changes in their regional blood flow that occur with pregnancy affect the degree of distention of the venous plexus. Engorgement of epidural veins from increased intra-abdominal pressure has often been implied as the mechanism for this phenomenon. Furthermore, animal studies have shown that during pregnancy, the onset of nerve conduction blockade by local anesthetic is faster and the resulting blockade is more intense (Datta et al. 1983; Flanagan et al. 1987; Kaneko et al. 1994; Otero et al. 2003). Flanagan et al. (1987) related these observations to increased progesterone levels during pregnancy. Interestingly, patients with pyometra have been found to have similar progesterone levels to patients in the final stages of gestation (Bigliardi et al. 2004). Given these observations, pregnant animals typically require lower volumes of epidurally administered local anesthetics to achieve a given level of epidural anesthesia.

Age and physical condition

Older patients require relatively lower doses of local anesthetics. With aging, the dura mater becomes more permeable to local anesthetics due to a progressive increase in the size and number of arachnoid villi. This provides a greater area through which local anesthetics can diffuse into the subarachnoid space (Shanta and Evans 1972). It has also been proposed that a progressive decrease in the number of myelinated fibers in nerves and a general deterioration of nerve sheaths allows local anesthetics to penetrate nerve roots more readily (Bromage 1962; Dorfman and Bosley 1979).

Baricity and specific gravity

Table 14.1 Density of different injectate combinations.

Solution	Density (g mL^{-1})	Baricity
Normal saline	0.99970	0.98980
5% Dextrose	1.0130	1.00297
0.5% Bupivacaine	0.99950	0.98961
0.5% Bupivacaine with 5% dextrose	1.00085	0.99094
0.5% Bupivacaine with 8% dextrose	1.01678	1.00671
Fentanyl	0.99959	0.98969

Adapted from Hallworth et al. 2002.

When drugs are administered spinally (into the CSF), there is mixing with CSF. The "specific gravity" of a solution is the ratio of the density of the solution when compared with the density of water. The "baricity" of a solution is the ratio of the density of a solution when compared with the density of CSF. The density of CSF has been reported to be approximately 1.010 (1.005–1.017) g mL^{-1} in dogs and 1.010 (1.005–1.021) g mL^{-1} in cats (Mosing et al. 2006). As a general rule, drug formulations with densities >1.010 are considered to be hyperbaric to CSF (Table 14.1). Hyperbaric solutions will "sink" within the CSF, promoting blockade of areas located downmost and will tend to travel along the spine following gravity. Hypobaric solutions will tend to float within the CSF therefore promoting blockade of areas located uppermost. Isobaric solutions are distributed homogeneously within the CSF and remain suspended in solution regardless of the patient's position (Faust et al. 2003).

These considerations are only applicable to the spinal administration of solutions and do not have any bearing on spread following epidural administration of drugs (the majority of cases for small animal patients).

Autonomic blockade

Cardiovascular

The negative cardiovascular effects of spinal and epidural anesthesia are usually the result of preganglionic sympathetic blockade, although there may also be some contribution from other effects following systemic absorption of the drugs from the epidural space. The typical cardiovascular effects that follow epidural administration of local anesthetics include vasodilation in the affected dermatomes with resultant hypotension, and more rarely, bradycardia.

The degree of sympathetic nerve blockade caused by spinal or epidural anesthesia is directly related to the anatomic extent of the block. In people, sympathetic nerves located two to six dermatomes further cranial than the level of the sensory block may become blocked following spinal or epidural anesthesia (Brull and Greene 1991; Veering and Cousins 2000). This observation may explain why vasodilation and hypotension are seen so commonly following epidural anesthesia in small animals as well. Fibers in the sympathetic chain arise from the T1 to L4 segments of the spinal cord. Sympathetic fibers maintain a background level of vascular tone on arteries and veins throughout the body. Blocking spinal nerves arising between T5 and L3 will result in vasodilation, pooling of blood in venous circulation, and subsequent decreased venous return (preload) to the heart. This will effectively decrease cardiac output and may manifest as systemic hypotension. Usually, these effects are predictable, minor, and pose no risk to cardiovascularly stable patients. When hypotension occurs, administration of intravenous fluids for volume expansion can easily be instituted. Based on these cardiovascular effects, epidural administration of local anesthetics should be avoided in patients with uncorrected hypovolemia and hypotension as these effects can potentially worsen their condition.

The cardiac accelerator nerve fibers that innervate the heart arise from the T1 to T4 segments of the spinal cord and stimulate increases in heart rate and inotropy in response to decreases in arterial blood pressure. In cases where local anesthetic solutions are administered across the T1 to T4 levels (e.g. inadvertent cranial spread, use of a thoracic epidural catheter), heart rate and cardiac contractility may be decreased when sympathetic outflow from these segments is blocked. If a patient experiences cardiovascular collapse (extreme hypotension without manifesting an increase in heart rate), this mechanism must be considered and appropriate supportive actions should be taken immediately.

Metabolism and hormones

Surgical trauma typically produces a localized inflammatory response, a systemic neuroendocrine response, and activation of somatic and visceral afferent nerve fibers. In people, epidural anesthesia has been shown to inhibit surgically induced signs of stress, including the increases in plasma levels of cortisol, aldosterone, renin, epinephrine, and norepinephrine that are typically seen (Covino and Scott 1985). Blockade up to the level of T11 can potentially block the adrenal pathways and partially or totally suppress these stress responses. Almeida et al. (2007) reported that plasma norepinephrine concentrations (but not cortisol) decreased after epidural administration of bupivacaine, fentanyl-bupivacaine, and sufentanil-bupivacaine. Sibanda et al. (2006) reported a significant decrease in cortisol levels after epidural administration of a bupivacaine-morphine solution. In a study involving dogs, no changes in plasma cortisol concentration were observed following epidural administration of 2% lidocaine (Simeonova et al. 2008).

Indications and contraindications

Indications

Epidural anesthesia for small animal patients is typically administered by a single injection via the lumbosacral intervertebral space, and can be used to provide anesthesia and analgesia for surgical, medical, or diagnostic procedures caudal to the patient's umbilicus. Most commonly, the technique is used to provide analgesia for surgery of the pelvis, pelvic limbs, perineal procedures, and some caudal abdominal procedures. Recently, the use of epidural anesthesia for blockade of thoracic segments in dogs has been reported (Oliveira et al. 2009). Additionally, epidural analgesia can be used as method of providing postoperative pain relief for variable periods of time, whether as a single injection or through use of an indwelling epidural catheter. For example, lumbosacral epidural administration of morphine to dogs and cats can reduce the requirements for analgesics during the postoperative period for up to 24 hours (Pascoe and Dyson 1993; Troncy et al. 2002).

Single-shot epidurals are limited in their duration of effect by the pharmacology of the drugs that are used. In many cases, prolonged durations of analgesic effect are desirable, especially for severely injured patients or for those patients that are undergoing extensive surgical procedures. Similar to their use in people, indwelling catheters are useful for providing repeated or long-term epidural anesthesia and analgesia to veterinary patients. Many epidural catheter products are available to veterinarians, and the methods used to place them in patients have been well described, along with their benefits (see below).

Contraindications/precautions

There are several absolute contraindications, as well as some relative contraindications, that need to be remembered prior to administration of epidural or spinal anesthesia to small animal patients.

- Epidural anesthesia is contraindicated in patients with bleeding disorders (thrombocytopenia, coagulation disorders) due to their increased risk of hemorrhage. As the small epidural vessels and sinuses reside within the vertebral canal, if the spinal needle inadvertently lacerates a small vessel during performance of the epidural block, the bleeding would be non-compressible and may result in an epidural or subarachnoid hematoma and subsequent spinal compression and neurological deficits. In patients with clinical bleeding disorders, epidural anesthesia should be avoided.
- Epidural anesthesia using a local anesthetic should be avoided in patients with uncorrected hypovolemia and hypotension. This is due to the increased risk of hypotension following sympathetic nerve blockade, as local anesthetics administered into the epidural space will not only block pain and motor fibers, but also sympathetic fibers. Even in normal patients, local anesthetics will cause some degree of hypotension by inducing vasodilation in the blocked dermatomes. In cases where a patient is already hypovolemic and hypotensive, these effects will be more profound and the patient will be unable to control its vasomotor tone in the blocked areas. This is only a concern when

local anesthetics are used, and other agents such as opioids may still be used safely in these patients to provide analgesia without causing motor or sympathetic blockade.
- Epidural anesthesia should be avoided in patients with documented infections or neoplasia at the site of lumbosacral injection. If infection or tumor cells are introduced into the vertebral canal, there may be catastrophic neurologic consequences. Alternative routes of epidural anesthesia (e.g. sacrococcygeal route) may be considered, but most often, alternative analgesic protocols are used instead.
- It has been suggested that epidural anesthesia using a local anesthetic should not be recommended for patients with left ventricular outflow obstruction (e.g. valvular aortic stenosis, hypertrophic subaortic stenosis, mitral stenosis) as compensatory increases in cardiac output in response to drug-induced vasodilation and hypotension may be limited in these patients. However, Ho et al. (2008) published successful epidural anesthesia management of 1947 people with diagnosed aortic stenosis.
- Neuroaxial anesthesia in the presence of sepsis or bacteremia may predispose patients to hematogenous spread of the infection into the epidural/spinal space. This would likely only occur if a vessel in the epidural space were lacerated and hemorrhage occurred into the vertebral canal. This consideration is controversial, and is considered by some authors to be a relative contraindication as the overall risk of bleeding is low when an epidural is performed properly.
- Congenital or traumatic anatomic abnormalities may represent a relative contraindication due to the potential increase in technical difficulty when performing the block. If the anatomic landmarks are not able to be identified with confidence, epidural anesthesia should not be performed.
- Preexisting neurologic deficits in the area to be blocked are a contraindication to performing epidural anesthesia (or any local and regional anesthetic technique). If a patient has deficits that need to be monitored for resolution or to determine prognosis, epidural anesthesia should not be performed. Despite the relatively short-lived (less than 24 hours) effects of most of the agents used, their use may make it difficult to determine if the continued presence of deficits are the result of preexisting disease or are complications from the epidural.

General considerations

Sedation and anesthesia requirements

- To prepare the patient for the procedure, an intravenous catheter should be placed.
- In most cases, patients are fully anesthetized and maintained on an inhalant anesthetic delivered with oxygen.
- Alternatively, sedation can be used. For sedation, a combination of either intravenous fentanyl (2–5 $\mu g\,kg^{-1}$) or dexmedetomidine (0.5 $\mu g\,kg^{-1}$) and propofol 2–3 $mg\,kg^{-1}$ can be administered. In these cases, oxygen may need to be supplied to the patient to minimize possible drug-induced ventilatory depression leading to hypoxemia. Additionally, local infiltration with a local anesthetic such as lidocaine 2% may be necessary at the puncture site and in the supra- and interspinous ligaments if the patient is sedated rather than anesthetized.
- In either case, the use of monitoring devices such as ECG, pulse oximetry, and blood pressure monitoring during the procedure is also highly recommended.

Animal positioning

Patient positioning is an important aspect of the procedure. Standardized positioning helps to improve the quality of the block and to minimize the risk for complications. The lumbosacral approach is technically easy to perform in dogs and cats due to the relatively wide intervertebral space at L7–S1, regardless of the patient position selected (Valverde 2008).

To perform an epidural injection, the animal may be placed in either sternal or lateral recumbency, depending on the patient's medical condition and the clinician's preference (Figures 14.8, 14.9, and 14.10). In a study carried out on canine cadavers following epidural injection of new methylene blue solution, cephalad migration was greater when

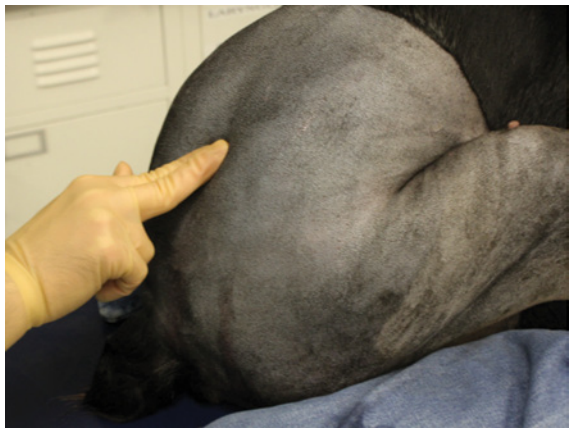

Figure 14.8 A dog has been placed into sternal recumbency. The lumbosacral area has been clipped and surgically prepared. The anesthetist's index and middle fingers are placed on the midline at the lubosacral intervertebral space (L7–S1).

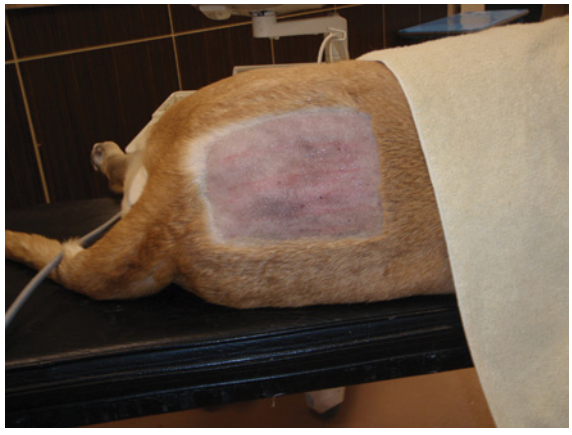

Figure 14.9 A dog has been positioned in lateral recumbency and the hair over the lumbosacral area has been clipped prior to epidural administration of local anesthesia.

dogs were positioned in lateral recumbency than when they were in sternal recumbency (Gorgi et al. 2006). However, no differences were observed in the number of stained nerve roots on either side of the epidural canal.

Sternal recumbency

Many people perform lumbosacral anesthesia in dogs and cats with their patients positioned in sternal recumbency. The spine is often easier to palpate when the patient is positioned in sternal

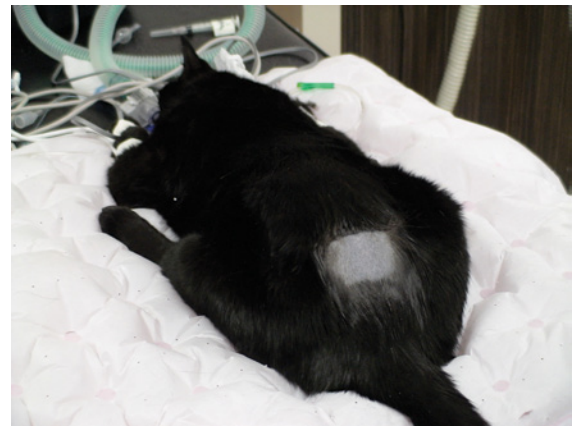

Figure 14.10 A cat is positioned in sternal recumbency prior to administration of epidural anesthesia.

