Ultrasound-Guided Regional Anesthesia for Peripheral Nerve Blocks: An Evidence-Based Outcome Review

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Ultrasound-guided regional anesthesia (UGRA) has increased in popularity over the past 5 years. This interest is reflected by the plethora of publications devoted to technique development as well as randomized and controlled trials. The journal of the American Society of Regional Anesthesia and Pain Medicine (ASRA), Regional Anesthesia and Pain Medicine, has recently devoted a dedicated section to UGRA. Further evidence of the interest in ultrasonography by our community is the comprehensive coverage of UGRA at national and international meetings. Despite the excitement around ultrasound (US), skeptics argue that there is a lack of evidence-based medicine to support the unequivocal adoption of UGRA as a “standard of care.” This article summarizes and critically assesses current data comparing traditional approaches to localizing nerves with those that use US guidance. In addition, the authors explore the potential benefits of UGRA that go beyond current information available from comparative studies.

CHARACTERIZING THE IDEAL REGIONAL ANESTHETIC

When comparing regional anesthesia with general anesthesia, general anesthesia is clearly the more popular choice for providing surgical anesthesia; this is especially
true in many smaller community hospitals. General anesthesia is reproducible, nearly painless, is easy to perform, enjoys a rapid onset, and has a near 100% success rate. In addition, general anesthesia is safer than it has ever been as a result of current state-of-the-art advances in monitoring, drug development, and airway devices. However, regional anesthesia has indisputable advantages in anesthesia practice. Regional anesthesia provides superior pain control, decreases opioid-related morbidity, and decreases hospital admissions. Such attributes may serve to improve meaningful long-term outcomes. Although these benefits are generally agreed upon, the mechanism by which we can generate a successful block, to realize such benefits, is subject to debate. Specifically, is US “better” than traditional landmark techniques? To answer this question, we must first define the outcome variables that characterize “better.” The following list summarizes important outcome variables:

1. Performed quickly and easily by most anesthesiologists
2. Facilitates faster onset of block
3. Provides for a reliable and predictable quality block with appropriate duration
4. Minimal patient discomfort
5. Reduction in dose of local anesthetic required
6. Improved safety profile
7. Easy to teach with objective end points
8. Allows for the expansion of the practice of regional anesthesia.

Although few may argue with the points in this list, whether UGRA can provide all of these advantages over traditional techniques is unclear. We should now look at what the existing literature can tell us, so as to critically assess these important end points of regional anesthesia. The majority of the randomized controlled trials (RCTs) performed to date focus on upper extremity and lower extremity nerve blocks. For the purposes of this review, the authors sought to review RCTs that specifically compared US alone with traditional landmark techniques. In addition, the focus is predominately on studies that have a clearly defined specific end point as the primary outcome and are adequately powered to detect that primary outcome.

PERFORMANCE TIME

Performance time, or the time necessary to perform the block, is an important quality measure when practicing regional anesthesia. Nineteen RCTs that recorded performance time were identified. In 6 of these RCTs, it was the primary outcome measured. The definition of performance time varied in different studies. For US-guided nerve blocks, 2 common definitions of performance time were: (1) the time interval between needle puncture to the end of local anesthetic injection or needle removal, therefore excluding the US scanning time; or (2) the time interval between US transducer placement on the patient to the end of local anesthetic injection or needle removal. For landmark nerve blocks a common definition for performance time was the time from needle placement to the end of local anesthetic injection or needle removal. For landmark nerve blocks a common definition for performance time was the time from needle placement to the end of local anesthetic injection or needle removal. In 11 of the 19 RCTs, US had a statistically significant advantage in minimizing the performance time over conventional landmark techniques, whereas 5 RCTs demonstrated no difference. Three RCTs involving ankle blocks in volunteers favored the landmark approach. It is important to note that the US scanning and image acquisition times were not included in the 5 RCTs that either favored the use of US or showed no difference in performance time. On the contrary, in these same 5 RCTs the landmark groups did not include the time consumed in
ONSET TIME

Most RCTs defined onset time as the time interval from the injection of local anesthetic and removal of the needle to a complete sensory block. Similar to performance time, onset time is an important quality measure when performing regional anesthesia. The authors identified 17 RCTs in which onset time was clearly defined and measured. Most favored the use of US in minimizing the onset time. In 3 RCTs there was no statistical difference in onset time between the US group and the traditional landmark groups. When looking at onset time as the primary outcome variable, 5 of 7 of RCTs favored the use of US in minimizing onset time, while in 2 RCTs there was no statistical difference. Caution must be exercised when interpreting these results. Nevertheless, US appears to decrease the overall onset time by 2 to 12 minutes when performing a nerve block, perhaps because US allows for closer needle approximation and local anesthetic distribution to the target nerves.

