Ultrasound guidance in peripheral regional anesthesia: philosophy, evidence-based medicine, and techniques
Brian D. Sites\textsuperscript{a} and Richard Brull\textsuperscript{b}

Purpose of review
This article introduces the use of ultrasound to facilitate peripheral regional anesthesia.

Recent findings
Regional anesthesia, despite its well known clinical benefits, has not gained the popularity of general anesthesia. This is secondary to multiple shortcomings including a defined failure rate, lack of simplicity, and the potential for patient discomfort or injury. Many of the negative aspects of regional anesthesia evolve from the reality that current nerve-localization techniques are unreliable. Given the great variation in human anatomy it is not surprising that even the most veteran clinician can be challenged by techniques that demand anatomical assumptions. The recent use of ultrasound imaging for nerve localization is an innovative application of an old technology which addresses many of the shortcomings of current techniques. Specifically, ultrasound imaging allows the operator to see neural structures, guide the needle under real-time visualization, navigate away from sensitive anatomy, and monitor the spread of local anesthetic.

Summary
Ultrasound technology represents an ideal mechanism by which the regional anesthesiologist can attain the safety, speed, and efficacy of general anesthesia. Ultimately, it is the correct peri-neural spread of local anesthetic around a nerve that provides safe, effective, and efficient anesthetic conditions.

Keywords
nerve blocks, regional anesthesia, ultrasound

Introduction
Over the past 5 years there has been growing enthusiasm surrounding the use of ultrasound to facilitate peripheral regional anesthesia. This clinical interest is evidenced by the plethora of research and continuing medical education focus. This review article will define the current problems with traditional approaches to performing peripheral regional anesthesia. It will be argued that, in order to capitalize on the known clinical benefits of regional anesthesia, the blocks must be performed quickly, safely, and efficaciously. Evidence-based medicine will be presented to support the concept that ultrasound guidance may facilitate the realization of these goals. After a discussion of the principles of ultrasound guidance, we will offer several techniques for performing various upper and lower-extremity nerve blocks.

Background
Regional anesthesia, with or without general anesthesia, offers multiple benefits compared with general anesthesia alone. These include a reduction in morbidity and mortality [1–5], superior postoperative analgesia [6–8,9,10,11], and enhanced cost-effectiveness [12]. These benefits are accompanied by a low rate of serious complications [13–18]. In comparison with general anesthesia, regional anesthesia can reduce postoperative opioid and antiemetic consumption, shorten recovery-room stays, and expedite hospital discharge, all culminating in greater patient satisfaction [8,9,10,11]. Finally, regional anesthesia allows for rapid postoperative recovery of cognitive function [19,20] and can play an important role in preventive analgesia [21,22].

Unfortunately, regional anesthesia is also associated with several shortcomings. Most importantly, general anesthesia affords a near 100% success rate in comparison with regional anesthesia, which carries an inherent failure rate even in experienced hands [23]. Indeed, more anesthesiologists are familiar with providing general anesthesia compared to regional anesthesia [24]. General anesthesia can be performed faster than regional anesthesia and the technical skills needed to administer general anesthesia are easier to acquire than regional anesthesia. Further, regional anesthesia has lost clinical prominence as modern short-acting general-anesthetic agents result in fewer adverse effects [25], shorter recovery times [26], reduced hospital costs [27], and superior patient satisfaction [27] in comparison with older general-anesthetic agents. It
follows that general anesthesia is the most widely practiced anesthetic technique for ambulatory surgery in the USA [28].

One important reason for the failure rate associated with peripheral nerve blockade (PNB) is that the conventional nerve-localization techniques can be inaccurate and misleading. Traditional techniques for nerve localization (i.e., nerve stimulation and paresthesiae induction) rely upon anatomical assumptions based on surface landmarks. Given the variation in human anatomy, it is not surprising that nerve localization can frustrate even the most veteran clinician. Further, despite the time-tested safety record of traditional techniques, the potential for severe complications, including local anesthetic toxicity and severe neurological injury, remains a distinct possibility [18,29,30]. Hematoma formation following an accidental vascular puncture can result in a neural ischemia [31]. Intraneuronal injection of local anesthetic can cause nerve injury by way of mechanical trauma [32], direct neurotoxicity [33], and neural ischemia [34]. With conventional techniques, the ability to detect and avoid unintentional neural puncture and intraneuronal injection is limited. Surrogate indicators of intraneuronal injection, including pain, dysesthesia, and resistance to injection can be misleading [35–37]. During nerve stimulation, the minimum threshold current required to elicit a motor response cannot exclude the possibility of incorrect needle location [38–41].