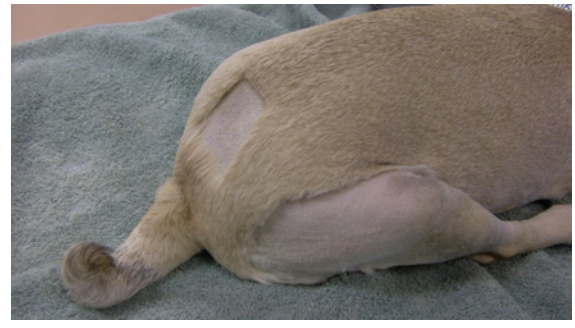

Figure 14.11 A Pug has been positioned in sternal recumbency with its pelvic limbs pulled forward (kyphosis), opening up its lumbosacral space prior to administration of epidural anesthesia.

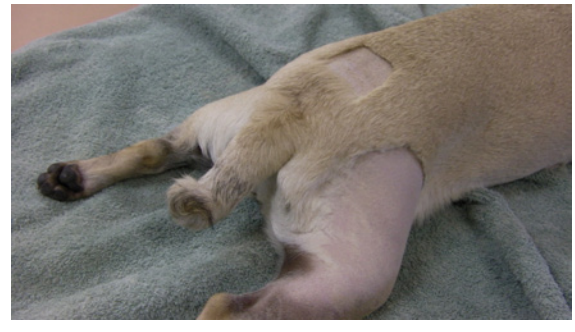

Figure 14.12 A Pug has been positioned in sternal recumbency with its pelvic limbs extended backwards. This will result in narrowing of its lumbosacral intervertebral space, making performance of a lumbosacral epidural more difficult than when the positioning in Figure 14.11 is used.

recumbency, especially in obese animals (Figure 14.8). Puggioni et al. (2006) showed that the interarcuate space was widest when animals were placed in sternal recumbency with the spine flexed in a kyphotic position (legs pulled forward rather than extended behind the patient) (Figures 14.11 and 14.12). However, if alternative approaches are used (e.g. thoracolumbar puncture between T13 and L6), sternal positioning may make the procedure more difficult. For this reason, use of sternal recumbency is not widely advocated for punctures above L6.

Lateral recumbency

Other veterinary anesthetists prefer to perform lumbosacral anesthesia in dogs and cats with their patients positioned in lateral recumbency (Figure 14.13). In lateral recumbency the spine can be either in a neutral position or flexed. In some cases, lateral recumbency is preferred over sternal recumbency as it is easier to position a patient that has pelvic or femoral fractures in lateral recumbency. In some cases, it can be more difficult to palpate the dorsal midline of overweight patients when they are positioned in lateral recumbency.

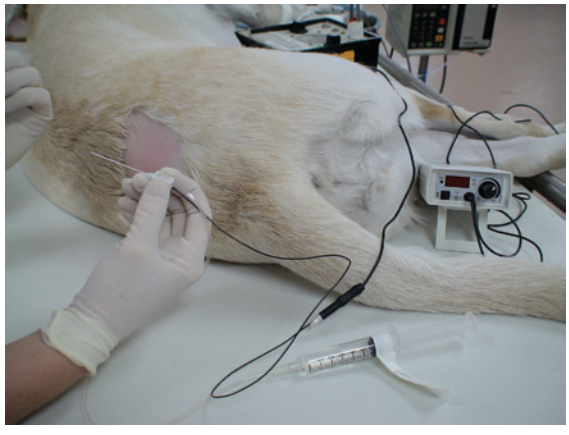

Figure 14.13 A dog has been positioned in lateral recumbency and the hair over the lumbosacral area has been clipped prior to epidural administration of local anesthesia. A nerve stimulator is being used to assist with identifying the epidural space prior to drug administration.

Methods for locating the epidural space

Several methods have been developed for confirming needle placement in the epidural space including: loss of resistance, use of a "hanging drop," and electrostimulation. Although in many cases the aid of electronic devices (plethysmography, electrolocation) may increase the degree of certainty regarding the correct positioning of the needle, no method can replace the need for knowledge of anatomy and the training of the clinician to safely and correctly perform the technique.

Loss of resistance (LOR)

Until the tip of the needle is correctly located in the epidural space, resistance to injection of air or fluid is felt while the needle is advanced through the ligaments (Figures 14.14 and 14.15). If pressure is being applied to the plunger of the syringe, a "pop" and a sudden loss of resistance to injection are usually appreciated when the needle punctures the ligamentum flavum and enters the epidural space. A false positive (LOR but incorrect needle placement) may result if the needle is located within fat. It is also possible to obtain a false negative (correct placement but no LOR) if foreign

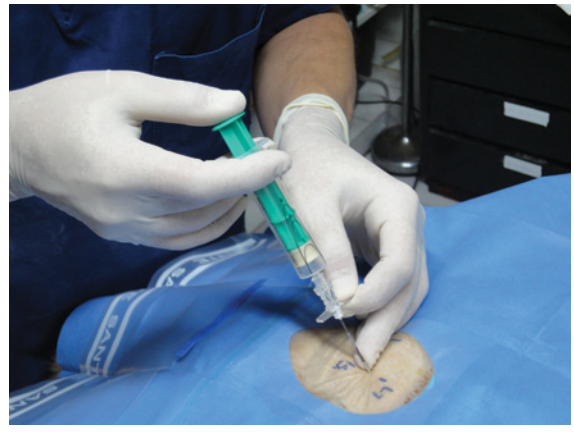

Figure 14.14 A loss of resistance (LOR) syringe is used to identify the epidural space in a dog. As the needle is slowly advanced, slight pressure is applied to the plunger of the LOR syringe. In most cases, the anesthetist will appreciate a sudden loss of resistance on the syringe when the needle has entered the epidural space. No further air should be injected.

material (blood clots, fat, periostium, skin) fills the needle shaft and causes obstruction.

If air is used for the LOR technique, a very small volume should be injected as investigators have shown that when air is used to test for the LOR ($0.3\,mL\,kg^{-1}$), there can be uneven cranial distribution of the solution and occasional compression of the spinal cord (Iseri et al. 2010). In people, air is no longer used to test needle location following placement due to the risk of injecting air into the CSF and having it migrate up the spinal cord and into the brain. Stevens et al. (1989) suggested that injection of large volumes of epidural air should be avoided, particularly when N_2O is used as part of the anesthetic or when performing diagnostic peridurography as N_2O may expand the volume of existing bubbles and interfere with filling of the epidural space by local anesthetics or contrast material.

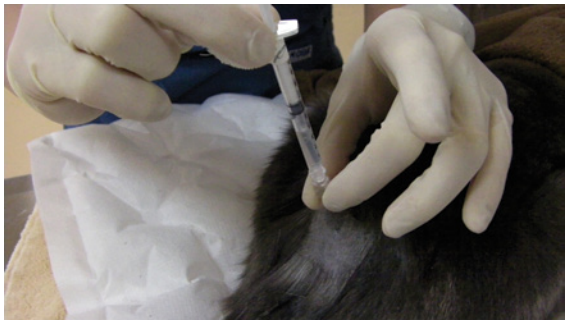

Figure 14.15 A local anesthetic solution is being administered to a cat. Once the syringe is connected to the needle, an air bubble is used to assess resistance to injection. During injection, if the air bubble undergoes compression, resistance is being detected and the injection should be stopped.

Hanging drop

In dogs, pressure within the epidural space has been reported to vary between -6 and 15 mmHg (Iff et al. 2007), suggesting that epidural pressure may be influenced by anatomic and individual differences. In most cases, if a drop of saline or local anesthetic solution is placed in the hub of the needle, as the needle penetrates the epidural space it will usually be aspirated into the space due to the subatmospheric pressure within the vertebral canal (Figure 14.16). This technique only works if the animal is positioned in sternal recumbency. Naganobu and Hagio (2007) reported positive aspiration of a saline drop in seven out of eight dogs when the epidural space was entered with the animal in sternal recumbency, and 100% false negatives when the technique was performed with the animal in lateral recumbency. The "hanging-drop" technique is useful in medium to large breed dogs, but is less reliable in smaller dogs and cats where negative pressure within the epidural space does not consistently result in positive aspiration.

Electrolocation

Electrolocation can be used to perform epidural anesthesia with the patient positioned in either lateral or

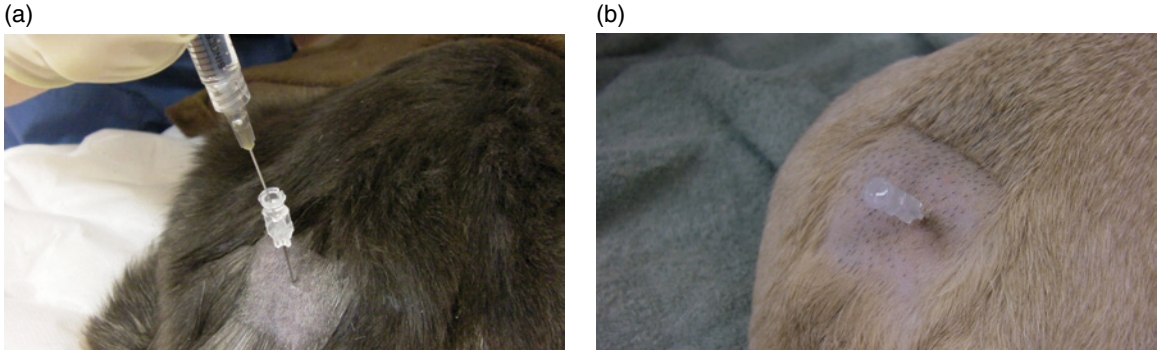

Figure 14.16 (a) A needle has been placed into the epidural space of a cat. After inspection for blood and cerebrospinal fluid, several drops of a local anesthetic solution are injected into the hub of the needle. (b) Epidural anesthesia being performed in a Pug. Several drops of local anesthetic solution have been injected into the hub of the needle and are being slowly aspirated into the epidural space which is under negative pressure. This is a positive "hanging-drop" test and confirms correct needle placement. The remainder of the drug solution should be slowly injected to complete the block.

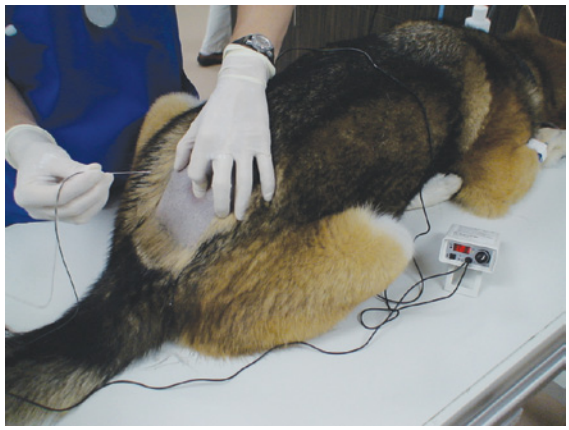

Figure 14.17 A nerve stimulator is being used to assist with identifying the epidural space prior to drug administration in a dog positioned in sternal recumbency.

dorsal recumbency (Figures 14.13 and 14.17). The current that is necessary to elicit motor responses decreases as the needle approaches the spinal nerve roots or enters the intrathecal space. Several studies have demonstrated that each layer of the spinal cord requires a different threshold current to elicit a motor response (Tsui et al. 1999, 2004, 2005; Tsui and Kropelin 2005). In dogs, the electric threshold to elicit hind limb and/or tail twitches when the lumbosacral approach is used to identify the epidural space is approximately 0.3 mA at a pulse width of 0.1 ms (Read 2005, 2007; Garcia-Pereira et al. 2010). However, when approaches other than the lumbosacral intervertebral space are used (e.g. more cranial locations), these values may be different as the dura mater is present. Usually no twitches will be seen until the needle penetrates into the epidural space. At that time, twitches in the pelvic limb and tail will be observed grossly, and stimulating currents will be <1 mA.

Epidural anesthesia in dogs and cats

Equipment

- Clippers;
- skin preparation solutions;
- Tuohy needle (22–18-gauge) or spinal needle (22–20-gauge). Surface markings at 1 cm intervals along the needle are useful;
- loss of resistance (glass or plastic) syringe;
- syringes and needles;
- extension set;
- local anesthetic ± adjuvant;
- sterile gloves; and
- fenestrated sterile drapes.

In addition to the materials listed above for single-shot epidural injections, if a catheter is to be placed into the epidural space, the following is also required:

- epidural catheter kit;
- bacterial filter; and
- light dressing material.

Lumbosacral approach to the epidural space

Anatomic landmarks

Several approaches to the epidural space can be used in small animal patients. Usually, "lumbosacral" anesthesia is performed, and the needle is placed in the epidural space between the L7 and S1 vertebrae. This is the easiest location to perform the technique, and is the one most commonly described for dogs and cats. Alternative approaches can also be used depending on the particular situation. In some cases, single-shot blocks and placement of epidural catheters can be achieved in lumbar regions cranial to L6. Recently, sacrococcygeal approaches to the epidural space have been reported for use in cats (O'Hearn and Wright, 2011). In any case, epidural anesthesia can be achieved with a combination of drugs, but the location and volume of drug solution should be considered relative to the desired effects.

Step-by-step procedure (single-shot)

Lumbosacral approach

- The patient is positioned in lateral or sternal (preferable) recumbency.
- The puncture site is located between the spinous processes of L7 and S1 (medial sacral crest) on the dorsal midline of the patient (Figure 14.8).
- The patient's hair should be clipped over the planned site and the skin should be prepared according to accepted standards (see Chapter 3).
- The needle is inserted perpendicular to the skin on the dorsal midline, caudal to the spinous process of L7.

