Ultrasound Guidance

The Inevitable Evolution of Locoregional Anesthesia

CHAPTER 1

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There's a way to do it better. Find it.

—Thomas Edison

INTRODUCTION

It should come as no surprise that advancements in veterinary medicine often follow those in human medicine, and it is no different with the evolution and use of locoregional anesthesia. This is despite the fact that animals are often used to study and develop new techniques before they are ever used in people. Even Carl Koller, the Austrian ophthalmologist who first used topical cocaine to induce sensory anesthesia of the cornea in a patient for glaucoma surgery in 1884, first experimented with its desensitizing effects on the corneas of dogs and guinea pigs (Calatayud and González 2003).

The interest in, and use of, locoregional techniques has increased significantly. Much of the research up until the mid-1990s focused on the discovery of new drugs (e.g. bupivacaine, ropivacaine, bupivacaine liposome injectable suspension), techniques (e.g. nerve block catheters), and adjuvants (e.g. dexamethasone, clonidine, etc.) that could be used to extend the duration of anesthesia and analgesia provided to patients (Dahl et al. 1988; Eledjam et al. 1991; McGlade et al. 1998). Additionally, methods to assist in nerve location (i.e. paresthesia, electrical nerve stimulation) were sought to provide ways other than anatomic landmarks to target peripheral nerves, and hopefully, improve patient safety and increase success. In 1994, this search culminated in the use of ultrasound guidance when Kapral et al. (1994) published a randomized, controlled trial examining ultrasound-guided brachial plexus blocks in people. A new era in locoregional anesthesia had begun.

ULTRASOUND TECHNOLOGY

A BRIEF HISTORY

The discovery of piezoelectricity by brothers, Jacque and Pierre Curie in 1880, provided the foundation for the development of the modern-day ultrasound transducer. By applying an electric current to quartz crystals, they caused the crystals to vibrate and produce ultrasonic waves. This revolutionary finding became critical to the development of sonar that was used by submarines in World War I, and of ultrasound therapy whereby physicians could use the vibrations that were produced to treat a variety of illnesses (Duck 2021). It was not until 38 years later, in 1928, that Russian physicist SY Sokolov utilized ultrasound for imaging purposes. He invented an ultrasound transducer using a single transmitter and receiver that, when placed on opposite sides of a metal sheet, was able to detect imperfections in the metal and display line images produced from the disruptions in sound wave transmission (Duck 2021).

Ultrasound for medical imaging eventually emerged after several researchers struggled to develop transducers that could work in a hospital setting. In 1956, a predecessor of today's B-mode (i.e. "brightness" mode) ultrasound, the 2-D compound scanner, was developed by obstetrician Ian Donald and engineer Tom Brown to image an unborn fetus (Whittingham 2021) (Figure 1.1). Worldwide advancement of ultrasound technology continued throughout the 1960s and 1970s, culminating in the invention of the linear array transducer that utilized several rows of transducer elements to produce real-time scanning (Whittingham 2021).

USE OF ULTRASOUND FOR LOCOREGIONAL ANESTHESIA

Using ultrasound technology to assist with performing locoregional blockade was first reported by la Grange et al. (1978) who, after identifying the subclavian artery using Doppler ultrasound, performed supraclavicular brachial plexus blocks in 61 patients using anatomy and the presence of paresthesia to determine where to deposit the local anesthetic. It was not until 1994, however, that the use of ultrasound was first described to help guide a stimulating needle toward the target nerve trunks when performing brachial plexus blocks via both axillary and supraclavicular approaches (Kapral et al. 1994).

ULTRASOUND-GUIDED LOCOREGIONAL ANESTHESIA IN VETERINARY SPECIES

As the use of ultrasound guidance in regional anesthesia grew in human medicine, its use slowly started to emerge in the veterinary literature, first with a paper describing the sonographic appearance of canine sciatic nerves in 2007, followed