Practitioners may avoid regional anesthesia due to the additional time required for block performance, unpredictable onset time, and concerns regarding reliability. Moreover, the fear of legal action is always a concern [42]. Indeed, the American Society of Anesthesiologists’ Closed Claims Project demonstrated that regional anesthesia is more frequently associated with nerve-injury claims compared with general anesthesia [43] despite the fact that the damaging event in more than half of the nerve-injury claims involving PNB were deemed unrelated to the nerve block [30]. The ideal PNB would therefore be as reliable and safe as general anesthesia, but maintain the important aforementioned benefits. Additionally, the ideal method of nerve localization would be time-efficient, cost-effective, and easy to learn. The use of ultrasound imaging for nerve localization during PNB is an innovative application of an old technology which addresses many of the shortcomings of the traditional ‘blind’ techniques.

Advantages

The single most important advantage of ultrasound for PNB is the ability to confirm local anesthetic spread around the target nerve. This is the salient difference from conventional blind techniques, which can fail because local anesthetic does not uniformly surround the target nerve. Ultrasound virtually eliminates the need for multiple trial-and-error needle passes that can plague nerve localization during PNB by prolonging performance times and subjecting the patient to injury and discomfort. Using ultrasound, the operator can puncture the skin close to the target nerve with little regard for anatomical assumptions or the often challenging appreciation of surface landmarks. The operator can then manipulate the needle under direct vision to the appropriate depth and place the needle tip immediately adjacent to the target nerve. With ultrasound imaging, the spread of local anesthetic is readily appreciated and needle position changes can be made freely if needed. Preliminary experience with ultrasound imaging has revealed that nerves are often displaced by light pressure [44] or injection of local anesthetic, which likely contributes to the failure rate of the blind techniques.

The second important advantage is safety. In addition to imaging the needle and nerve, ultrasound clearly reveals the surrounding hazardous structures, including blood vessels, pleura, and viscera [45]. Therefore, the risks of systemic toxicity due to intravascular injection, peripheral neuropathy due to mechanical trauma and/or intraneuronal injection, pneumothorax, and perhaps visceral injury [46,47] should be diminished with ultrasound guidance. Furthermore, because local anesthetic can be meticulously deposited around the nerve with precision, our experiences with ultrasound-guided PNB at the Dartmouth-Hitchcock Medical Center and Toronto Western Hospital suggest that the volume of local anesthetic required for surgical anesthesia is considerably less than that required when using conventional blind techniques.

The third important and increasingly indispensable advantage of ultrasound is the ability to teach students, residents, fellows, and anesthesiologists alike the clinical anatomy essential to the safe and successful PNB.

Evidence-based medicine

Techniques using ultrasound guidance have been described for the performance of all variations of upper and lower-extremity PNB [48–52]. The vast majority of these studies are feasibility studies or case reports. To date, there are only a handful of controlled trials in which ultrasound guidance is compared to traditional nerve-localization techniques.

Upper extremity

In 2003, Williams and colleagues [53] demonstrated that ultrasound-guided supraclavicular blockade is performed more rapidly than and with superior quality to those performed by anatomical landmarks. Although there was a trend toward improved surgical anesthesia in the ultrasound group, these differences did not reach statistical significance. In a randomized controlled trial
comparing trans-arterial to ultrasound-guided axillary blockade, ultrasound improved both the performance time (3.2 min faster) and success rate for surgical anesthesia (71% for trans-arterial; 100% for ultrasound) [54]. When comparing ultrasound-guided axillary and interscalene blockade with traditional landmark techniques, Soeding and colleagues [55] found that ultrasound improved block quality and reduced the incidence of unintended paresthesias. Finally, for pediatric infraclavicular blockade, Marhofer and colleagues [56] demonstrated that ultrasound guidance produced faster onset times and a reduction in visual analog scale (VAS) pain scores during block placement compared with nerve stimulation in children.