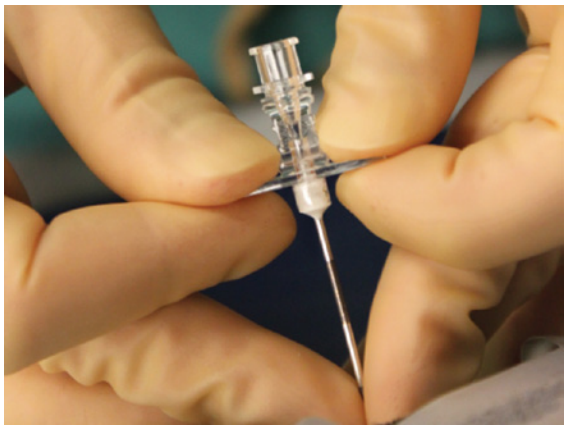

Figure 14.18 Winged Tuohy needle. Note that the index fingers and thumbs of both hands hold the wings of the needle, and the middle fingers are held in an extended position to stabilize the needle shaft as the needle is advanced.

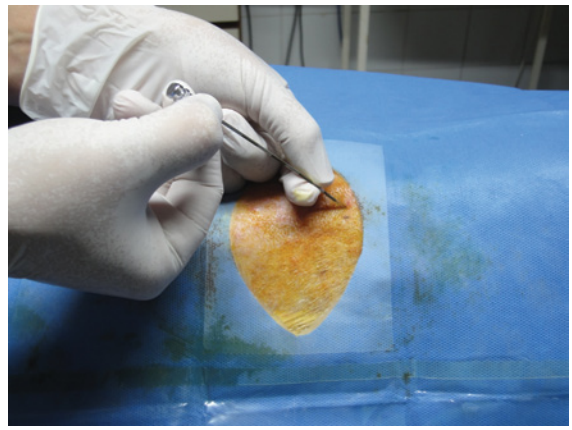

Figure 14.19 Wingless Tuohy needle. Note that the index finger and thumb of the dominant hand hold the needle hub, and the index finger and thumb of the nondominant hand stabilize the needle shaft as the needle is advanced.

- Winged needles should be handled with the index fingers and thumbs of both hands holding the wings and with the tips of the middle fingers held in an extended position to keep the needle shaft stable (Figure 14.18).
- Wingless needles should be handled with the index finger and thumb of the dominant hand holding the needle hub. The index finger and thumb of the nondominant hand can be used to palpate the anatomic landmarks or to hold the needle shaft if necessary (Figure 14.19).
- The needle is advanced through the skin and into the subcutaneous tissue. Usually there is no palpable resistance to needle advancement in these tissues.
- The needle is then advanced through the interspinous ligament until it is thought to be embedded in the ligament. Resistance will be appreciated by the anesthetist as the needle penetrates this ligament.
- At this point, if the LOR technique is to be used, the needle stylet is removed. A syringe filled with air or fluid is then connected to the needle. Slight pressure is applied on the plunger of the syringe while the needle is advanced further (Figure 14.14).
- The needle is then advanced slowly until a sudden loss of resistance is felt and the epidural space is entered.
- If during any of these manipulations the needle comes into contact with bony structures, it should be withdrawn slightly and redirected caudally or cranially as applicable. "Walking" the needle off the adjacent bones will help to identify the intervertebral space. Movements should be gentle and controlled so as to minimize the risks of causing tissue trauma.
- After the epidural space is correctly identified, the LOR syringe should be disconnected and the needle hub should be checked for the presence of CSF or blood (Figure 14.20). If either fluid is observed, the needle should be removed from the patient and the procedure should be repeated from the beginning.
- If desired, an extension set can be attched to the needle to make drug administration easier (Figure 14.21).
- Once it is determined that injection can be safely made, READ THE LABEL ON THE SYRINGE TO ENSURE THAT THE CORRECT SOLUTION IS BEING USED, and inject the anesthetic solution slowly over 1–2 minutes.
- Alternatively, the needle can be advanced through the skin, through the interspinous ligament, and into the epidural space without connecting a LOR syringe. In this case, once a "pop" is appreciated as the needle penetrates the ligamentum flavum, the stylet of the needle is removed and the hub is inspected for the presence of blood or CSF. If it is safe to proceed,

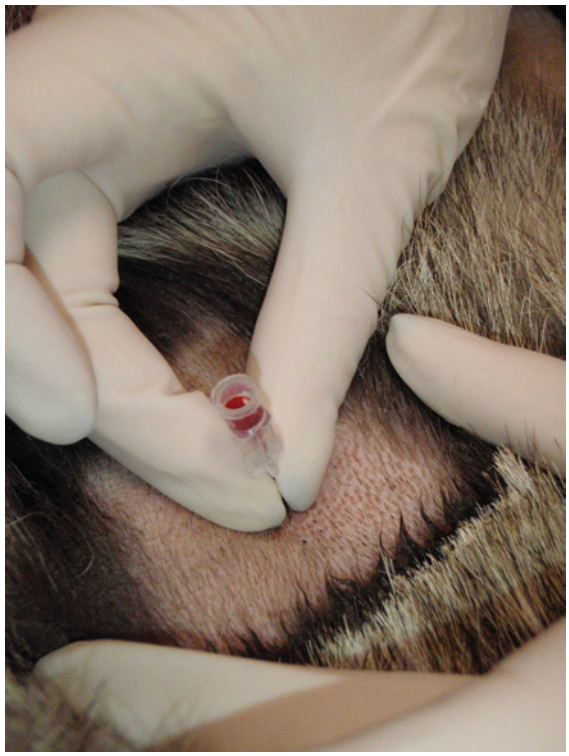

Figure 14.20 Blood is detected in the hub of a needle that has been placed into the vertebral canal of a dog. This suggests that the tip of the needle has inadvertently penetrated a venous sinus on the ventral aspect of the vertebral canal. The needle should be withdrawn and a new needle used to repeat the epidural technique.

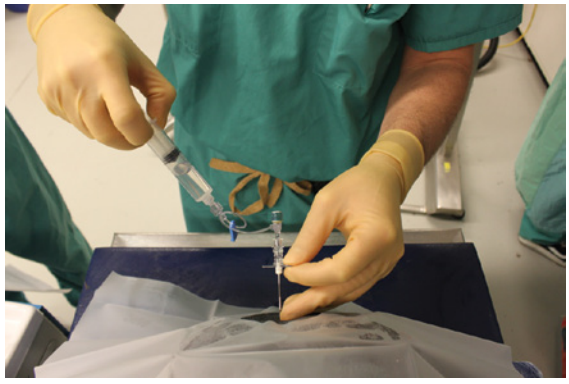

Figure 14.21 An extension set can be attached to the epidural needle, allowing the anesthetic solution to be injected with less risk of inadvertently moving the needle in the patient when the syringe is connected and the solution is administered.

several drops of injectate or saline are injected into the needle hub (Figure 14.16a). If the tip of the needle is correctly located in the epidural space, the fluid will usually be aspirated into the needle. As mentioned above, if the patient is in lateral recumbency this technique cannot be used for confirming epidural needle placement.

- During and after the injection, watch for potential adverse effects in the patient such as pain (in sedated animals), tachycardia, hypotension, arrhythmias, muscle twitches, tremors, or seizures.
- Rapid injection may cause adverse effects such as an irregular block or excessive cephalad progression of the solution administered.
- In sedated patients, it is recommended to warm the solution to body temperature in order to reduce discomfort during administration.
- There should be no resistance to injection into the epidural space.
- Excess pressure in the epidural space has been considered a possible cause of damage to the nervous tissue (Torske and Dyson 2000).

As the dural sac extends further caudally in cats, the anesthetist should concentrate on stopping needle advancement as soon as the epidural space is entered. Penetration of the dura mater is almost inevitable if the needle tip is advanced further into the vertebral canal. When the needle enters the epidural space, it is common to observe a slight flicking movement of the tail, movement of the hind limbs, or twitching of the skin over the area of the lumbosacral intervertebral space. This is due to stimulation of the spinal cord or fibers of the cauda equina. No adverse effects have been obsereved as a result of this.

Interlumbar approach

In adult animals, the presence of the spinal cord and dural sac makes the epidural space relatively smaller in the segments cranial to L5. For this reason, performing epidural puncture at levels other than the lumbosacral space should only be performed when sufficient experience has been acquired. In order to access the epidural space in the lumbar segments cranial to L6, a paramedian approach must be used. Using this technique, the needle enters the epidural space at a more oblique angle than that which is used for the standard

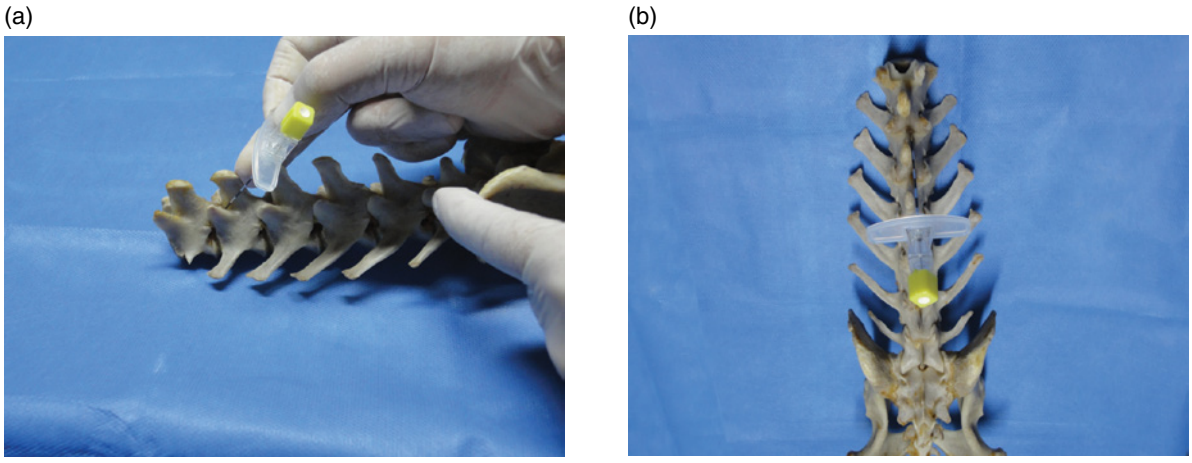

Figure 14.22 (a) Lateral view of a dog skeleton. A Tuohy needle has been advanced into the intervertebral space between L1 and L2. (b) Dorsal view of a dog skeleton. A Tuohy needle has been advanced into the intervertebral space between L1 and L2.

dorsal midline approach, reducing the possibility of damaging the structures contained in the spinal canal (Figure 14.22).

- Identify the dorsocaudal edge of the spinous process caudal to the selected puncture site.
- Insert the needle lateral to midline.
- Advance the needle until it contacts the vertebral lamina.
- The needle should be redirected cranially (±45°) and medially (±15°), advancing it past the cranial articular process into the intervertebral space until it penetrates the ligamentum flavum and enters the epidural space.
- LOR is the most widely recommended technique for this approach.

Sacrococcygeal/intercoccygeal approach

- A midline approach is recommended (Zimmerman and Smith 2003; O'Hearn and Wright 2011).
- With the animal in sternal or lateral recumbency, the intercoccygeal articulation between Cd1 and Cd2 is identified by palpating the corresponding spinous processes.
- Moving the tail up and down helps to identify the articulation between Cd1 and Cd2 by creating a palpable depression.
- A 22-gauge needle is inserted from the dorsal midline at a 45° angle to the skin surface (directed cranially), caudal to the spinous process of Cd1, and advanced until it enters the epidural space (Figure 14.23).
- Because of the limited amount of epaxial musculature and the normal thinning of the ligamentum flavum caudal to the lumbosacral space, there is minimal resistance to needle advancement.
- LOR technique is the most widely recommended for this approach.

Epidural catheter placement

Equipment In addition to the materials used to perform epidural injection (listed above), the following is required:

- epidural catheter kit (including a Tuohy needle);
- bacterial filter;
- extension set;
- syringe;
- elastomeric pump/syringe driver; and
- light dressing material.

Patient positioning

- Same as for single-shot injection, with sternal recumbency preferred over lateral recumbency.

Anatomic landmarks

- Same as for single-shot injection.

Step-by-step procedure

- It is advisable to broaden the sterile field and to use sterile drapes so that inadvertent

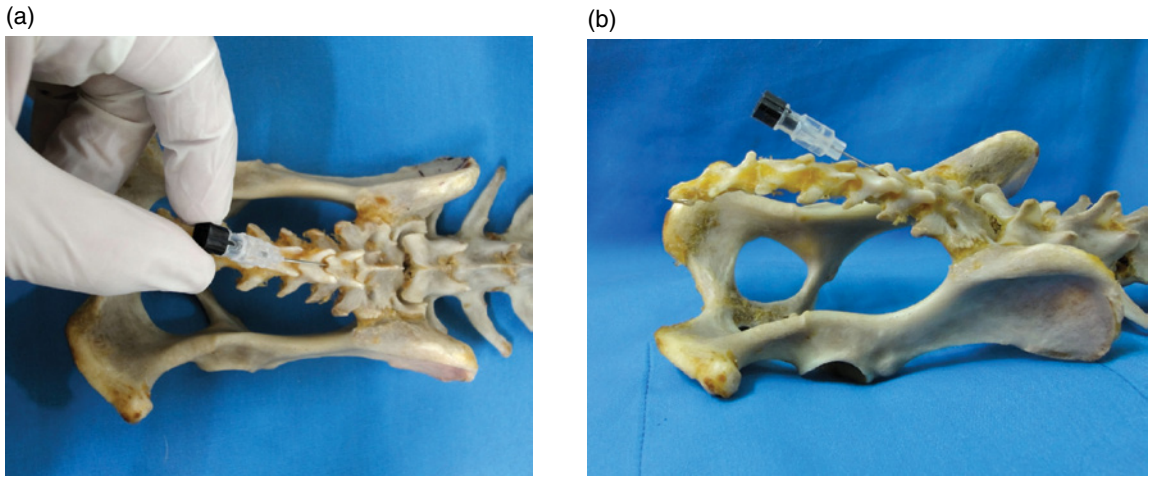

Figure 14.23 (a) Dorsal view of a dog skeleton. A spinal needle has been advanced into an intercoccygeal space. (b) Lateral view of a dog skeleton. A spinal needle has been advanced into an intercoccygeal space.