QUALITY

The definition of the quality of a nerve block varies between different RCTs. Most RCTs define the success or the quality of a nerve block as a complete sensory nerve block in all nerve territories examined by a predefined time period, that is, 20 to 30 minutes. However, when a nerve block is used as the surgical anesthetic, other definitions of quality include the need for analgesic supplementation or conversion to general anesthesia. Of importance, a nerve block that does not achieve a complete sensory block within a predefined time frame does not always lead to the need for supplemental analgesics or conversions to general anesthesia; this is because a nerve block may have achieved surgical conditions at a point beyond the 20 to 30 minutes, which is the usual time frame for the current studies. It can be argued that the need for conversion from a regional anesthetic to a general anesthetic is a more objective measure of the quality of a nerve block than relying on the more subjective sensory loss assessment.

The authors identified 25 RCTs in which the quality or efficacy of a nerve block was assessed. Assessments were based on one or more of the following: complete sensory block at a predefined time interval, the need for supplemental local or systemic analgesics, conversion to general anesthesia, or the quality of postoperative analgesia. Overall, 15 of the 25 RCTs showed some benefit to the use of US over
landmark techniques, 6,8,10,11,14–17,21–23,27,30–32 whereas 10 studies did not find any difference in the quality of nerve block regardless of technique. 4,5,7,9,12,13,18–20,26 In no RCTs was the quality of a block superior in the landmark technique as compared with a US-guided technique. Seventeen 4–12,18–21,23,26,27,32 of the 25 RCTs specifically measured the conversion from regional anesthesia to general anesthesia because of a failed surgical block. On critical evaluation of these data, 13 of the 17 RCTs 4–10,12,18–20,26,27 showed no statistical difference between US and a landmark technique, while 4 of the 17 RCTs 11,21,23,32 supported the use of US. One may wonder why the results comparing US and landmark techniques are equivocal when “success” is measured by the conversion of regional anesthesia to general anesthesia. It is important to be aware that most RCTs are not powered to detect this difference, and caution must be exercised when interpreting these results. 28 In fact, the quality assessment of a nerve block serving as the primary outcome occurred in 11 of the 25 RCTs. 6,8,10,11,15–17,22,27,31,32 However, in only 1 of these 11 RCTs was “failed surgical blocks” the quality measure of interest. 11 The remaining 10 RCTs assessed “complete sensory block” and not “failed surgical blocks.” The conversion of regional anesthesia to surgical anesthesia is a more objective measure of block quality and success than is assessing loss of sensation. When assessing the “quality” of a peripheral nerve block as defined by the conversion of regional anesthesia to general anesthesia, larger and adequately powered RCTs are needed to perhaps detect a statistical difference between US and landmark techniques.

PATIENT SAFETY

Compared with conventional landmark techniques, US offers anesthesia providers the distinct ability to visualize neural structures, surrounding tissues, the needle, and the correct spread of local anesthetic. Whether these advantages translate to improved patient safety is subject to debate. 33,34 Complications or side effects of interest included neurologic injury, local anesthetic systemic toxicity, pneumothorax, and hemidiaphragmatic paresis (HDP). US may allow the anesthesiologist to avoid vascular trauma, nerve trauma, and intravascular injection.