**Lower extremity**

Marhofer and colleagues [51] randomized 40 patients to have a single-injection femoral nerve block using either real-time ultrasound guidance or nerve stimulation. Ultrasound guidance was found to decrease onset time, improve quality, and increase the success rate of actual 3-in-1 blockade (i.e. femoral, lateral femoral cutaneous, and obturator nerves). In a follow-up study of femoral nerve block, the same group found that ultrasound guidance reduced the amount of local anesthetic required for surgical anesthesia compared to nerve stimulation [52]. In 2005, ultrasound was compared to the ‘fascial click’ method for performing ilioinguinal and iliohypogastric nerve blocks in children having inguinal hernia repair, orchiopexy, or hydrocelectomy [57]. Results demonstrated a reduction in failure rates (defined by postoperative fentanyl consumption) from 26% (fascial click group) to 4% (ultrasound group).

**Economics**

Little information is known regarding the economic impact of ultrasound in regional-anesthesia practice. Costs include the machine, probe, maintenance, probe covers, training, and education. Potential savings can be generated by an increase in the number of blocks performed (i.e. a reduction in performance times) and a reduction in complications. Further, if ultrasound improves block success, then this could translate into superior postoperative analgesia and reduced nausea and vomiting, both of which are associated with faster discharge times, and thus distinct economic savings [58]. Sandu and colleagues [59] reported data in 2004 suggesting that ultrasound in comparison with nerve stimulation saves US$13.90 per block when placing infraclavicular catheters. These savings were attributed to the reduction in performance times [59].

**Basic principles of ultrasound-guided regional anesthesia**

Ultrasound waves are generated when piezoelectric crystals inside the transducer (probe) vibrate at high frequency in response to an alternating current. This generates areas of compression and relaxation (pressure changes) of the molecules in which the probe is in contact with (lubricant, skin, fluid, etc.). These pressure changes move through space and when they are of the correct frequency, they are known as ultrasound waves. Like ocean waves, ultrasound waves propagate away from its source (the probe) to eventually strike a structure of interest; some of the ultrasound waves pass through the structure and some are reflected back towards the probe. When these returning echoes strike the probe, the piezoelectric crystals will vibrate once again, transforming the sound (i.e. mechanical) energy into electrical energy. This electrical energy is fed into the computer software and a two-dimensional image is generated. The degree to which the ultrasound reflects off of a structure and returns to the probe determines the signal intensity on an arbitrary black–white scale. Structures which strongly reflect echoes generate large signal intensities and appear whiter, or hyperechoic. Hypoechoic structures only weakly reflect ultrasound and appear darker.

From a clinical perspective there are two key concepts: penetration and resolution. In general, resolution refers to the ability to assess details of a given structure. In other words, resolution refers to how well a system can distinguish one object from another. The greater the resolution then the better the image detail will be. Resolution varies directly with the frequency of the ultrasound, which is expressed in megahertz. Tissue penetration depends on the wavelength of the ultrasound, which is expressed as the distance between two pressure peaks of the sound wave. The larger the wavelength, the better the penetration. Ultrasound systems with high frequencies (>10 MHz) can effectively visualize peripheral neural structures. However, given the shorter wavelength, these high-frequency systems can only accomplish visualization for superficial structures (<3 cm) such as the interscalene brachial plexus. Therefore, as resolution (frequency) increases, penetration (wavelength) decreases.

Most peripheral nerves described in the anesthesia literature have been imaged on the short axis (cross-section). Alternatively, if the probe is moved 90° from the short-axis view, the long-axis view is generated. The short-axis view is generally preferred, because it allows the operator to assess the lateral–medial perspective of the target nerve, which is lost in the long axis view (Fig. 1). In the literature, two techniques have emerged regarding the orientation of the needle with respect to the ultrasound beam (Fig. 2). The in-plane view generates a long axis view of the needle, allowing full visualization of the shaft and tip of the needle. The out-of-plane view generates a short-axis view of the needle. This image appears as a small hyperechoic dot representing a
Figure 1 Demonstration of the differences between imaging a structure on short axis and long axis

Top left: probe position to image the sciatic nerve on the short axis in the popliteal fossa. Bottom left: the corresponding short-axis ultrasound image of the sciatic nerve. Note the characteristic circular appearance of the nerve. On short axis, the anesthesiologist has simultaneous anterior–posterior and lateral–medial perspectives on the nerve. Top right: if the probe position for the short-axis view is turned 90° (either clockwise or counterclockwise), the long-axis view of the same structure will now be generated. Bottom right: the long-axis ultrasound image of the popliteal sciatic nerve. Note the characteristic tubular appearance. When imaging a nerve on the long axis, the operator loses the lateral–medial perspective. This can be disadvantageous when trying to identify needle location and circumferential spread of local anesthesia (L) around the nerve.