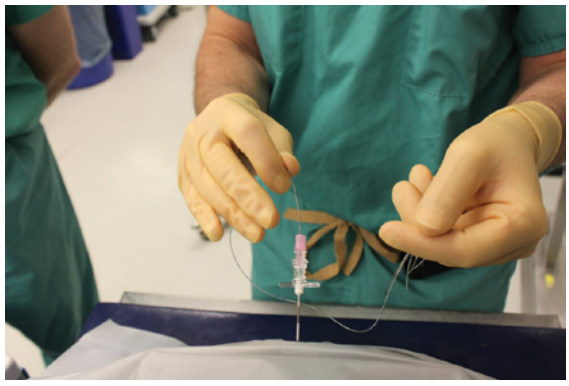

Figure 14.24 An epidural catheter is being placed in a dog in sternal recumbency. Note that the catheter is coiled and is held by the nondominant hand in order to prevent it from falling outside the sterile area and becoming contaminated.

contamination of the catheter does not occur during handling and manipulation (Figure 14.24).

- The epidural tray should be opened sterilely and all of its component parts identified. The stylet of the Tuohy needle should be removed and the catheter advanced into the needle. This ensures that it will pass into the needle when the needle is in the patient. The markings on the catheter should be used to identify when the catheter is near the tip of the needle, giving the anesthetist more information about how far to advance the catheter into the needle when it is already *in situ*. Once this measurement is taken, the catheter should be carefully removed from the needle and the stylet replaced into the needle for use.
- If the patient is sedated rather than anesthetized, infiltrate the puncture site as well as the supra- and interspinous ligaments with 2% lidocaine to increase patient tolerance to the procedure.
- Place the Tuohy needle into the epidural space using standard techniques (described above). Make sure to direct the needle bevel (curve) cranially to assist with placement of the catheter. Once it is in place, tipping the needle hub caudally will further facilitate catheter exit from the needle tip and will assist with its advancement into the epidural space.
- After confirming correct needle placement (using LOR, hanging-drop, etc.), a small volume of the initial dose of local anesthetic is injected through the needle into the epidural space. This will facilitate insertion and advancement of the catheter.
- An adapter can be attached to the needle hub (threading aid) to provide rigidity to the catheter.
- While the needle is held firmly in position using the nondominant hand, the catheter is coiled and held by the dominant hand to prevent it from falling outside the sterile area (Figure 14.24).

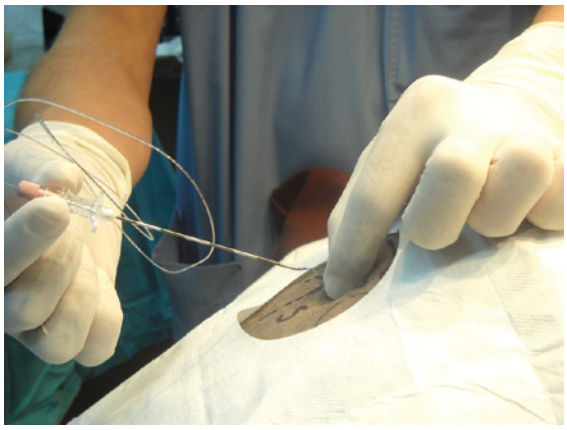

Figure 14.25 An epidural catheter is being placed in a dog in sternal recumbency. After the catheter is in position, the needle must be removed over the catheter. As the needle is withdrawn, the anesthetist should hold the catheter at its point of entry to prevent its inadvertent removal with the needle.

- The needle stylet is removed and the epidural catheter is threaded through the needle, paying attention to the previously identified depth markings on the catheter. Once the catheter is determined to be at the needle tip, slight pressure is sometimes required to advance the catheter around the "corner" of the Tuohy needle. At this point, the second distance marker on the catheter will be visible at the needle hub.
- The catheter should be advanced out of the needle several centimeters to the desired level of the blockade.
- Once the catheter is advanced into the epidural space to the desired level, the needle can be carefully withdrawn over the catheter. To withdraw the needle, the catheter is held at its point of entry between the thumb and index fingers, while the needle is removed (Figure 14.25).
- The catheter should now be secured in place. Subcutaneous tunneling of the catheter several centimeters away from its point of entry provides additional fixation while at the same time minimizing the potential for catheter site contamination (Figure 14.26).
- After confirming the absence of spontaneous flow of CSF or blood from the catheter by holding the end of the catheter in a dependent position, an adapter is attached to the end of the catheter. An aspiration test for CSF or blood is attempted with a 3 mL syringe.

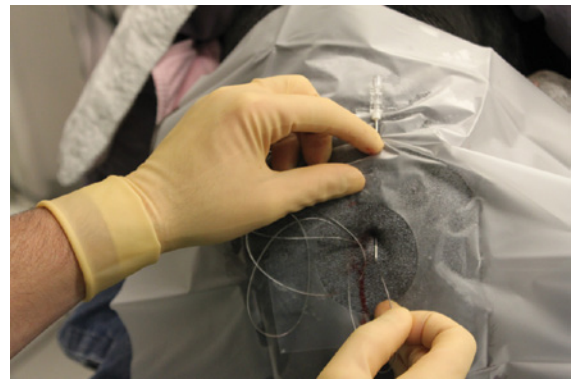

Figure 14.26 Securing an epidural catheter. Subcutaneous tunneling of the catheter several centimeters away from its point of entry provides stable fixation while at the same time minimizing potential catheter site contamination.

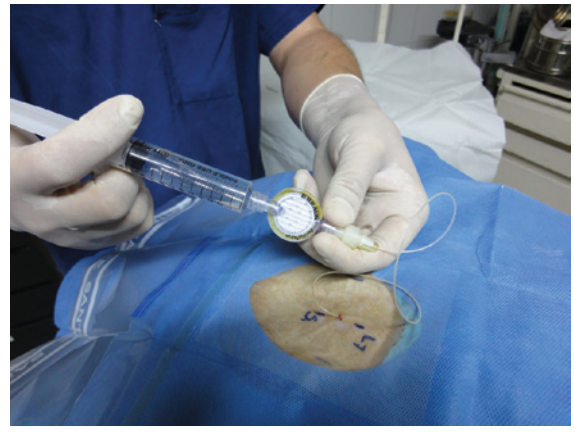

Figure 14.27 Following negative aspiration for blood or cerebrospinal fluid, the local anesthetic solution can be administered. Note the use of a pre-primed bacterial filter located between the syringe and the epidural catheter.

- Next, a bacterial filter is connected to the adapter (Figure 14.27). To avoid excessive amounts of air being injected into the epidural space, the filter should be primed with the local anesthetic solution before connecting it to the adapter.
- The catheter can now be secured in place using one of a variety of transparent dressings and adhesive devices (Figure 14.28).
- Following a negative aspiration, the remainder of the initial bolus of local anesthetic can be administered into the epidural space through the catheter.

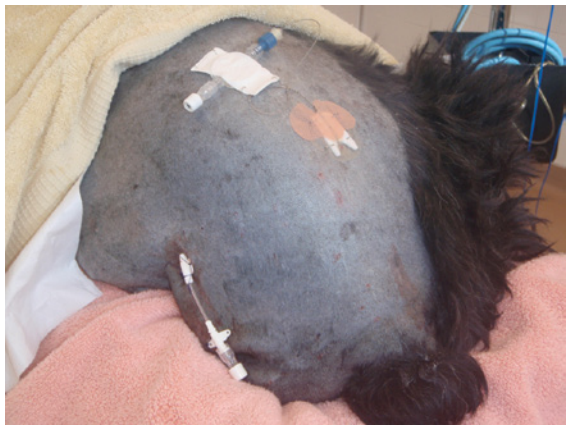

Figure 14.28 An epidural catheter has been secured in place in a dog. Note the adhesive bandage used at the site of entry, as well as how the filter has been attached to the dog with the use of skin staples.

The method used for placing catheters in the epidural space in cats is similar to that used in dogs (described above). However, the incidence of inadvertent intrathecal placement of the catheter in this species is high, reaching 27% in some reports (Hansen 2001). For this reason, great care must be taken to ensure the absence of CSF. It seems important that the needle should be inserted at an angle of about 30° to the skin and advanced carefully in order to detect resistance in the ligamentum flavum. Some authors report that the placement of epidural catheters in cats results in high failure rates. Even when using a 20-gauge Tuohy needle and a 24-gauge blunt-tipped catheter, Dobromylskyj et al. (2000) were unable to place epidural catheters in cats without accessing the subarachnoid space.

Clinical tips

- If resistance to catheter advancement is encountered, the catheter and needle should be withdrawn as a single unit. The catheter should never be removed with the needle left in place due to the risk of shearing the catheter at the needle bevel and having it break off in the patient.
- Resistance to injection through the catheter is normally greater than when injecting through a needle.
- Correct positioning of the catheter can be confirmed by ultrasound (Chawathe et al. 2003; Galante 2011), radiography, or fluoroscopy. However, clinical efficacy and the patient's response will always be the factors that define the correct positioning of the catheter.

Catheter removal

When the catheter is no longer needed, it can be removed. To do this, all adhesives and securing devices should be removed and the catheter gently pulled out of the patient by grasping the catheter close to its point of entry into the skin. It is recommended to maintain sterility as the catheter is removed, in case the catheter tip needs to be submitted for culture purposes. Once the catheter is completely removed, its integrity should be inspected. The distal tip of the catheter should be positively identified, otherwise there is a risk that the catheter has broken off and remains in the patient.

Injection volume

Two main methods are used for determining the volume of drugs to be administered epidurally: body weight and spinal length.

Body weight

The typical doses that are recommended for epidural anesthesia in dogs and cats are presented in Tables 14.2, 14.3, and 14.4. Most sources recommend a total final volume of 0.2 mL kg^{-1} (1 mL 5 kg^{-1}) body weight to achieve blockade up to the level of L1. This volume is useful for procedures involving the caudal abdomen, pelvic limbs, and perineal areas. If procedures are limited to the pelvic limbs, lower volumes may be used (approximately 1 mL 7 kg^{-1}). Even lower volumes are required for procedures of the tail and perineal area (approximately 1 mL 10 kg^{-1}).

Spinal length

When spinal column length is used to calculate the volume to be injected, total vertebral column length (L_{OC}) is measured from the occipital condyle to the first coccygeal vertebra. Given the relationship between cephalad progression of solutions instilled in the epidural space and the L_{OC}, this can be used as an alternative method for calculation of the volume of local anesthetic solution to be administered for breeds with abnormal spinal lengths (dachhounds) or abnormally obese patients (Otero et al. 2009). To calculate the volume to be injected in terms of the L_{OC}, Otero et al. (2009) developed a normogram in which the extension of the block is expressed as a percentage (%) of the patient's total

Table 14.2 Doses (mL kg^{-1}) for local anesthetics in dogs.

Drug	Puncture site	Dermatome	Volume (mL kg^{-1})	Reference
Bupivacaine 0.25%	Lumbosacral	L3	0.2	Freire et al. 2010
Bupivacaine 0.5%	Lumbosacral	Adequate for ovariohysterectomy*	0.36	Almeida et al. 2007
Bupivacaine 0.25%	Lumbosacral	T9	0.4	Freire et al. 2010

*The ovaries are supplied by the sympathetic chain via the hypogastric nerves (T10–L1).

Table 14.3 Doses (mL kg^{-1}) for local anesthetics in cats.

Drug	Puncture site	Dermatome	Volume (mL kg^{-1})	Reference
Methylene blue solution	Lumbosacral	L1–L2	0.2	Lee et al. 2004a
Methylene blue solution	Lumbosacral	T7	0.3	Lee et al. 2004a
Methylene blue solution	Lumbosacral	T6–T10	0.4	Lee et al. 2004a

Table 14.4 Doses (mg kg^{-1}) for opioids and α-2 adrenoreceptor agonists used for epidural analgesia.

Drug	Dose* (mg kg^{-1})	Onset (min)	Duration (h)	Reference
Morphine	0.1	30–60	6–24	Valverde et al. 1989a
Meperidine (pethidine)	2	2	0.5–1	Amarpal et al. 2003
Oxymorphone	0.05–0.1	20–40	7–10	Torske et al. 1999
Fentanyl	0.01–0.005	15–20	3–5	Naganobu et al. 2004
Sufentanil	0.0007–0.001	10–15	1–4	Almeida et al. 2007
Methadone	0.3	30–40	8–12	Leibetseder et al. 2006
Butorphanol	0.25	10–20	3–4	Troncy et al. 1996
Buprenorphine	0.005	60	16–24	Smith and Yu 2001
Xylazine	0.02–0.25	20–30	2–5	Soares et al. 2004
Medetomidine	0.005–0.01	20–30	2–6	Branson et al. 1993
Dexmedetomidine	0.001–0.002	20–30	4–6	Sabbe et al. 1994
Morphine + xylazine	0.1 + 0.02	30–60 20–30	5–10	Keegan et al. 1995
Morphine + medetomidine	0.1 + 0.005	30–60 20–30	10–20	Pacharinsak et al. 2003
Morphine + bupivacaine 0.5%	0.1 + 1.0	10–15	16–24	Kona-Boun et al. 2006
Morphine infusion	0.3 mg kg^{-1} 24 h^{-1}	–	–	Otero 2004
Morphine + bupivacaine 0.5%	0.3 mg kg^{-1} 24 h^{-1} + 0.75 mg kg^{-1} 24 h^{-1}	–	–	Otero 2004
Morphine + ketamine S (+)	0.05 + 0.5	30–60 5–10	8–12	Acosta et al. 2005

*Final volume injected into the epidural space 0.22 mL kg^{-1}. Volume completed with 0.9% saline or local anesthetic.