Of the RCTs directly comparing US alone with traditional landmark techniques, 3 RCTs 3,5,8,27 were identified in which US resulted in a statistically significant reduction in unintended paresthesias during block placement. The authors also identified 4 RCTs in which US resulted in a decrease in the incidence of vascular puncture compared with landmark techniques. 4,5,10,19,21 Liu and colleagues, 12 studying adverse events as the primary outcome during axillary blocks, reported a decrease in the overall incidence of paresthesia, vessel puncture, and subcutaneous hematoma by using US. In a prospective observational study, Borgeat and colleagues 35 demonstrated that postoperative neurologic symptoms are common after interscalene nerve blocks and shoulder surgery. Using traditional landmark techniques they reported an incidence of 14% at 10 days and 0.2% at 9 months. Liu and colleagues, 4 using neurologic symptoms as the primary outcome and powered to detect a fourfold decrease (16%–4%) with the use of US, did not show a statistically significant difference in outcome between US and landmark techniques. It must be noted that Liu and colleagues used large volumes of local anesthetic (45–55 mL for <50 kg and 55–65 mL for >50 kg) in both groups. Given that local anesthetics are to some degree neurotoxic and that US has proven to reduce the volume of local anesthetic required for successful nerve blockade, it is unknown if reducing the volume of local anesthetic will decrease the incidence of postoperative neurologic symptoms.
Peripheral nerve injury after regional anesthesia is multifactorial. Factors involved include anesthetic risk factors as well as surgical and patient risk factors. Anesthetic risk factors involved in perioperative nerve injury include mechanical trauma, neural ischemia, and local anesthetic neurotoxicity. By directly visualizing key structures (needle, nerve, and local anesthetic), US has potential to modify risk factors such as mechanical nerve injury. In addition, local anesthetic neurotoxicity may be decreased by the use of smaller volumes of local anesthetic. The possibility of neural ischemia may be additionally reduced if compressive neuropathies from hematoma formation can be avoided. US will not, however, have any direct impact on patient risk factors such as sex, increasing age, elevated body mass index, preexisting nerve damage, or surgical risk factors. US may have the ability to identify sonopathology such as neuritis, anatomic variation, and peripheral nerve tumors allowing modification or abortion of the block plan. Overall, limited literature directly comparing UGRA to traditional landmark techniques would suggest that UGRA neither increases nor decreases short-term or long-term peripheral nerve injury. This result is in agreement with a large prospective audit of more than 7000 peripheral nerve blocks in which unintended paresthesia during block placement and block-related late neurologic injury did not differ between UGRA and landmark techniques.

Local anesthetic systemic toxicity may occur from a direct intravascular injection or by systemic absorption. US has the potential to decrease the rate of local anesthetic toxicity by avoiding intravascular injections and reducing local anesthetic volumes. Multiple investigators have demonstrated that US allows for effective nerve blockade with smaller volumes of local anesthetic. US allows for precise needle to nerve proximity, and therefore avoids using “volume” as a vehicle for effective nerve blockade. For example, it is routine for the authors to use 5 to 10 mL of local anesthetic to provide an effective interscalene brachial plexus nerve block, not the 45 to 65 mL used in the study by Liu and colleagues. It is debatable whether an HDP should be considered a “complication” as opposed to a “side effect” of interscalene nerve blocks, because HDP has traditionally been reported to have a 100% incidence with interscalene nerve blocks. Nevertheless, preliminary data would suggest that US might reduce the incidence of HDP with smaller volumes of local anesthetic. Riazi and colleagues demonstrated an approximately 55% reduction in the incidence of diaphragmatic paralysis when low volumes (5 mL) of local anesthetic was injected versus standard volumes (20 mL) without difference in pain scores, sleep quality, or morphine consumption up to 24 hours. In addition, patients with phrenic nerve palsy in the low-volume group had significantly better preservation of lung function than the high-volume group. Although these results are promising, a 50% incidence of HDP with low-volume US-guided nerve blocks is still clinically significant and would possibly preclude this block in a patient with critically compromised pulmonary function. However, this study allows us to make better-informed risk benefit decisions in patients with mild and perhaps moderate compromise in pulmonary function. In an RCT, Renes and colleagues compared the incidence of diaphragmatic paresis between US-guided interscalene nerve blocks and traditional nerve stimulator landmark techniques. Diaphragmatic paresis occurred in 2 of 15 (14.3%) patients in the US group and 14 of 15 (93.3%) patients in the nerve stimulator (NS) group (P<.0001). Of importance, the 2 patients in the US group with diaphragmatic paresis had complete recovery of diaphragm movement and ventilatory function by 180 min. These investigators used 10 mL of 0.75% ropivacaine and injected posterior and lateral to the C7 nerve root. In a similar study Renes and colleagues also examined the incidence of diaphragmatic paresis during a supraclavicular nerve block, and demonstrated a 50%
incidence of HDP during an NS technique and 0% incidence during a US technique. Spirometric function was preserved in the US group while it was significantly reduced in the landmark group. To achieve these results the investigators used 20 mL of 0.75% ropivacaine while injecting in a careful manner caudal and posterolateral to the brachial plexus. Despite these promising results for both interscalene and supraclavicular blocks, they should be considered preliminary data because of the small number of patients. These two studies are unique in the US literature in that the investigators intimately describe the morphology of spread of local anesthetics that generated their results. To accurately study, verify, and translate research findings into routine practice, the regional anesthesia community needs to be able to consistently reproduce the desired spread of local anesthetics. In the era of nerve stimulation, the defined motor response was always sought and well appreciated; now, it is the “correct” peri-neural spread. This “correctness” must be explicitly defined. Most studies lack detailed explanations of “bad” versus “good” spreads.44