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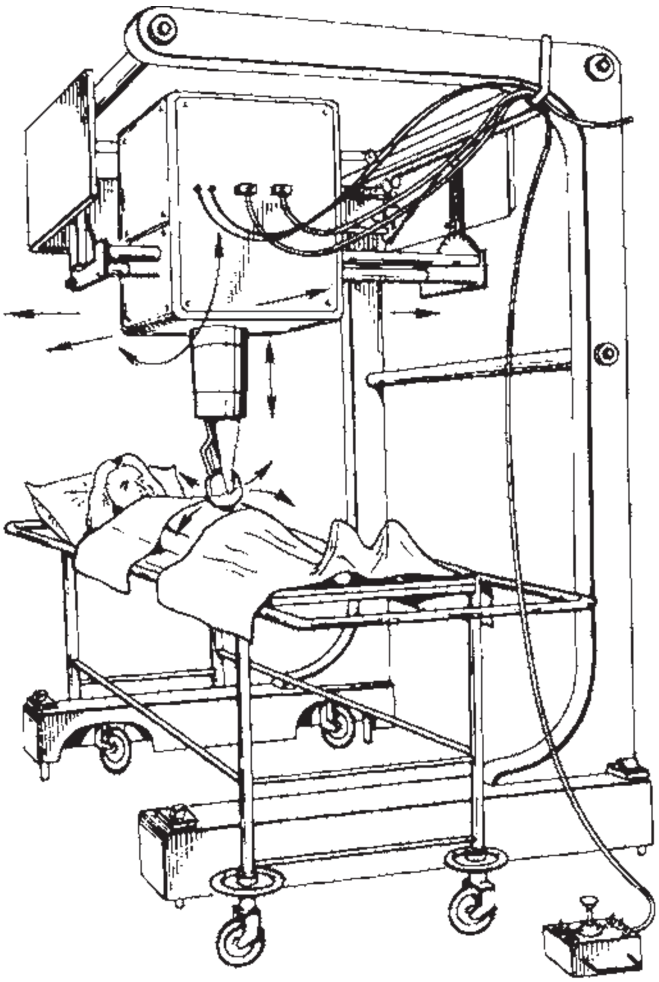

FIGURE 1.1 Drawing of the 2-D compound scanner, developed through the collaborative efforts of Dr. Ian Donald and Tom Brown. Source: McNay and Fleming (1999)/with permission of Elsevier.

shortly thereafter by a similar study that described the use of ultrasound for evaluation of the canine brachial plexus (Benigni et al. 2007; Guilherme and Benigni 2008).

The first study to describe the use of ultrasound-guided blocks in dogs was accepted for publication in 2009 (Campoy et al. 2010). That study reported using an in-plane needle technique to approach the brachial plexus and the femoral and sciatic nerves in medium- and large-breed dogs. Each approach was followed by deposition of a mixture of lidocaine and methylene blue at the target site, allowing for later identification of nerve staining after euthanasia of the dogs for unrelated purposes. Later that same year, the first efficacy study that documented successful sensory blockade following ultrasound-guided saphenous and sciatic nerve blocks in dogs was submitted for publication by Costa-Farré et al. (2011), and the first description of using ultrasound-guided blocks in cats was published by Haro et al. in 2013. Since then, use of ultrasound guidance for nerve blocks has been reported in a wide range of veterinary species (De Vlamynck et al. 2013; Hughey et al. 2022).

HOW ULTRASOUND GUIDANCE HAS CHANGED LOCOEGIONAL ANESTHESIA

Objective measurement of the impact a new modality or treatment has on an industry, in this case medicine, can be difficult to determine, particularly when it is first being instituted. Fortunately, the impact of ultrasound guidance on regional anesthesia has been established. In 2017, Vlassakov and Kissin (2017) published a study assessing notable advances in regional anesthesia from 1996 through 2015. They evaluated meta-analyses that had been published on a variety of regional anesthesia topics based on their ability to demonstrate measurable clinical benefits. Various topics were analyzed based on their level of academic interest, findings of statistically significant effects, their overall risk of bias, the degree of heterogeneity between the studies within each meta-analysis, and the determination of a minimal clinically important difference (MCID). Of all the topics they analyzed, they concluded that within this 20-year time period, the discovery and development of ultrasound guidance for performing upper and lower limb peripheral nerve blocks was the one of greatest clinical importance.