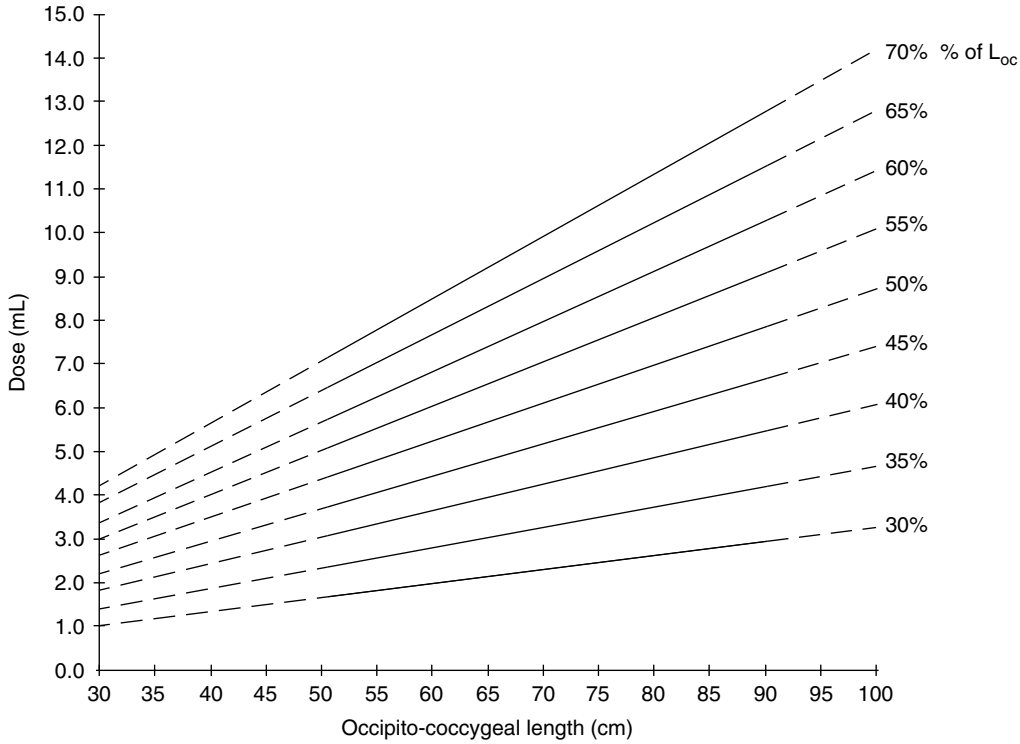

Figure 14.29 Diagram of the relationship between dose (volume of injectate, mL), measured occipito-coccygeal distance (cm), and the desired spread of contrast medium (% L_{OC}) for lumbosacral epidural anesthesia in sedated dogs that were positioned in sternal recumbency. Hash marks represent extrapolated values that were outside the limits of the data obtained in this study. From Otero et al. 2009.

L_{OC} (Figure 14.29). Their normogram was developed using ropivacaine in combination with a radiographic contrast agent (iohexol). Studies using other local anesthetics show that when the physical characteristics of the solution injected into the epidural space remain similar, the behavior of the spread is consistent (Kim et al. 1998; Vas et al. 2003).

The epidural anesthetic volume is calculated as mL cm L_{OC}^{-1}:

- 0.05 mL cm L_{OC}^{-1} will block 30–35% of the L_{OC}.
- 0.1 mL cm L_{OC}^{-1} will block 55–60% of the L_{OC}.
- 0.15 mL cm L_{OC}^{-1} will block 70–75% of the L_{OC}.

If this method is being used, position the patient in sternal recumbency during the epidural injection and keep it in this position for at least five minutes following the injection. When performing the block, the needle bevel should be directed cranially.

Drug choices and dosing

Pharmacology

Local anesthetics, opioids, and α_2-agonists, or combinations of these agents are the drug classes most commonly used for epidural anesthesia in small animals. The choice of drug combination depends on the desired action (sensory only vs. sensory and motor block) and the desired duration of action. The method of administration should also be considered as single-shot injections generally require higher drug concentrations and doses in order to obtain prolonged effects compared with those that are used with continuous infusions.

In general, lipid solubility regulates the bioavailability of different agents at their respective sites of action. In addition, the shorter the distance traveled by the drug until it reaches its site of action, the lower the amount of nontarget tissues in which it must be dissolved (connective, fatty tissue, and blood vessel walls). Consequently, the onset of

Table 14.5 Onset time of local anesthetics following epidural administration.

Agent	Onset (min)	Reference
Lidocaine	5	Cruz et al. 1997
Mepivacaine	10	Cruz et al. 1997
Bupivacaine, levobupivacaine, and ropivacaine	10–20	Feldman et al. 1996; Gomez de Segura et al. 2009; Duke et al. 2000; Otero et al. 2007

Table 14.6 Duration of motor blockade following epidural administration of local anesthetics in the dog.

Drug	Duration (min)	Reference
Lidocaine 2% 4.4 mg kg^{-1}	120	Cruz et al. 1997
Bupivacaine 0.75% 0.14 mg kg^{-1}	160	Feldman and Covino 1988; Cruz et al. 1997
Ropivacaine 0.75% 0.14 mg kg^{-1}	100	Feldman and Covino 1988
Levobupivacaine 0.5% 1 mg kg^{-1}	180	Gomez de Segura et al. 2009
Levobupivacaine 0.75% 1 mg kg^{-1}	360	Gomez de Segura et al. 2009

Table 14.7 Duration of sensory blockade following epidural administration of local anesthetics in the dog.

Drug	Duration (min)	Reference
0.75% Ropivacaine 0.22 mg kg^{-1}	140	Duke et al. 2000
0.5% Ropivacaine 0.22 mg kg^{-1}	115	Duke et al. 2000
0.75% Bupivacaine 0.22 mg kg^{-1}	145	Duke et al. 2000
0.5% Bupivacaine 0.22 mg kg^{-1}	140	Duke et al. 2000

action for drugs administered by the spinal route will be shorter than that of the same drugs when administered by the epidural route.

The duration of nerve blockade depends on the physical characteristics of the local anesthetic itself, the addition of adjuvants, and other factors. The main determinants of block duration include:

- type of local anesthetic: short, intermediate, long duration (Tables 14.6 and 14.7);
- concentration and volume administered—higher concentrations and larger volumes will produce a longer duration of action (Duke 2000; Gomez de Segura et al. 2009; Freire et al. 2010);
- lipid solubility (Bernards 2004);
- systemic absorption through the epidural vascular network (Emanuelsson et al. 1997);
- binding to nerve cell proteins;
- local vasodilator/vasoconstrictor effects of each agent (ropivacaine is the only local anesthetic with intrinsic vasoconstrictor effect) (Nakamura et al. 1993);
- the addition of epinephrine increases the duration of action of these compounds by between 40% and 60%, most probably by decreasing vascular absorption. This effect is less effective with longer acting agents such as bupivacaine and ropivacaine (Duke et al. 2000).

For epidural analgesics such as opioids whose main site of action is the gray matter (dorsal horn of the spine), the main determinants of onset, therapeutic duration, and efficacy are:

- the partition coefficient in the CSF—a measure of water solubility and the fraction of drug that stays in the CSF as opposed to diffusion into the spinal cord;
- its dispersion along the neuroaxis (Bernards 2004).

Large variations in the duration of analgesia have been reported after the epidural administration of opioids. A direct correlation exists between the degree of lipid solubility of the various agents and the average duration of sensory analgesia (Bernards et al. 2003a). Agents with greater lipid solubility (fentanyl, butorphanol, methadone) exit the CSF at the site of action more readily and have shorted durations of effect. This results in "segmental" blockade that is concentrated in close proximity to the site of administration (Bernards 2004). Conversely, agents such as morphine that are less lipid soluble (more hydrophilic) remain dissolved in the CSF for longer periods of time. This increases their bioavailability relative to the site of action, in addition to providing a more extensive distribution of sensory analgesia. This explains why lumbosacral epidural administration of morphine in dogs and cats (0.1 mg kg^{-1}) reduces anesthetic requirements during the perioperative period (Valverde et al. 1989a, 1991; Golder et al. 1998) and analgesics during the postoperative period up to a maximum of 24 hours (Pascoe and Dyson 1993; Troncy et al. 2002). When morphine is dissolved in saline to a final volume of 0.3 mL kg^{-1}, it can provide analgesia to structures as far cranial as the thoracic wall and thoracic limbs (Pascoe and Dyson 1993; Troncy et al. 2002).

α_2-Adrenergic agonists mimic the effects of descending antinociceptive fibers that originate in the brainstem. It has been suggested that when combined with a local anesthetic solution, they enhance the activity of the local anesthetic by means of their vasoconstrictive activity, direct inhibition of impulse conduction, or blockade of the hyperpolarization-activated cation (I_h) current (Eisenach et al. 1996; Brummett et al. 2008; Yoshitomi et al. 2008). However, epidural administration of α_2-agonists usually results in dose-dependent systemic effects as a result of systemic absorption including; sedation, supraspinal analgesia, bradycardia, atrioventricular conduction blocks, peripheral vasoconstriction, and vomiting (Vesal et al. 1996; Soares et al. 2004). When administered via the epidural route, α_2-agonists reduce the minimum alveolar concentration (MAC) of inhalation anesthetics. Soares et al. (2004) showed that epidural administration of xylazine (0.1, 0.2, and 0.3 mg kg^{-1}) in the dog decreased the MAC_{ISO} in a dose-dependent manner and the same observation was reported by Campagnol et al. (2007) after epidural administration of dexmedetomidine (1.5, 3, and 6 µg kg^{-1}) in dogs anesthetized with isoflurane. The combination of α_2-agonists and opioids has been studied in dogs (Vesal et al. 1996; Pacharinsak et al. 2003) and in cats (Steagall et al. 2009). A recent study by Konakci et al. (2008) reported that epidural administration of preservative-free dexmedetomidine to rabbits may produce spinal neurotoxicity characterized by demyelinization of the oligodendrocytes in the white matter. These effects have not been reported in other species.

Ketamine is an N-methyl-D-aspartate (NMDA) spinal cord receptor antagonist and inhibits the excitatory effects of the endogenous agonist (glutamate), thereby reducing hypersensitization and nociception. Epidural injection of 2 mg kg^{-1} of ketamine is associated with minimal hemodynamic effects during isoflurane anesthesia (Martin et al. 1997; Duque M et al. 2004). Epidural administration (0.6 mg kg^{-1}) of ketamine or S(+) ketamine has been shown to reduce post-incisional hyperalgesia in dogs, with the duration of the effect being longer for the racemic compound (720 vs. 90 minutes, respectively) (Duque M et al. 2004). In the dog, systemic effects associated with the epidural administration of ketamine (0.6–2.5 mg kg^{-1}) include hind limb incoordination or paralysis, salivation, and nystagmus (Martin et al. 1997; Hamilton et al. 2005).

Continuous delivery through catheters

A main objective of providing continuous epidural administration of analgesics is the provision of analgesia. The analgesics most frequently used by the authors for continuous epidural anesthesia are bupivacaine (0.125–0.25%) or ropivacaine (0.2%) combined with fentanyl (1–2 µg mL^{-1} of solution). The recommended infusion rate through the catheter is 0.02–0.05 mL kg^{-1} h^{-1}. If the analgesia is not found to be adequate, the volume of the subsequent injections is increased while maintaining the original concentrations. If the extension of blockade is found to be excessive, the volume is subsequently reduced. If signs of muscular weakness appear, the concentration is reduced while maintaining the same volume. If signs of deep sedation appear, the dose of the opioid is reduced.

Clinical tips

- From the lumbosacral space, catheters may be advanced to the level of the spinal column that will provide optimal analgesic benefit for the patient (L_7 to T_1). Unless otherwise indicated, it is recommended not to advance the catheter more than a few centimeters (three to four intervertebral spaces) in order to avoid complications such as perforation of the dura mater or a blood vessel, lateralization of the catheter through an intervertebral foramen, or curling of the catheter within the epidural space.
- The patient's bladder should be frequently assessed for size and for the ability to be emptied.
- Check the catheter site regularly for signs of kinking or contamination.

Spinal (intrathecal) anesthesia and analgesia

Although it is used less frequently in veterinary medicine, spinal injection offers certain advantages over the epidural approach:

- correct needle placement is more objective due to presence of CSF;
- onset of anesthesia is more rapid;
- anesthesia is more profound;
- the level and lateralization of the anesthesia can be "controlled" by using solutions of varying baricity and by altering the patient's body position.

It should be noted that the risk of serious complications (e.g. cardiac arrest, neurologic injury, radiculopathy) following spinal injections in people has been reported to be significantly higher when compared with epidural injections (Aldrete 2003).

Equipment

- Clippers;
- skin preparation solutions;
- spinal needles
  - small dogs and cats: 38 mm (1.5 inch), 22-gauge;
  - large dogs: 63 mm (2.5 inch), 22-gauge;
  - obese large or giant breed dogs: 88 mm (3.5 inch), 22-gauge or 20-gauge;
- syringes and needles;
- local anesthetic ± adjuvant;
- sterile gloves; and
- sterile fenestrated drapes.

Patient positioning

- The patient is placed in the chosen recumbency, seeking to maintain the longitudinal axis of the spine parallel to the table.
- The use of a cradle allows flexing the spine to facilitate the paramedian approach of the lumbar spaces when the animal is placed in sternal recumbency.

Anatomic landmarks

- The landmarks are the same as for an interlumbar approach to an epidural technique (Figure 14.30a).

Step-by-step procedure

- Identify the cranial aspect of the spinous process caudal to the selected puncture site.
- The spinal needle is introduced through the skin barely lateral to the spinous process until it contacts the lamina.
- The needle is then advanced in a cranioventral orientation and towards midline at a 30° to 60° angle until the intervertebral space is identified.
- Once the needle has punctured the dura, a "pop" may be felt (may be accompanied by jerking of the pelvic limbs). The needle stylet is then removed and the needle hub is inspected for the presence of CSF (Figure 14.31).
- The syringe with local anesthetic is then attached and after gentle aspiration to check for the presence of blood, the solution is slowly injected.
- Position the patient according to side to be blocked and baricity of the injectate.

Injection volume

- As a general rule, we suggest the use of hyperbaric solutions to supplement general anesthesia for thoraco-abdominal surgery.

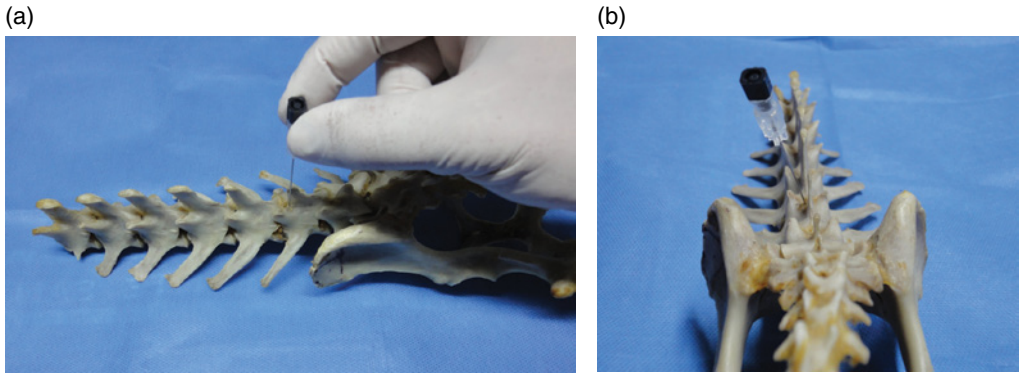

Figure 14.30 (a) Lateral view of a dog skeleton. A spinal needle has been advanced into the intervertebral space between L5 and L6 to landmark the location that would be used to perform spinal anesthesia in a dog. (b) Dorsal view of a dog skeleton. A spinal needle has been advanced into the intervertebral space between L5 and L6 to landmark the location that would be used to perform spinal anesthesia in a dog.