A pneumothorax is a serious complication of regional anesthesia, which may occur during the performance of a paravertebral, infraclavicular, or supraclavicular nerve block. Pneumothorax with supraclavicular nerve blocks has traditionally been a real concern with landmark-based techniques. Through direct visualization, US has the potential to eliminate this devastating complication. US has repopularized supraclavicular nerve blocks in recent years. In a series of 500 patients undergoing US supraclavicular nerve blocks, Perlas and colleagues45 did not report a single incidence of a pneumothorax. Although 500 patients is a relatively small number on which to base any firm conclusion on the safety of preventing a pneumothorax with UGRA, a recent query of the Dartmouth Hitchcock Medical Center regional anesthesia database resulted in 1433 US-guided supraclavicular nerve blocks performed with trainees without a single pneumothorax being encountered.

One must acknowledge that although US has the potential to avoid complications of mechanical nerve injury, intravascular injections, and pneumothorax, case reports of these events do occur even with the use of US.46–49 Such outcomes stem primarily from the training and experience of the anesthesiologist using US technology. It is the authors’ observational experience that novices inexperienced with US-guided nerve blocks misinterpret US images. In addition, the appropriate skill set of maintaining simultaneous visualization of the nerves, needle, and local anesthetic injection takes time and practice to develop. Sites and colleagues50 demonstrated that failure to visualize the needle during advancement occurred in up to 43% of novices (<10 US-guided blocks). As experience with UGRA grows and appropriate training occurs through residency programs as well as training pathways for anesthesiologists in practice, UGRA has the potential in experienced hands to decrease and possibly eliminate the incidence of these avoidable complications.

LIMITATIONS OF THE CURRENT RCTS

It appears from the data presented that US decreases the amount of local anesthetic, shortens the onset time, and quickens the performance time. It may also perhaps improve the efficacy of the block. However, some of the current RCTs do not fairly compare landmark with US techniques. For example, Kapral and colleagues23 showed that US improved the quality of an interscalene nerve block compared with a traditional landmark technique. In their study, US allowed for a successful surgical anesthetic in 98.8% of patients while landmark with nerve stimulation had a 91.3% success rate (P<.01). However, Kapral and colleagues used a hand and forearm motor response in the NS group and not a deltoid/bicep response, which would have been
the preferred motor response.\textsuperscript{51,52} Accepting a bicep/deltoid response may have altered their final results. To draw a meaningful conclusion, future studies should use the best NS response for the landmark/NS groups.\textsuperscript{51,53}

For most practitioners, nerve stimulation is a single injection technique. A nerve is localized by obtaining the appropriate motor response and the local anesthetic is deposited in one location. US, on the other hand, is a multi-injection technique, as the needle may be repositioned several times to obtain the appropriate spread of local anesthetic. Therefore, it has been suggested that to fairly compare US with nerve stimulation, a multi-injection NS group should be compared with a US group.\textsuperscript{50} For example, Perlas and colleagues\textsuperscript{6} demonstrated a higher success rate (defined by loss of sensation of the tibial and common peroneal nerve at 30 minutes) during popliteal sciatic nerve blocks when using a pure US-guided technique compared with a landmark technique for foot and ankle surgery. In the US technique, the needle was positioned as needed to guide the appropriate spread of local anesthetic. However, in the landmark technique a single injection was performed after obtaining any foot or toe response. This study has been criticized because the appropriate motor response (a tibial nerve response and specifically foot inversion) was not elicited. However, would a double stimulation technique by obtaining a tibial nerve and common peroneal nerve have altered their results? Danelli and colleagues\textsuperscript{9} performed a similar study, comparing US with a double stimulation landmark technique for foot and ankle surgery. Specifically, the landmark group elicited a common peroneal and tibial nerve motor response at 0.4 mA. However, Danelli and colleagues were not able to detect a statistical difference between groups with respect to a complete sensory and motor block at 30 minutes or a difference in the conversion to general anesthesia. Although these results conflict with those of Perlas and colleagues, the authors believe that a double stimulation technique is concerning on several fronts. First, most anesthesiologists using US will reposition the needle only if local anesthetic is not covering the target structure. In a double stimulation technique, the second injection may be completely unnecessary. Further, the significant false-negative rate of NS must be considered,\textsuperscript{54,55} especially in the setting of a previous bolus of local anesthetic. Even if US-guided nerve blocks are equivocal to a multistimulation landmark technique, US has a distinct advantage of allowing for real-time visualization of the needle and correct spread of local anesthetic while potentially avoiding mechanical nerve trauma.