This has been supported in practice by several studies that compared the use of ultrasound guidance to other methods of nerve location (i.e. electrostimulation, paresthesia, etc.) for performing regional blocks. A compilation of these findings, published by the American Society of Regional Anesthesia and Pain Medicine (ASRA), provided an objective evidence-based assessment of the literature in order to determine if ultrasound guidance produced a positive effect on the performance, efficacy, and/or safety of regional blocks over other methods of nerve location (Neal et al. 2016). As interest has grown, the feasibility of incorporating ultrasound guidance into large-scale operations and its financial impact have also been investigated and addressed through cost-analysis studies (Liu and John 2010; Ehlers et al. 2012).

PERFORMANCE AND EFFICACY

The ASRA determined that when ultrasound guidance was compared to other methods of nerve location for extremity blocks, it was favored based on fewer needle passes, faster block performance, decreased onset time, and greater block success, with high levels of evidence and minimal differences between upper and lower extremities (Neal et al. 2016). Use of ultrasound guidance for neuraxial blocks also demonstrated superior performance when compared to palpation in terms of determining the correct vertebral interface, requiring fewer needle sticks, and the ability to accurately predict the needle insertion depth to the target ahead of time. Less demonstrable evidence was available at the time of that study to fully evaluate the impact of ultrasound guidance on the performance of truncal blocks, with many of the techniques currently being used still in development and/or lacking methods of comparison to other techniques.

SAFETY

When compared to other methods, one of the most notable benefits of incorporating ultrasound guidance into performance of regional anesthesia is a decreased incidence of local anesthetic systemic toxicity (LAST). Barrington and Kluger (2013) published a landmark study that evaluated the incidence of LAST following peripheral nerve blockade using either ultrasound-guided or non-ultrasound-guided techniques in 20021 patients (25336 blocks). They determined that use of ultrasound guidance reduced the risk of LAST by more than 65% compared to when other techniques were used. This was likely due to being able to visualize and avoid large blood vessels in the target area, recognizing potential intravascular injections earlier by noting the absence of local anesthetic spread in the area of interest, being able to use smaller local anesthetic doses to achieve successful blockade, and requiring fewer repeat blocks because of block failure (Marhofer et al. 1998; Barrington and Kluger 2013). Of particular interest, though not reported in other studies, was that there was no difference in the incidence of vascular puncture between the different groups. Barrington and Kluger postulated that when vascular punctures occurred during performance of ultrasound-guided blocks, they did not result in LAST because the intravascular injections were recognized by the anesthetist and halted before their patients developed clinical signs. With development of newer technologies, such as color power Doppler, the ability to identify smaller, low-flow blood vessels near the area of interest may be further improved, preventing vascular punctures, and accentuating the benefits of ultrasound- over non-ultrasound-guided techniques for preventing LAST to a greater extent (Martinoli et al. 1998).

While several areas within regional anesthesia have been impacted positively by the introduction of ultrasound guidance, the ASRA was unable to find an appreciable difference in the incidence of neurologic complications (i.e. sensorimotor deficits) following peripheral nerve blockade when ultrasound was used versus not (Neal et al. 2016). Several explanations were provided, including lack of technical skill or training of the anesthetist, the inability of ultrasound technology to provide the necessary resolution to allow discrimination between neural and nonneural tissues, and the presence of anatomical barriers that impair visualization of the needle tip.

A retrospective analysis comparing the incidence of neurologic outcomes following interscalene brachial plexus blocks in people before and after the institution of ultrasound guidance was published the same year as the ASRA assessment (Rajpal et al. 2016). Those authors found that the incidence of neurologic complications was significantly lower with ultrasound guidance than the historical rates that were published for the same block using electrostimulation (2% versus 10%, respectively). These results could indicate that ultrasound guidance, when specific blocks are evaluated (particularly those with higher risk of nerve injury), may demonstrate a better risk profile for postoperative neurologic symptoms versus evaluating all blocks as a whole. The potential benefit of using ultrasound to reduce the incidence of neurologic injury has not been definitively proven, so anesthetists need to demonstrate continued diligence when performing blocks, even if ultrasound is being used.