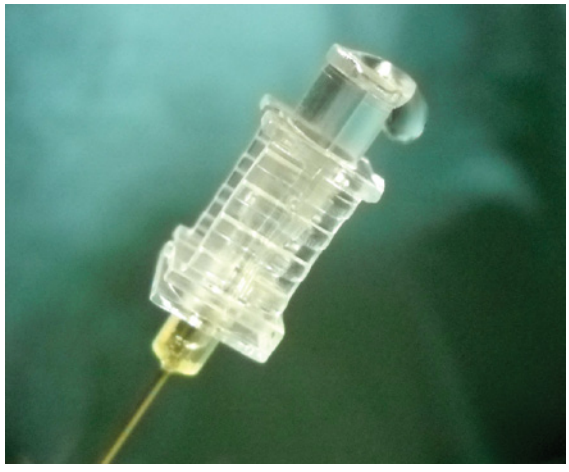

Figure 14.31 A spinal needle has been placed in a subarachnoid (intrathecal) location. Note the cerebrospinal fluid that fills the needle hub.

  - The suggested dose is 0.05 mL kg^{-1} of 0.5% hyperbaric (heavy) bupivacaine.
  - Following an intrathecal injection, the dog should be maintained for five minutes in a 10° head-down position.
- For pelvic and pelvic limb surgery, isobaric solution of 0.5% bupivacaine may be used.
  - A suggested dose of 0.05 mL kg^{-1} will result in a block up to L3 dermatome.
- When morphine is added to the local anesthetic solution the suggested dose is 0.01–0.03 mg kg^{-1} (Novello et al. 2008).

Clinical tips

- Due to the broad range of CSF baricity in dogs (Mosing et al. 2006), if desired, a refractometer can be used to measure the specific gravity of the CSF for comparison with the specific gravity of the solution to be injected, helping to predict the drug's behavior.
- If morphine is used, hypobaric solution is recommended, even if thoraco-abdominal pain is to be treated.
- The use of isobaric solution for thoraco-abdominal surgery is associated with a high rate of failure (Sarotti et al. 2011).

Potential complications of neuraxial anesthesia and how to avoid them

Complications related with neuraxial blocks can range from simple technique failure to life-threatening issues.

Complications related to the technique

Accidental drug administration

O'Kell and Ambros (2010) reported on the inadvertent administration of thiopental via the epidural route. Correct syringe labelling and implementation of "time-outs" are strongly

recommended to prevent this type of operator-error from occurring.

Neural damage/neurotoxicity

Appropriate technique and equipment should be used to minimize tissue trauma. Formulations containing phenol, formaldehyde, benzetonium chloride, chlorbutanol, disodium EDTA, methylparaben, sodium metabisulfite, and sodium bisulfite have been historically attributed to neurotoxic effects without conclusive evidence to support these conclusions. Current research is lacking. Until more information is known, the use of preservative-free, "for epidural use"-approved solutions would seem prudent.

Infections

Failure to follow aseptic techniques can result in bacteria being introduced from the patient, clinician's skin, or from contaminated injectates or materials. During extradural anesthesia it is possible to puncture blood vessels leading to local hemorrhage and hematoma formation. In the medical literature, it has been hypothesized that these areas of hemorrhage provide ideal locations for bacteria to seed after hematogenous spread (Grewal et al. 2006), especially in immunocompromised patients. In the veterinary literature, MacFarlane and Iff (2011) described a case of discospondylitis in a dog after attempted epidural anesthesia. Remedios et al. (1996) also reported a case of epidural abscessation with associated discospondylitis post-epidural injection in a dog. Strict adherence to best practice and standard of care in terms of skin preparation (see Chapter 3 for more information) and technique is recommended.

Delayed hair growth

Delayed hair growth in the area where the patient was clipped for the epidural has been reported with a low incidence (Valverde et al. 1989b; Herperger 1998). However, a recent report on dogs concluded that a direct correlation between drugs injected epidurally and delayed hair growth and pruritus could not be shown (Kalchofner et al. 2009).

Complications related to use of local anesthetic solutions

Hypotension/bradycardia

As described earlier, sympathetic outflow from the spine is distributed from T4 to L3. Blocking spinal nerves between T5 and L3 will cause vasodilation of the splanchnic circulation, pooling of blood, and decreased venous return to the heart leading to systemic hypotension. Hypotension caused by epidural administration of local anesthetic solutions can be profound (Iff and Moens 2008; Bosmans et al. 2011a, b; Sarotti et al. 2011). Administration of intravenous fluids prior to an epidural injection may be indicated to minimize hypotension, particularly if the patient is dehydrated or hypovolemic prior to neuroaxial anesthesia. However, Bosmans et al. (2011b) reported the lack of effectiveness of intravenous fluids for preventing a decrease in blood pressure prior to epidural administration of local anesthetics. Vasopressors and anticholinergic drugs can also be used as appropriate.

Inadvertent subarachnoid/spinal or subdural injection

Positive CSF aspiration implies a subarachnoid (intrathecal/spinal) needle location. The incidence of inadvertent intrathecal injection in the dog has been reported (Blass and Shires 1986; Kona-Boun et al. 2003; Savvas et al. 2006). Inadvertent dural puncture and subsequent intrathecal injection in the cat is high, reaching 27% in some reports (Hansen 2001); it is therefore recommended to check for absence of CSF and deliver a test dose before delivering the full dose to rule out intrathecal or subdural needle insertion.

Unintended injection at any of these levels may carry serious consequences such as total spinal anesthesia or death. It is therefore recommended to deliver a test dose (0.1 mL) and wait at least one minute before delivering the full dose to rule out intrathecal or subdural needle insertion.

Inadvertent intravascular injection

When the needle is located in an intravascular location such as the ventral venous plexus, positive

blood aspiration or passive blood flow may occur. Unintended intravascular injection may carry serious consequences such as severe local anesthetic toxicity or death. Additionally, uncontrolled hemorrhage at this level may cause compression of cauda equina and or dural sac.

Horner's syndrome

Horner´s syndrome can be observed if local anesthetic reaches cervical dermatomes. The incidence is low and generally associated with inadvertent intrathecal or subdural injections. This syndrome is reversible and is characterized by palpebral ptosis, miosis, and enophthalmus.

Bosmans et al. (2009) reported Horner's syndrome in one dog following lumbosacral administration of ropivacaine 0.75% 0.22 mL kg^{-1}.

Respiratory depression

Total spinal

Total spinal is a local anesthetic-induced depression of the cervical spinal cord and the brainstem. It may follow excessive spread of an intrathecal injection of local anesthetic, or inadvertent spinal injection of an epidural dose of local anesthetic. Savvas et al. (2006) reported a case with a possible total spinal after attempted epidural injection. Bosmans et al. (2011b) also reported a fatal case after an attempted epidural administration of local anesthetic in a dog with possible total spinal and death. Symptoms include:

- hypotension due to venous and arterial vasodilation resulting in a reduced venous return, cardiac output, and systemic vascular resistance. It should be treated with volume expansion and vasopressors;
- bradycardia. It should be treated with anticholinergic agents (e.g. atropine, glycopyrrolate), or ß-adrenergic agonists;
- difficulty in breathing. Respiratory depression can occur in extensive epidural or spinal anesthesia, and is mostly attributed to intercostal nerve blockade as opposed to phrenic nerve paralysis (Oliveira et al. 2009). Sudden respiratory arrest is usually caused by hypoperfusion of the respiratory centers in the brainstem and circulatory insufficiency at the respiratory center (Brown 2005);
- cardiac arrest may occur due to hypotension and hypoxemia;
- other symptoms may include thoracic limb weakness, loss of consciousness, and pupillary dilatation.

Complications related to opioids

There are several reports in the veterinary literature of the specific side effects of epidural administration of opioids, including:

- pruritus (Burford and Corley 2006; Haitjema and Gibson 2001);
- urinary retention (Herperger 1998; Kona-Boun et al. 2003);
- nausea, vomiting (Mathis et al. 2011).

There are no reports that mention respiratory depression as a frequent complication following the administration of opioids used at suggested doses and intervals. This complication would appear to be more of a concern in people than in animals.

With respect to urinary retention, cystometric studies show that canine detrusor muscle relaxes and bladder capacity increases after epidural injection of morphine. The likely mechanism for these effects is interruption of sacral parasympathetic outflow (Rawal et al. 1983). The consequence is that some dogs require urethral catheterization or intermittent manual bladder expression following neuroaxial administration of morphine (Rawal et al. 1983). All dogs should be monitored over the first 24–48 hours following epidural morphine and treated symptomatically as needed.

Potential complications associated with continuous epidural administration

Swalander et al. (2000) reported an incidence for catheters left in place for up to seven days of:

- dislodgement of the catheter (16%);
- inflammation (2.4%);
- contamination at the catheter site (2.4%).

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15 Intravenous Regional Anesthesia

Francesco Staffieri

Rationale for IVRA

Intravenous regional anesthesia (IVRA) is a technique that can be used to provide intraoperative analgesia for surgical procedures lasting less than 90 minutes that involve the distal extremities (Davis and McConachie 1998). In some sedated animals, IVRA can be used as the sole anesthetic technique for the procedure. However, in most veterinary patients, IVRA is used to provide the analgesic component of a balanced (multimodal) general anesthetic protocol.

The mechanism of analgesia with IVRA is relatively straightforward: a tourniquet is applied to the limb proximal to the surgical site and a local anesthetic is injected intravenously distal to the tourniquet. The technique was first described in people in 1908 by a German surgeon, August Bier; hence the technique is frequently referred to as a "Bier block" (Bier 1908, 1910). Bier reported that the intravenous administration of pilocarpine produced complete loss of sensation and muscle paralysis, and that this technique could be used to provide anesthesia for amputation of the upper extremity.

In 1963, Holmes published the results of a series of cases in which he used a simplified technique that used lidocaine as the local anesthetic (Holmes 1963). This new technique increased the popularity of IVRA for use in people, and it soon became one of the most popular regional anesthetic techniques in the USA (Brill et al. 2004). One survey showed that 86% of human anesthesiologists in North America regularly perform Bier's blocks in their practices (Henderson et al. 1997).

For whatever reason, IVRA has never enjoyed the same popularity in small animal veterinary medicine and there are relatively few reports of its use in the published literature. Veterinary reports typically relate to the use of IVRA in ruminants for standing surgical procedures of the claws (Elmore 1980; Estill 1977; Jones and Prentice 1974; Manohar et al. 1971; Prentice et al. 1974) and in small animals as an adjunct analgesic technique in dogs under general anesthesia (DeMarzo et al. 2008; Duke 2000; Kushner et al. 2002; Novello 2003; Staffieri et al. 2010; Webb et al. 1999; William et al. 1992). Studies conducted in people and dogs have demonstrated that IVRA provides comparable levels of intraoperative analgesia for surgical procedures of the distal thoracic limb when compared with brachial plexus blocks (Chan et al. 2001; Staffieri et al. 2010).

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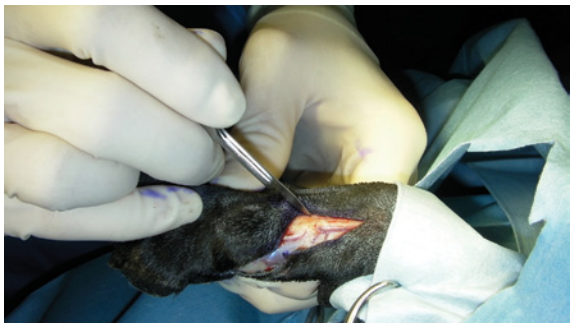

Figure 15.1 Photograph of the distal thoracic limb of a dog undergoing amputation of its second digit. IVRA has already been performed, and a tourniquet has been applied proximally on the limb. Note the lack of bleeding associated with the surgery.

The main advantages of IVRA are its relative simplicity, reliability, and consistency as an analgesic technique for selected surgical procedures. Additionally, as the technique involves the use of a tourniquet applied proximal to the surgical site, blood loss during the procedure is minimized (Figure 15.1). This is often seen as an advantage since visualization of the operative tissues is enhanced. The main limitations of IVRA are the restriction on the duration of the planned procedure and the lack of prolonged postoperative analgesia following release of the tourniquet.

Indications

Intravenous regional anesthesia is a loco-regional anesthetic technique that can be used to provide analgesia and anesthesia for short surgical procedures involving the distal extremities (distal to the elbow and the hock). Prolonged application of a tourniquet must be avoided due to the potential for tissue ischemia underneath and distal to the tourniquet, and the ischemic pain that is associated with the compression of these tissues (Davis and McConachie 1998). In people, IVRA is commonly used in combination with light sedation as an anesthetic technique to facilitate both elective and emergency procedures (Davis and McConachie 1998; Farrell et al. 1985). As most hospitalized small animal patients do not tolerate the level of handling that is required for performance of this anesthetic technique when they are awake, when IVRA is used in dogs and cats it is usually used in combination with general anesthesia or deep sedation.

Intravenous regional anesthesia can be used to facilitate a variety of small animal surgical procedures, including:

- foreign body removal;
- digit amputation;
- ostectomy/osteotomy of the distal radius or ulna;
- fracture repair;
- wound suturing;
- pancarpal arthrodesis;
- tarsal arthrodesis;
- mass removal.