Figure 2 The needle in relation to the probe

Top left: needle is in-plane (long axis) with the ultrasound beam. Bottom left: the corresponding ultrasound image of the needle in-plane with the ultrasound beam. Top right: out-of-plane technique with the needle imaged in the short axis. This is also referred to as a cross-sectional view. Bottom right: the corresponding ultrasound image of the needle out-of-line with the ultrasound beam and imaged on the short axis.
cross-section of a variable portion of the needle. The needle view selected depends on various factors, including the depth of the target nerve, the surface anatomy surrounding the needle-insertion site, and operator preference. It follows that the needle orientation can differ greatly from the classical teachings of the blind techniques.

**Techniques**

One of the major downsides to ultrasound-guided regional anesthesia is the cost of the equipment and the time burden of training current and future clinicians with respect to core competencies. We are currently in the process of scientifically defining the core competencies involved with ultrasound-guided regional anesthesia. Our preliminary evidence suggests that the skills required for safe and successful ultrasound-guided PNB include needle visualization, probe stability, machine familiarity, and appreciation of normal – and abnormal – two-dimensional neurovascular anatomy. With respect to these core competencies, needle visualization and probe stabilization appear to be the most challenging. Since the current state of the art is still two-dimensional imaging, the full length of the needle (including the tip) will only be visualized if it is completely in-line with the ultrasound beam. Subtle hand movements or probe sliding will result in the needle being imaged orthogonally with respect to the ultrasound beam. This will degrade the image of the needle, possibly resulting in malposition of the needle tip and accompanying iatrogenic injury. The readership is encouraged to keep

**Figure 3** Probe position for the interscalene brachial plexus

**Figure 4** Ultrasound image of the interscalene brachial plexus

**Figure 5** Image of the interscalene brachial plexus at the level of the roots, demonstrating correct needle location

**Figure 6** Image of the same patient as in Fig. 5 following 5 ml of local anesthetic injection

Short-axis view using a 5–12 MHz linear-array transducer probe (Philips HDI 5000 system; Bothell, WA, USA). ASM, anterior scalene muscle; CA, carotid artery; IJ, internal jugular vein; MSM, middle scalene muscle; SCM, sternocleidomastoid muscle; arrows, roots of the brachial plexus.

The needle (indicated by the white triangles) is seen transgressing the middle scalene muscle with the tip located within the neural sheath between C6 and C7. AS, anterior scalene muscle; MS, middle scalene muscle.

Note the distension of the brachial plexus sheath by the hypoechoic local anesthetic. It is now harder to visualize the individual neural roots secondary to the similar acoustic impedance of the local anesthetic and the roots. L, local anesthetic; AS, anterior scalene muscle; MS, middle scalene muscle.
this distinct limitation of ultrasound-guided nerve blocks in mind as they embark on the learning process.

**Upper extremity**

Upper-extremity PNB is ideally suited to ultrasound-guided techniques. Due to the superficial location of the brachial plexus, high-frequency systems (10–15 MHz) can generate images in immaculate detail. Further, the major blood vessels in close proximity serve both as landmarks and potential obstacles for needle insertion. Our preference for performing interscalene,
supraclavicular, infraclavicular, and axillary blocks is to image all structures in the short axis and to utilize the in-plane technique for visualization of the needle.

**Interscalene**
With the patient positioned supine and head turned slightly to the contralateral side, the anechoic compressible internal jugular vein and pulsatile carotid artery are visualized medial to the anterior scalene muscle and deep to the triangular-shaped sternocleidomastoid muscle. The roots of the brachial plexus appear as distinct hyperechoic oval or round bodies arranged in a cephalo-caudal orientation in between the bulky anterior and middle scalene muscles [60] (Figs 3–6).

**Supraclavicular**
In the supraclavicular fossa, the divisions of the brachial plexus are visualized as a cluster of hypoechoic nodules immediately cephalad and lateral to the anechoic pulsatile subclavian artery and above the first rib [61] (Figs 7 and 8).