RCTs comparing US with landmark techniques are usually performed at medical centers with well-organized and successful regional anesthesia programs. Experts in regional anesthesia are usually performing or at least supervising novices performing these nerve blocks. Therefore, the results seen in RCTs may not reflect what occurs in the larger community. The proficient conduct of UGRA requires a skill set that is unique from traditional landmark techniques, including the mastering of 2-dimensional image interpretation. This difference must be considered when interpreting the results of any clinical trials. Operator bias, with respect to both techniques, is a real and unavoidable limitation. Current and past studies reveal essentially no objective information regarding the training and proficiency of the operators. If the results of an adequately powered trial reveal “no difference” between US versus nerve stimulation, is it because the operators were really experts only in nerve stimulation? In fact, one could argue that the results should be interpreted as a “win” for US because equivalence was demonstrated despite the fact that the operators were not as equally skilled in both techniques. This situation is likely to be a common one, as many “expert” groups have been performing UGRA for 5 years or less, whereas the experience with nerve stimulation goes back to the early 1990s. It should be noted that
operator bias can be argued from both sides of the aisle, with many emerging research
groups only expert in US and with little NS experience.

EDUCATING THE ANESTHESIOLOGIST IN ULTRASOUND-GUIDED
REGIONAL ANESTHESIA

No RCTs have characterized the learning curves and early success rates for
US-guided regional anesthesia versus traditional landmark-based regional anes-
thesia. For a community-based anesthesiologist interested in offering regional
anesthesia to his or her patients, would attending a workshop in either US-guided
regional anesthesia or traditional landmark-based regional anesthesia lead to differing
success? It is the authors’ anecdotal experience with teaching residents and prac-
ticing anesthesiologists in regional anesthesia that US may decrease the learning
curve and provide early success. The idea of sonographically objectifying the steps
of a nerve block allows needle and injection corrections based on defined goals rather
than assumptions of unconfirmed anatomy. These benefits are especially attractive to
the supervisor of the novice. With respect to the popular supraclavicular block, if
a novice follows a traditional NS approach and advances the needle, and no twitch
occurs, what are the next steps? What does the supervisor recommend? The authors’
suspicion is that the recommendations would be quite variable. “Fanning” the needle
to contact the first rib as described by leading textbooks would unlikely be champ-
ioned by the novice or supervisor. However, using the in-plane US approach, the
novice can see that the needle is lateral to the brachial plexus (as an example) and
thus the operator objectively decides to redirect the needle closer to the subclavian
artery. Using this supraclavicular example, it makes sense that there are suggestions
in the literature supporting the notion that it is easier to guide a novice through
a successful US-guided nerve block than through a landmark-based technique with
nerve stimulations. Mariano and colleagues, assessing trainees placing popli-
teal sciatic, femoral, and infraclavicular catheters, suggested that trainees had relative
ease in placing peripheral nerve catheters using US compared with landmark and
NS-based techniques. When performing infraclavicular catheters, trainees success-
fully placed 14 of 20 nerve catheters using nerve stimulation. However using US, all
20 catheters were successfully placed by trainees (P<.01).

Sites and colleagues characterized the behavior of novice residents in training
during a dedicated 1-month rotation in US-guided regional anesthesia. The two
most common errors consisted of failure to visualize the needle before advancement
and unintentional probe movement. Other quality-compromising behaviors identified
in novices were: (1) failure to recognize the maldistribution of local anesthesia, (2)
failure to recognize an intramuscular location of the needle tip before injection, (3)
fatigue, (4) failure to correctly correlate the sidedness of the patient with the sidedness
of the US image, and (5) poor choice of needle-insertion site and angle with respect to
the probe preventing accurate needle visualization. However, both speed and accu-
racy improved throughout the rotation. All residents performed at least 66 nerve
blocks, with an overall success rate of 93.6% and 4 complications.