Contraindications/precautions

- Infection: if there is infection of the tissues at the planned site of the block, IVRA should not be used. Placement of an intravenous catheter (for the injection of the local anesthetic solution) in a contaminated area could lead to systemic spread of the infection, and the changes in tissue pH that occur with infection can potentially influence the efficacy of the local anesthetic solution (Davis and McConachie 1998; Novello 2003).
- Patients with clinically important nodal arrhythmias: there is a relative contraindication to use of IVRA in these patients as they may potentially be more susceptible to the cardiotoxic effects of systemically administered local anesthetics (Choyce and Peng 2002; Novello 2003). However, this concern would likely only be an issue for the patient if the entire administered dose of the local anesthetic were inadvertently delivered into systemic circulation (e.g. under an incompetent tourniquet) or if a gross overdose of the local anesthetic were administered (e.g. incorrect volume of local anesthetic was used). Using the techniques, doses, and volumes of local anesthetic solution described below, this complication is unlikely. Further, patients with cardiac disease typically benefit from the use of a regional anesthetic technique as it lowers the requirements for the major anesthetics being used concurrently, lessening the systemic side effects of those drugs.

Choice (and dosing) of local anesthetics and adjuncts

- Lidocaine: lidocaine neat is the only local anesthetic promoted for use with IVRA in the veterinary literature and has been used at a range of dosages (2.5–5 mg kg^{-1}) and concentrations (0.25–2%) (DeMarzo et al. 2008; Duke 2000; Kushner et al. 2002; Novello 2003; Staffieri et al. 2010; Webb et al. 1999). In dogs and cats, the author uses a dilute lidocaine neat solution (0.5%) at a total dose of 3 mg kg^{-1} (for a total injected volume of 0.6 mL kg^{-1}). As there is always the possibility of inadvertent systemic administration of the injected solution (Kushner et al. 2002), the lidocaine used should not contain epinephrine or any preservatives.
- Prilocaine: in Europe, prilocaine is used for IVRA, but this drug is no longer licensed in the USA for this use as it has been linked to the complication of methemoglobinemia in people (Brill et al. 2004; Turan et al. 2002).
- Bupivacaine: on first consideration, bupivacaine might seem to be an attractive drug for IVRA because of its prolonged duration of analgesic action when compared with lidocaine and the familiarity that most people have with its use for other regional anesthetic blocks. However, bupivacaine is much more cardiotoxic than lidocaine and has a very narrow therapeutic index between the dose that is required for its local anesthetic effects and the dose that results in systemic toxicity (Feldman et al. 1989). When used for IVRA, bupivacaine has been associated with severe complications including death (Moore 1984; William et al. 1992). For this very important reason, BUPIVACAINE SHOULD NEVER BE USED FOR IVRA.
- Ropivacaine: recently, studies have evaluated the efficacy of ropivacaine (0.2–0.25%) for IVRA in people (Asik et al. 2009; Hartmannsgruber et al. 1999). The use of this drug results in a longer duration of analgesic action after release of the tourniquet when compared with lidocaine, and it is associated with fewer cardiovascular and central nervous system complications when compared with bupivacaine. These encouraging results suggest that ropivacaine could be considered as an alternative to lidocaine for IVRA; however, those data are from a small number of human patients and the routine clinical use of ropivacaine for IVRA in veterinary patients should first be supported by animal studies.

In people, several adjunct drugs have been tested for use in combination with local anesthetics in an attempt to reduce the severity of tourniquet pain, to improve the quality of the nerve blockade, and to prolong the duration of postoperative analgesia (Choyce and Peng 2002). Opioids such as meperidine, fentanyl, morphine, and tramadol have been added to lidocaine without any significant beneficial effects. Ketamine has been reported to offer minimal analgesic benefits and it can cause hallucinations in some human patients after the tourniquet is released following the procedure (Choyce and Peng 2002). Nonsteroidal anti-inflammatory drugs appear to be the most effective drugs for improving postoperative analgesia and tourniquet tolerance during IVRA. Ketorolac and tenoxicam have been combined with lidocaine and prilocaine for IVRA in people (Choyce and Peng 2002; Reuben et al. 1995). α_2-Adrenergic agonists such as clonidine appear to prolong a patient's tolerance to the pain resulting from tourniquet application and can improve postoperative analgesia when added to lidocaine for IVRA in people (Reuben et al. 1999). The addition of 0.5 µg kg^{-1} of dexmedetomidine to 0.5% lidocaine reduced the severity of intraoperative tourniquet pain and prolonged postoperative analgesia when compared with the use of lidocaine alone (Memis et al. 2004). Alkalinization of the solution with bicarbonate, alteration of the temperature of the solution, and addition of potassium to the solution have all been investigated and show little benefit to the patient or to the anesthetist (Choyce and Peng 2002). In the veterinary literature, there are no reports of using adjuncts to local anesthetics for IVRA in either small or large animals.

Distribution of local anesthesia

Atkinson (1969) demonstrated that the placement of a small tourniquet around a finger before blocking the hand with the intravenous injection of a local anesthetic prevented anesthesia of the affected finger. The results of Atkinson's experiment led to

the theory of a peripheral mechanism of action of the local anesthetic on nerve endings. Peripheral nerve endings in the extremities are nourished by small blood vessels (referred to as the vasa nervorum). Injection of a local anesthetic solution into the venous system will result in diffusion of the local anesthetic from these small vessels into the nerve endings themselves, with the subsequent development of anesthesia (Lillie et al. 1984). As blood vessels and nerves are typically found in close proximity in the extremities, following intravenous injection the local anesthetic spreads from the vessels into the nearby tissues to reach the nerve trunks (Lillie et al. 1984). Finally, mechanical compression of nerves and local tissue ischemia can also contribute to the loss of sensation in the extremity that occurs within 30 minutes of tourniquet application (Casale et al. 1992). Most likely, it is a combination of all these mechanisms that contribute to the anesthetic effects of IVRA (Rosenberg 1985). Overall, the local anesthetic action on peripheral nerve endings appears to be responsible for the immediate onset of analgesia, and blockade of the larger peripheral nerves occurs after the local anesthetic spreads from the vessels into the adjacent tissues (Lillie et al. 1984).

Intravenous regional anesthesia results in anesthesia of the entire extremity distal to the tourniquet. Human patients report "pins and needles" in the extremity within five minutes of the local anesthetic solution being administered (Davis and McConachie 1998). The onset of anesthesia and muscle paralysis appears to begin distally and progress proximally; thus the local anesthetic should be injected as far distally as possible in the limb to be blocked (Skarda 2007). Following release of the tourniquet at the end of the procedure, the analgesic effects of lidocaine persist for up to 30 minutes (Davis and McConachie 1998; DeMarzo et al. 2008; Staffieri et al. 2010).

Equipment

The following equipment should be available to the anesthetist:

- clippers;
- solutions for aseptic skin preparation prior to intravenous catheterization;
- intravenous catheters of appropriate sizes for the patient;
- sterile gloves;
- appropriate syringes and needles;
- local anesthetic solution ± desired adjunct: a typical volume for dogs and cats is 0.6 mL kg^{-1} of lidocaine neat that has been diluted to 0.5% (5 mg mL^{-1});
- esmarch bandage or a similar elastic bandage: this bandage will be used to exsanguinate the extremity distal to the planned location of the tourniquet. The author almost exclusively uses Vetrap® bandage material to exsanguinate the limb because of its ready availability, ease of use, low cost, and the fact that it is unlikely to traumatize the leg in patients with injured tissues (e.g. fractures, open wounds); and
- tourniquet: the tourniquet plays critical roles in both the successful performance of the IVRA block and the overall safety of the procedure. If the tourniquet does not effectively prevent arterial blood flow from entering the distal limb or does not effectively prevent the injected local anesthetic from entering the systemic circulation, complications can occur (Hoffmann et al. 1995). There are two main types of tourniquets: nonpneumatic tourniquets that are made of rubber or elasticized cloth, and pneumatic tourniquets that have cuffs that are inflated with a compressed gas or by manual inflation.

Nonpneumatic rubber tourniquets are commonly used for IVRA in small animals because they easily accommodate for different anatomic locations (i.e. front leg or hind leg) and the variations in the size, circumference, and the shape of the legs that exist across the different types of small animal patients seen in practice. The main disadvantages of using nonpneumatic tourniquets are the high pressures that are potentially applied to the underlying tissues, and the inability to measure these pressures. As a result, when using nonpneumatic tourniquets for IVRA, patients usually experience more pain from tourniquet-related ischemia and there is an increased risk of tissue damage. Protecting the area where the tourniquet will be placed with soft padding can help in the prevention of compressive tissue damage (Novello 2003), and the upper limits must be strictly adhered to for the duration of tourniquet application.

Pneumatic tourniquets are available with both single- or double-cuff configurations. All pneumatic tourniquets that are used for IVRA should have a pressure gauge (manometer) that indicates the pressure in the tourniquet cuff bladder. In some cases, an automatic pressure control system regulates the pressure in the cuff bladder over time in order to maintain a constant predetermined pressure that is set by the operator (McEwen 2009). An inexpensive alternative is to use a simple blood pressure cuff used in combination with a sphygmomanometer as pneumatic tourniquet. The sphygmomanometer is used to inflate the blood pressure cuff and to monitor the pressure in the cuff over time. The pressure level in the cuff must be frequently monitored over the course of the procedure and the cuff's level of inflation must be adjusted as needed to maintain adequate pressure. Before use, the cuff should first be tested for leaks. Obviously, only intact cuffs should be used as tourniquets for IVRA.

Step-by-step procedure for the thoracic limb

- Clip: clip the limb as needed for the surgery and for intravenous catheter placement. If a pneumatic tourniquet is to be used, also consider clipping the area where the tourniquet will be placed on the limb to allow for closer contact of the cuff with the leg.
- IV catheterization: using standard aseptic technique, catheterize a distal vein in the limb. For a better distribution of the local anesthetic it is important to catheterize the vein in the more distal part of the limb. The venous valves would impair the distribution of the anesthetic solution in case of a proximal injection site (Skarda 2007) (Figure 15.2). The catheter should be capped with a PRN adapter (or similar device) and temporarily secured with tape in order to avoid its dislocation during exsanguination of the limb.
- Identify a peripheral pulse: palpate a distally located arterial pulse. One example is the palmar artery that is found distal to the carpal pad in the metacarpal region on the palmar aspect of the paw. When a pulse is located, it is helpful to mark the area where the pulse is readily palpable with a pen. Following exsanguination of the limb and application of the tourniquet, the absence of the pulse at this location will verify proper application of the tourniquet.
- Identify the lower occlusion pressure: if a pneumatic tourniquet is to be employed, it is useful to determine the lower occlusion pressure (LOP) for the cuff. This measurement corresponds to the lowest pressure in the cuff that will prevent arterial flow distal to the tourniquet (i.e. the level at which no arterial pulses are able to be detected distal to the cuff) (Wilson and Lyon 1989). In human patients, it is common practice to place a pulse oximeter probe on a finger in order to confirm the absence of digital perfusion once the cuff is inflated. This technique is not always applicable in veterinary patients; however, placement of a Doppler ultrasonic probe over the palmar artery is a reasonable alternative. The LOP will not only be different between patients, but it can also vary over time over the course of an individual patient's anesthetic. The LOP is indirectly affected by factors that affect arterial blood pressure, as well as by mechanical factors (limb movement, cuff size, cuff design, and cuff position). The baseline LOP should be recorded on the patient's record, as the cuff pressure will need to be maintained well above this level during the procedure.

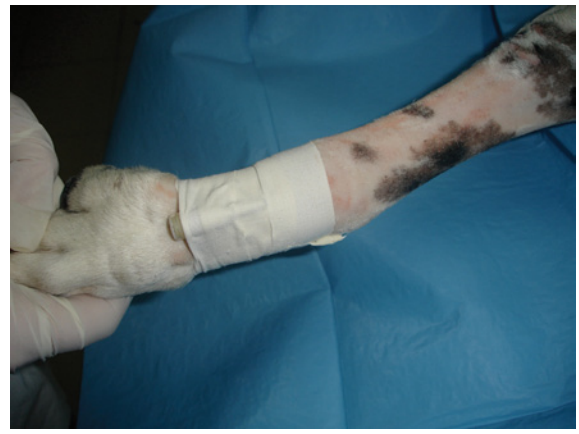

Figure 15.2 Photograph of the distal thoracic limb of a dog scheduled for pancarpal arthrodesis. Note that an intravenous catheter has been placed in the more distal part of the limb and it has been well secured with tape.

- Exsanguination: if blood flow into the distal limb is not stopped, it will dilute the administered local anesthetic and will negatively impact the diffusion of the local anesthetic solution out of the vessel into nerve endings and peripheral nerve fibers. This can lead to incomplete nerve blockade, especially if low initial concentrations of local anesthetic solutions are used. When exsanguinating the limb, the leg can be initially elevated for three to five minutes to allow for passive venous drainage. Following this step, an elastic bandage (e.g. Esmarch or Vetrap®) should be applied. The bandage should be wrapped concentrically around the limb starting from the toes and wrapping proximally, while being careful not to dislodge the IV catheter that was previously placed. It is helpful to stretch the bandage slightly before applying the next turn in order to maintain a tight wrap on the limb (Figure 15.3).
- Tourniquet application: The tourniquet is then applied to the limb. If a pneumatic tourniquet is used, the cuff should be inflated to a pressure 50–100 mmHg above the previously measured LOP (Figure 15.4). In the case of a nonpneumatic rubber tourniquet, the band should be placed above the elastic wrap that was used for exsanguination and secured tightly to prevent its inadvertent release (Figure 15.3). The time that the tourniquet is applied should be recorded on the patient's anesthetic chart. The remaining procedures (completion of IVRA, preparation for surgery, surgery) should be limited to 90 minutes from the time that the tourniquet was applied in order to avoid complications from prolonged ischemia and compression of tissues under the tourniquet.
- Bandage removal: once the tourniquet is in place and secure, the elastic bandage that was used to exsanguinate the limb should be carefully removed (Figure 15.5). As with its application, take care to avoid dislodging the intravenous catheter as the bandage is being unwrapped.
- Confirm absence of peripheral pulse: before local anesthetic administration, the absence

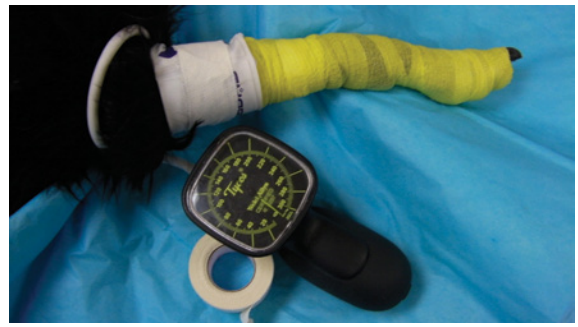

Figure 15.4 Photograph of the distal thoracic limb of a dog. The pneumatic cuff has been inflated by a sphygmomanometer and is well above the LOP of the patient (approximately 300 mmHg).