FINANCIAL IMPACT

Incorporation of new modalities is often associated with a price tag. Cost, in many situations, may determine whether a new technique has the ability to be utilized by a larger medical population. Studies in people have investigated the financial impact of using ultrasound guidance for performing locoregional blocks versus other methods. A study that used computer modeling to evaluate cost differences between ultrasound-guided and nerve stimulation for regional anesthesia determined that, when used in an ambulatory setting, ultrasound-guided blocks only became more expensive than using nerve stimulation if the block success rate for nerve stimulation was >96% (Liu and John 2010). This is considerably higher than success rate outcomes for several randomized controlled studies where complete sensory block using nerve stimulation occurred 27–76% versus 87–100% of the time when using ultrasound guidance (Liu 2016).

A prospective clinical study evaluating the cost-effectiveness of ultrasound-guided versus nerve stimulator-guided catheter insertion for continuous sciatic nerve blocks had similar, albeit more relevant, findings (Ehlers et al. 2012). Those authors used the ratio of added cost to the number of additional successful nerve blocks to determine that the use of ultrasound guidance is 84.7% more likely to be effective and less expensive than use of nerve stimulation. It is important to remember, however, that these numbers have the ability to be influenced by several factors, including fluctuating costs of equipment, caseload, and expertise of personnel.

VETERINARY MEDICINE

PERFORMANCE, EFFICACY, AND SAFETY

Only two studies have evaluated the use of ultrasound guidance versus other methods of nerve location in veterinary species, likely a reflection of the relative newness of these techniques and the number of individuals performing them. Both studies compared ultrasound guidance to nerve stimulation in dogs undergoing brachial plexus blocks. Using six Beagles in a crossover study, Akasaka and Shimizu (2017) found that the use of ultrasound guidance resulted in faster block performance, faster onset time, and longer duration of analgesia than when nerve stimulation was used with similar efficacy. Another small clinical study ($n = 32$) sought to determine the differences in complication rates and efficacy in dogs undergoing either ultrasound-guided or nerve-stimulator-guided brachial plexus blocks for thoracic limb surgery. Block success rate in this study was 87% (14/16 dogs) for ultrasound-guided blocks and 75% (12/16 dogs) for nerve stimulator-guided blocks ($P > 0.05$), with similar rates of minor complications (i.e. hypotension, Horner's syndrome) in both groups (Benigni et al. 2019). Unfortunately, these studies do not allow specific metrics or meta-analyses to be performed, leaving veterinary clinicians to rely upon those recommendations produced from studies in people until more data becomes available.