In 2009 the American Society of Regional Anesthesia in a conjoint effort with the
European Society of Regional Anesthesia established new guidelines and a curriculum
for US-guided regional anesthesia. The purpose of creating this document was to
define the scope of practice related to UGRA and to recommend practice pathways
useful in gaining clinical competency. The guidelines specifically define the core
competencies and skill sets associated with UGRA and suggest 10 common tasks
to be followed when performing an US-guided nerve block. In addition, the guidelines
suggest a residency-based training pathway as well as a training practice pathway for postgraduate anesthesiologists.

EXPANDING THE BENEFITS OF REGIONAL ANESTHESIA VIA ULTRASOUND TECHNOLOGY

In the past, outcomes from anesthesia included whether a patient survived surgery and was discharged from the hospital. Important modern-day outcomes positively influenced by the application of regional anesthesia include, but are not limited to, postoperative analgesia, nausea and vomiting, postoperative ileus formation, urinary retention, unplanned hospital admissions, and patient satisfaction. Long-term outcomes that may be positively influenced by regional anesthesia include the reduction in chronic pain syndromes and the prevention of cancer recurrence. Current RCTs consistently demonstrate that block onset and patient readiness for surgery is faster when US techniques are used as compared with traditional landmark techniques. In a busy practice setting with rapid turnover, surgical readiness from regional anesthesia is critical. Achieving surgical readiness quickly may affect whether these benefits of regional anesthesia are even offered to patients. The authors support the notion that any time saving is good, even if the reality is that it is less than 5 minutes.

There is currently a paucity of RCTs adequately powered to determine whether US improves the quality and success of peripheral nerve block as defined by the conversion to general anesthesia from regional anesthesia. Most studies assess this end point as a secondary outcome. Based on the current evidence, it is probably safe to conclude that US may not improve the success of a peripheral nerve block as defined by the conversion of regional anesthesia to general anesthesia. However, one must remember that in RCTs, experts are performing both US and landmark techniques, and success rates in RCTs may not translate to the success rate of an individual practitioner. For the sake of argument, let us assume that US and nerve stimulation are equivalent in terms of the generation of surgical anesthesia. Given that the “ultrasound” revolution has unequivocally expanded the use of regional anesthesia, one would have to accept that US is responsible for an improvement in meaningful outcomes such as improved postoperative analgesia, and decreased postoperative nausea/vomiting, ileus formation, urinary retention, unexpected hospital admissions, and opioid consumption, as well as overall improvement in patient satisfaction. Therefore, the question should not be “is ultrasound better?” but rather “can US improve meaningful perioperative outcomes by increasing the application of regional anesthesia?” It is the authors’ contention that regional anesthesia is now practiced by individuals who originally rejected regional techniques when they were based on anatomic assumptions without image guidance.

SUMMARY

US technology has been a significant advancement in the practice of regional anesthesia, with growing evidence to support its use. When compared with other forms of nerve localization, the data support its use in decreasing performance time and onset time, and therefore decreasing the time for surgical readiness from regional anesthesia. The quality of peripheral nerve blocks also appears to favor UGRA. There are insufficient data to declare that UGRA improves overall block success as defined by the conversion of regional anesthesia to general anesthesia. However, the authors believe that any surrogate to block success that improves the quality of a block as well as decreases the time to surgical readiness from regional anesthesia is clinically important, because these surrogates factor into the decision making of whether
Regional anesthesia is offered to patients in the first place. Therefore if US, through its proven surrogate measures of block success, is able to expand the application of regional anesthesia, then arguably UGRA will have proven clinical advantages over other methods of nerve localization. Although it is difficult to prove that UGRA can improve patient safety, by allowing for the use of smaller volumes of local anesthetic as well as the real-time interaction of the needle, the nerve, and the local anesthetic, US may decrease the risk of a pneumothorax or hemidiaphragmatic paresis, as well as local anesthetic systemic and neuronal toxicity. Future RCTs are needed with larger numbers of patients powered to detect a difference in block success as defined by the conversion of regional anesthesia to general anesthesia. These RCTs should objectify and consistently reproduce the correct perineural spread of local anesthetic to accurately study, verify, and translate research findings into routine practice. Finally, it must be emphasized that US is a powerful tool for nerve localization, and sufficient anatomic knowledge, training, and judgment are essential for the safe practice of UGRA.

REFERENCES


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