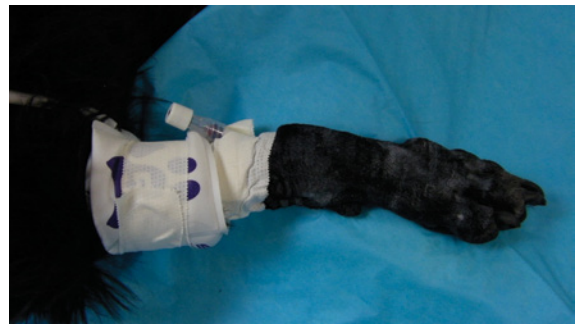

Figure 15.5 Photograph of the distal thoracic limb of a dog. The pneumatic tourniquet has been inflated and the elastic bandage has been removed.

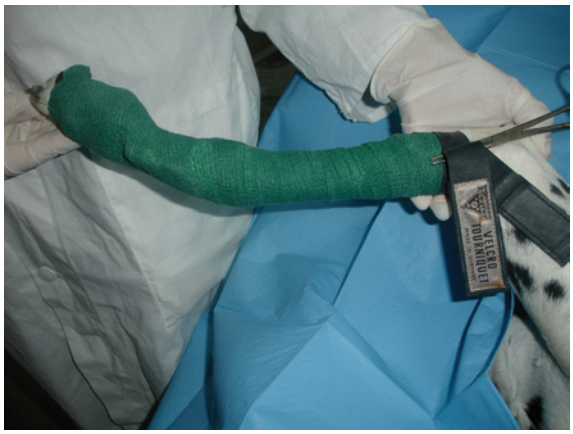

Figure 15.3 Photograph of the distal thoracic limb of a dog. Vetrap® has been wrapped around the entire limb and has been used to exsanguinate the limb prior to administration of IVRA. A non-pneumatic tourniquet has been applied distally and secured with a surgical clamp.

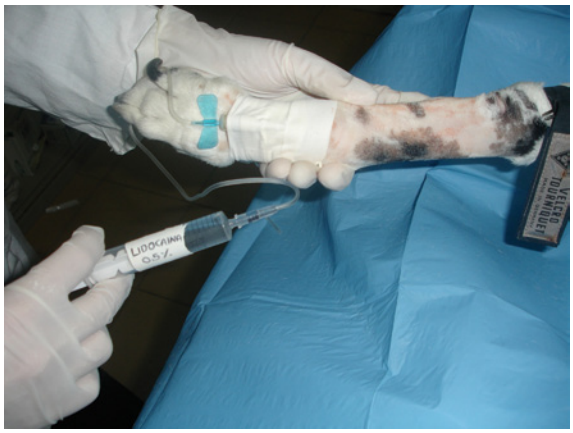

Figure 15.6 Photograph of the distal thoracic limb of a dog. A dilute solution of 0.5% lidocaine neat is slowly being injected over 2–3 minutes.

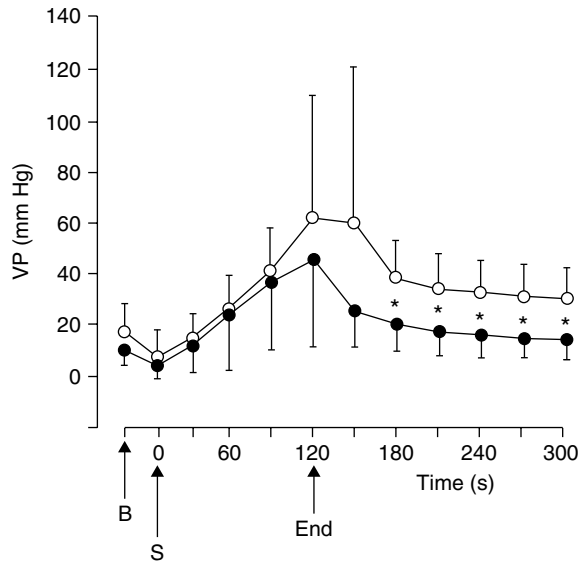

Figure 15.7 Venous pressures (VP) for the upper and lower limbs of people during 120 seconds of injection and during 180 seconds after the end of injection (mean ± SD). B = Before exsanguination, S = start of injection, End = end of injection. *$P < 0.05$. (From: AC Hoffmann et al. (1995). Used with permission.)

of a peripheral pulse at the previously documented location should be confirmed through palpation or use of a Doppler ultrasonic monitor.

- Injection: the local anesthetic solution should be slowly injected over two to three minutes (Figure 15.6). Avoid high injection pressures during injection of the solution, as large increases in venous pressure can lead to leakage of the local anesthetic under the tourniquet into systemic circulation (Figure 15.7). During injection, the area where the catheter penetrates the skin should be checked for evidence of extravascular injection. The time of local anesthetic administration should be recorded on the patient's anesthetic chart, and the patient should be observed for several minutes for signs of systemic toxicity.
- Catheter removal: following injection of the calculated volume of the local anesthetic solution, the catheter can be removed if necessary to facilitate the surgery.
- Tourniquet removal at the end of the surgery: At the end of the procedure the tourniquet can be removed. If a pneumatic tourniquet was used, the cuff should be deflated slowly to allow blood flow to return to the distal limb. If a nonpneumatic tourniquet was used, it should be slowly released in similar fashion so that arterial flow does not immediately return to normal levels over only a few seconds. Bleeding from the surgical site should also be evaluated as no assessment of hemostasis can be made during the surgical procedure while the tourniquet was in use and occluded arterial blood flow to the distal limb.

Step-by-step procedure for the pelvic limb

The technique is similar when the block is used for procedures involving the distal pelvic limb of small animals. In people, due to anatomic differences in limb size, it is reported that a larger volume of local anesthetic solution is required for lower extremity procedures when compared with those of the upper extremity. In dogs and cats, the author has had good results using the same calculated volume of 0.6 mL kg^{-1} of lidocaine 0.5% that was described previously for the thoracic limb. A major difference between performing IVRA for the thoracic limb versus the pelvic limb in small animals is that exsanguination of the pelvic limb is sometimes

more challenging due to the shape of the limb. Otherwise, the same steps that were described above for the thoracic limb should be followed when performing IVRA for the pelvic limb.

Clinical tips for performing IVRA

The size of the catheter that is used for the injection of the local anesthetic should be small in order to reduce the potential for oozing when the catheter is removed following administration of the anesthetic solution. The author typically uses 25-gauge or 22-gauge catheters, regardless of patient size.

The location of the planned surgical procedure is a major determinant of the location of the tourniquet. In case of surgery on the paw (e.g. digit amputation, foreign body removal), the tourniquet can be placed around the antebrachium, whereas when surgery on the carpus or the distal antebrachium is planned, the tourniquet should be placed at a more proximal location above the elbow.

If it is still possible to palpate a peripheral pulse after exsanguination and tourniquet application, no injection of local anesthetic should be made. Instead, the tourniquet should be removed, blood flow to the limb should be allowed to recover for several minutes, and the entire process repeated. Never proceed with the block if an arterial pulse is detected. This indicates that high-pressure pulsatile arterial blood is still entering the distal limb, while venous blood is likely not leaving it. If left uncorrected, the limb would progressively develop edema and swelling over the course of the procedure and other complications might occur.

Inject the local anesthetic solution slowly. If all of the previous steps were performed correctly, the injection should be easy to complete. If resistance to injection is experienced, stop the injection and investigate reasons for this unexpected observation. DO NOT CONTINUE TO INJECT WITH INCREASED PRESSURE. If the local anesthetic is injected too rapidly or under too high an injection pressure, venous pressure can increase and cause leakage of the anesthetic into the circulation, potentially leading to systemic toxicity (Figure 15.7). If no obvious reasons for the increased resistance to injection are detected, wait for several minutes and verify the onset of the anesthesia. Depending on the volume already administered to that point, the remaining local anesthetic solution may not be required to obtain complete blockade and the catheter can simply be removed.

It is recommended to have a short acting analgesic drug (e.g. fentanyl or alfentanil) available that can be administered intravenously in case the block is not sufficient for the procedure and the patient responds to surgical stimulation.

If a pneumatic tourniquet (e.g. blood pressure cuff and sphygmomanometer) is being used, cuff pressure and arterial blood pressure must be monitored together every few minutes. The tourniquet cuff pressure must be adjusted as necessary to maintain its pressure 50–100 mmHg above the measured systolic arterial pressure to prevent blood from entering the limb under the tourniquet. Even when performed correctly, leakage of local anesthetic under the cuff is possible, so correct dosing is imperative to ensure patient safety (Hoffman et al. 1995; Kushner et al. 2002).

Postoperative nerve injury has been linked to tourniquet pressures greater than 400 mmHg (52 kPa, 7.54 psi) (Fanelli et al. 1999). In cases where tourniquet pressure can be measured (when using a pneumatic tourniquet), do not apply pressures greater than 400 mmHg.

In order to increase safety during the period when the tourniquet is released, it is recommended to use a "step release" procedure. The tourniquet (or cuff pressure) is released for a short period of time (20–30 seconds), followed by reapplication to again limit arterial and venous blood flow to the distal limb. The tourniquet is left in place for several minutes, followed again by release. These steps are repeated several times over 5–10 minutes. Using the "step release" method of tourniquet removal has been shown to reduce the overall wash out of the local anesthetic into the systemic circulation and therefore potential for systemic toxicity (Davis and McConachie 1998).

The duration of the block is dependent on the continued presence of the tourniquet. There are two main factors that influence how long the tourniquet can remain in place: the risk of compressive and ischemic injury to the underlying tissues, and the occurrence of tourniquet-related pain. In human medicine, 90 minutes is considered to be the upper limit for the use of a tourniquet with IVRA in order to avoid major ischemic damage to the underlying tissues. Although similar studies have not been

performed in animals, this recommendation should also be followed in veterinary practice.

Ischemic pain resulting from the use of the tourniquet is one of the major complications reported in human patients and can interfere with the overall success of the procedure. Several techniques have been investigated in people in an attempt to limit this debilitating side effect: the co-administration of adjuncts with the local anesthetic solution, the infiltration of the skin under the tourniquet with a local anesthetic solution, the administration of systemic analgesic/hypnotic drugs (e.g. opioids, benzodiazepines), and the use of a double cuff tourniquet. Use of a double-cuff tourniquet appears to be the most effective.

Using this technique, IVRA is performed as described above with the proximal cuff inflated initially. As the procedure progresses and the patient begins to show signs of tourniquet pain (usually detected as sympathetic responses that are unresponsive to systemic analgesic treatments), the second cuff (the more distal of the two) is inflated and the proximal cuff is deflated. In this way, the distal cuff compresses an area of tissue that has already been blocked by the local anesthetic, and ischemia under the proximal cuff is relieved. When this

Table 15.1 Potential complications of intravenous regional anesthesia and steps to prevent them from occurring.

Potential complication	Avoidance strategies
Ischemia and nerve injury	• Limit the use of IVRA techniques and application of the tourniquet to a maximum of 90 min. If the procedure is expected to take longer than this upper limit, alternative techniques should be used and the IVRA technique should be discontinued or avoided altogether • Monitor tourniquet pressure and maintain cuff pressure less than 400 mmHg
Local anesthetic systemic toxicity	• This complication is usually due to an overdose of the local anesthetic being administered, and/or the tourniquet was incompetent and allowed leakage of local anesthetic into systemic circulation • To prevent a toxic dose from being administered, calculate the correct dose of the lidocaine neat to be used (e.g. $<5\ mg\ kg^{-1}$) • To prevent leakage under the tourniquet: 1) ensure that the tourniquet is reliable and that the appropriate pressure is maintained throughout the procedure (i.e. 50–100 mmHg above the lower occlusion pressure (LOP) for the patient), and 2) slowly inject the local anesthetic to avoid causing a rapid increase in venous pressure in the distal limb • At the end of the procedure, gradually release the tourniquet with two or more inflation–deflation cycles in order to minimize high systemic levels of the local anesthetic at the end of the procedure • NEVER USE BUPIVACAINE FOR IVRA
Hematoma	• Use a small gauge IV catheter (22-gauge, 25-gauge) for injection of the local anesthetic • When a superficial vein is punctured during an unsuccessful initial attempt at placing the IV catheter, apply firm pressure on the puncture site for 2–3 min to ensure hemostasis
Engorgement of the extremity	• This usually occurs if the tourniquet is applied incorrectly • In this situation, although the tourniquet prevents venous outflow, arterial flow into the distal limb is not adequately occluded • It is important to ensure that the tourniquet is fully functional and that the arterial pulse is absent prior to proceeding with the procedure • If a blood pressure cuff is being used as a tourniquet, it should be inflated 50–100 mmHg above the systolic arterial pressure of the patient • The cuff pressure and the patient's arterial blood pressure must both be monitored frequently throughout the procedure • The cuff inflation pressure may need to be adjusted from its initial level if the patient's arterial blood pressure increases during the procedure (i.e. in response to stimulation or tourniquet pain)
Ecchymosis and subcutaneous hemorrhage where the tourniquet is placed	• Padding can be used under the tourniquet as needed in some patients to limit local damage to tissues when the tourniquet is applied

method is used, the patient's vital signs stabilize and they appear to be more comfortable.

At the end of the procedure, the tourniquet is released and any remaining local anesthetic in the venous system of the distal limb is free to be delivered to the systemic circulation when blood flow is re-established. For this reason, it is important to closely monitor the patient for signs of cardiovascular instability (hypotension, bradyarrhythmias) over the next 10–15 minutes in order to recognize the signs of potential systemic toxicity.

When lidocaine is used, sensation of the blocked area will typically return within 15–30 minutes once the tourniquet is released. For this reason, it is important to administer other appropriate postoperative analgesics to the patient prior to tourniquet removal.

Potential complications and how to avoid them

In a regional anesthesia study involving 3996 human patients (Fanelli et al. 1999), the only variable that showed a significant predictive association with postoperative nerve injury was tourniquet pressure greater than 400 mmHg (52 kPa, 7.54 psi). Whenever possible, cuff pressures should be monitored and maintained in a reasonable range (see section on Clinical tips for more information).

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