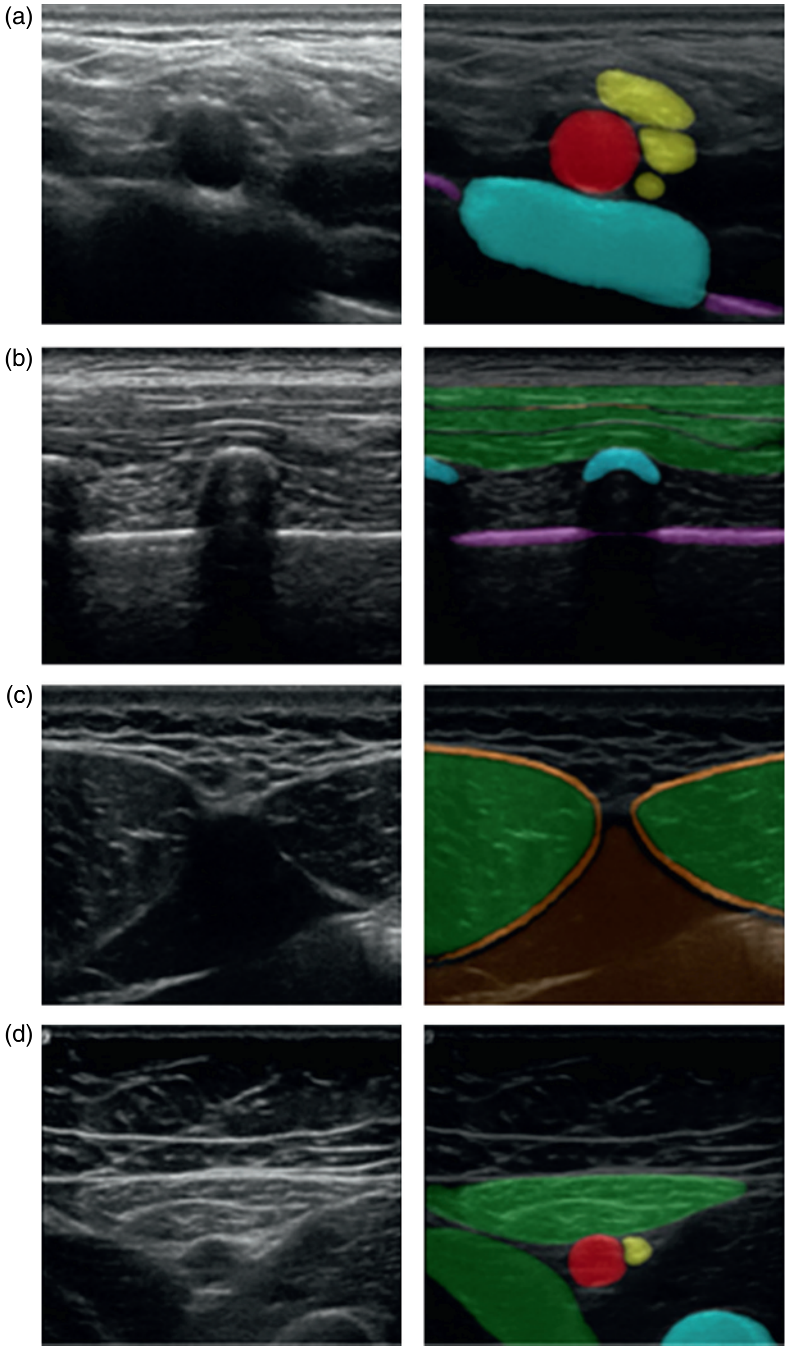

FIGURE 1.2 Ultrasound images of (a) brachial plexus (supraclavicular level); (b) erector spinae plane; (c) rectus sheath; and (d) adductor canal (mid-thigh). Images on the right have artificial intelligence (AI)-assisted identification (ScanNav™ Anatomy PNB) of bone (blue), blood vessels (red), nerves (yellow), fasciae (orange), pleura (purple), and peritoneum (brown). Source: From Bowness et al. (2021)/John Wiley & Sons.

FINANCIAL IMPACT

A recent study by Warrit et al. (2019) compared the financial impact of using ultrasound-guided lumbar plexus and sciatic nerve blocks that were confirmed with nerve stimulation versus no blocks in dogs undergoing tibial plateau leveling osteotomies. Those authors found that dogs that did not receive peripheral nerve blocks had more episodes of hypotension, more interventions to manage hypotension, and more requirements for postoperative rescue analgesia both immediately upon recovery, as well as over the next 12 hours, than dogs that received ultrasound-guided blocks. As a result, dogs in the no-block group had significantly greater and more variable anesthesia costs than the dogs receiving nerve blocks, despite the increased cost of using more advanced equipment such as the ultrasound machine. The authors acknowledged that these cost savings could vary or even be negated in patients that did not develop hypotension or other complications requiring additional interventions. It is worth mentioning that fixed anesthesia costs were not significantly different, with no difference in total anesthesia time being observed between the two groups ($P = 0.4$). This may speak to the use of ultrasound guidance and its ability to decrease the time it takes to perform peripheral nerve blocks, similar to what has been shown in people.

WHAT IS NEXT?

Many of the challenges of performing ultrasound-guided regional anesthesia have primarily been attributed to lack of anesthetist skill and training or technological limitations of currently available ultrasound equipment. These include the inability to identify the needle tip due to anatomic impediments, steep angles or deeper targets, and transducer resolution incapable of allowing identification of structures less than 1 mm in size (e.g. individual fascicles within the nerve) (Abdallah et al. 2016).

These challenges are being addressed, particularly with the advent of artificial intelligence (AI). Recent publications have incorporated AI software capable of identifying and delineating muscles, fasciae, blood vessels, and nerves to assist the anesthetist in image interpretation and subsequent nerve block performance (Figure 1.2) (Bowness et al. 2021). The benefits of such technology, particularly in the training of new regional anesthetists, are just starting to be recognized and appreciated.

SUMMARY

The evolution of ultrasound-guided regional anesthesia has soundly inserted itself into veterinary medicine. With a trajectory in line with its development in human medicine, the expectation can only be to assume that ultrasound guidance will phase out older technologies and become the new standard of care when performing regional anesthesia and analgesia in veterinary patients.

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