**Infraclavicular**
The cords lie relatively deep compared to the other portions of the brachial plexus, therefore a lower-frequency probe (e.g., 4–7 MHz) is recommended for better tissue penetration. The cords are visualized deep to the pectoralis major and minor muscles as distinct hyperechoic nodules positioned – as their names...
imply – lateral, posterior, and medial to the anechoic axillary artery [48,62] (Figs 9 and 10).

**Axillary**

The patient is positioned supine with the arm abducted to 90° and flexed at the elbow. The nerves are pictured as distinct hypoechoic nodules with internal hyperechoic punctuations typically situated lateral (median nerve), medial (ulnar nerve), and posterior (radial nerve) to the anechoic pulsatile axillary artery [44,45] (Figs 11 and 12). It is noteworthy that the location of these three nerves relative to the axillary artery can be highly variable [44].

**Lower extremity**

As with the brachial plexus, we prefer to image all structures in the short axis. The needle may be inserted using either the in-plane or out-of-plane technique.

**Femoral**

The femoral nerve in the infra-inguinal region is visualized as a hyperechoic triangle lying just lateral to the anechoic pulsatile and circular femoral artery. Another key structure to identify is the fascia iliaca which appears

---

**Figure 16** Short-axis view of the common peroneal and tibial nerves merging to form the sciatic nerve 7 cm proximal to the popliteal crease

A 5–12 MHz linear-array transducer probe (Sonosite Micromaxx system) was used. CPN, common peroneal nerve; TN, tibial nerve. Note the hypoechoic (dark) tissue surrounding the nerve complex. This is adipose tissue, which forms an attractive echo interface with the generally hyperechoic sciatic nerve.

---

**Figure 17** Patient and probe positioning for the popliteal approach to the sciatic nerve

Left: the patient is positioned prone and the needle is inserted via the in-plane technique. Right: patient position for the supine popliteal approach to the sciatic nerve. The leg is being rested on an adjustable table and is inserted from a lateral perspective. This approach will result in the needle being inserted completely parallel to the ultrasound beam/probe (see Fig. 18).

---

**Figure 18** Ultrasound image of the popliteal sciatic nerve with needle insertion as described for the right-hand panel of Fig. 17

SN, sciatic nerve. Arrows indicate the needle being inserted in-plane with the ultrasound beam.
as a hyperechoic line extending across the anterior aspect of the femoral vessels and nerve. The key to a successful block is to deposit local anesthetic posterior to the fascia iliaca (Figs 13 and 14).

**Popliteal**

With the patient in the prone or supine position, the tibial and common peroneal nerves are visualized as hyperechoic oval structures posterior to the circular, anechoic, and pulsatile popliteal artery at the level of the popliteal crease (Fig. 15). More proximally, the common peroneal nerve (a smaller hyperechoic circle) can be seen to join the tibial nerve to become the sciatic nerve (Fig. 16). It is at this site, where the block should be performed (Figs 17 and 18). The sciatic nerve can also be visualized and blocked in the subgluteal and gluteal regions. Due to the deep nature of the nerve at these locations (especially the gluteal region), a probe with a lower-frequency capability (4–7 MHz) is preferred.

**Saphenous**

The saphenous nerve, which is the terminal branch of the femoral nerve, can be blocked anywhere along the medial aspect of the lower leg (Fig. 19). It is not necessary to image the saphenous nerve (which can be difficult); it is only necessary to visualize the saphenous vein (a high-frequency system with a small-footprint probe will work best). Because these two structures are physically attached, the goal is to circumferentially deposit local anesthetic around the vein.

**Conclusion**

Ultrasound-guidance can facilitate PNB. There is growing evidence to suggest that ultrasound can moderate many of the clinical downsides to traditional techniques for nerve localization, including block failure, long performance times, and nerve injury. Our clinical experiences at the Dartmouth-Hitchcock Medical Center and Toronto Western Hospital are that ultrasound provides a vehicle for rapid assessment of normal and abnormal anatomy, guidance of the block needle under real-time visualization, and confirmation of correct local-anesthetic spread. We predict that ultrasound will soon become the international standard of care for the performance of PNB in modern regional anesthesia practice.

**References and recommended reading**

Papers of particular interest, published within the annual period of review, have been highlighted as:
• of special interest
•• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 665).


10. Patients who receive interscalene blockade report less pain in hospital, are ready for home discharge sooner, and are more satisfied with their care compared to those randomized to general anesthesia for ambulatory shoulder surgery.


