The Second American Society of Regional Anesthesia and Pain Medicine Evidence-Based Medicine Assessment of Ultrasound-Guided Regional Anesthesia
Executive Summary

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Objectives: In 2009 and again in 2012, the American Society of Regional Anesthesia and Pain Medicine assembled an expert panel to assess the evidence basis for ultrasound guidance as a nerve localization tool for regional anesthesia.

Methods: The 2012 panel reviewed evidence from the first advisory but focused primarily on new information that had emerged since 2009. A new section was added regarding the accuracy and reliability of ultrasound for determining needle-to-nerve proximity. Jadad scores are used to rank study quality. Grades of recommendations consistent with their level of evidence are provided.

Results: The panel offers recommendations based on synthesis and analysis of literature related to (1) the technical capabilities of ultrasound equipment and its operators, (2) comparison of ultrasound to other methods of nerve localization with regard to block characteristics, (3) comparison of block techniques where ultrasound is the sole nerve localization modality, and (4) major complications. Assessment of evidence strength and recommendations are made for upper- and lower-extremity, truncal, neuraxial, and pediatric blocks.

Conclusions: Scientific evidence from the past 5 years has clarified and strengthened our understanding of ultrasound-guided regional anesthesia as a nerve localization tool. High-level evidence supports ultrasound guidance contributing to superior characteristics with selected blocks, although absolute differences with the comparator technique are often relatively small (especially for upper-extremity blocks). The clinical meaningfulness of these differences is likely of variable importance to individual practitioners. The use of ultrasound significantly reduces the risk of local anesthetic systemic toxicity as well as the incidence and intensity of hemidiaphragmatic paresis, but has no significant effect on the incidence of postoperative neurologic symptoms.

What's New in This Update? This evidence-based assessment of ultrasound-guided regional anesthesia reviews findings from our 2010 publication and focuses on new meta-analyses, randomized controlled trials, and large case series published since 2009. New to this exercise is an in-depth analysis of the accuracy and reliability of ultrasound guidance for identifying needle-to-nerve relationships. This version no longer addresses ultrasound for interventional pain medicine procedures, because the growth of that field demands separate consideration. Since our 2010 publication, new information has either supported or strengthened our original conclusions. There is no evidence that ultrasound is inferior to alternative nerve localization methods.

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As paraphrased from the 2010 introduction to the American Society of Regional Anesthesia and Pain Medicine's (ASRA's) Evidence-Based Medicine Assessment of Ultrasound-Guided Regional Anesthesia and Pain Medicine executive summary[1]: We are approaching a quarter century since the first descriptions of using ultrasound as a tool for nerve localization prior to regional block placement. The first decade of ultrasound-guided regional anesthesia (UGRA) primarily established its feasibility and described approaches to common peripheral nerve blocks (PNBs). During the second decade, ultrasound technology improved, investigators began to experiment with deeper blocks and perineural catheter placement, and anesthesiologists began to appreciate UGRA's advantages and limitations. By the end of the second decade, a body of scientific knowledge had amassed that critically compared UGRA with other forms of nerve localization, providing the beginnings of an evidence base for analyzing ultrasound's (US's) potential to improve block effectiveness and enhance patient safety. Believing that this evidence base was ripe for critical analysis, the first ASRA evidence-based assessment of UGRA assembled and published its proceedings in 2010. Now, 5 years later, the second iteration of this exercise assesses critically the expanded body of literature that has built the foundation for one of the most revolutionary periods in the history of regional anesthesia. The goal of this second evidence-based assessment is identical to the first: "to enable practitioners to make an informed evaluation regarding the role of UGRA in their practice."

This executive summary represents an overview of the assessments and recommendations that are detailed and defended within the accompanying individual supporting articles.[2–9] Clinicians are encouraged to read these supporting articles for a more complete understanding of the evidence basis for UGRA.

METHODS

To paraphrase our 2010 executive summary,[1] in April 2008, the ASRA Board of Directors commissioned a panel of UGRA experts to review, assess critically, and present in evidence-based-medicine

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format the scientific underpinnings of US guidance (USG) as a tool for nerve localization. Because the literature of UGRA grew exponentially over the next few years, the ASRA Board in spring 2012 authorized a second iteration of the panel to come together for the purpose of updating previous findings and to present those findings in open forum at the Annual Regional Anesthesiology and Acute Pain Medicine Meeting in Boston, Massachusetts, on May 3, 2013. Panelists were charged with evaluating the evidence for their assigned topic and creating manuscripts that would be internally peer reviewed before external peer review in accordance with the standards of this journal. Panelists were chosen based on demonstrated expertise in UGRA research, clinical care, and/or education and guideline creation. Primary participants in this project are listed as authors of this article.

The second assessment panel reviewed their previously published findings[1] but focused attention primarily on new evidence published from 2009 forward, which was chosen to coincide with the last available published evidence prior to release of the 2010 article. Public presentation of this information was in 2013; subsequently, panelists updated the information contained within their supporting manuscripts and/or this executive summary with material available through spring 2015. The goals of this project did not change substantially from the original. First, we sought to compare UGRA with other nerve localization tools with regard to block- and performance-related outcomes (eg, block performance time, onset, success, and duration) and patient safety issues (2 global issues: postoperative neurologic symptoms [PONS] and local anesthetic systemic toxicity [LAST], and 2 block-specific issues: hemidiaphragmatic paresis [HDP] and pneumothorax). These parameters were evaluated separately for upper- and lower-extremity, truncal, and neuraxial blocks. Second, we assessed the role of USG in pediatric regional anesthesia. Third, a new topic was added that examined evidence for the accuracy and reliability of US equipment and its operators in assessing needle-to-nerve relationships. Because of significant growth in the evidence basis of USG for interventional pain medicine and the panelists' limited expertise, that topic was not addressed.

Identification of evidence followed the same procedure as in 2010. Specific methodologies for the various components of this project are detailed in the accompanying individual articles.[2–9] In brief, putative evidence was gathered using a variety of standard electronic search engines to identify relevant literature, concentrating on the period from 2009 through spring 2015. The specific search engines used, language limitations, and MeSH (medical subject headings) are described in the individual articles. Central to our collective search criteria was inclusion of only randomized controlled trials (RCTs), systematic reviews, meta-analyses, comparative studies, and/or case series of 10 subjects or more. Case reports and letters to the editor were used only to document rare complications. Cadaver or imaging studies and case series of fewer than 10 subjects were used to demonstrate feasibility, but not to determine comparative attributes of UGRA.[1] Studies that compared 2 or more USG techniques were not used to ascertain differences between US and another nerve localization modality.

Statements and recommendations were graded using the United States Department of Health and Human Services Agency for Health Care Policy and Research[10] construct for evaluating strength of evidence and grades of recommendation (Table 1). Study quality was ranked using the Jadad score, a validated measure of study design and quality of reporting (0 = weakest to 5 = strongest)[11] (Table 2). Assignment of strengths of evidence and grades of recommendation and determination of Jadad scores were performed independently by the individual supporting manuscript teams. These teams also resolved any related disagreements internally.

In our 2010 publication, we made no attempt to pool results for statistical analysis, because the literature was incomplete or too heterogeneous to justify meta-analysis. Since 2009, at least 5 meta-analyses of UGRA[6,12–15] and a Cochrane review[16] have been published.

FINDINGS AND RECOMMENDATIONS

As paraphrased from our 2010 discussion,[17] the literature of UGRA remains a heterogeneous mix of generally small studies that compare USG with another form of nerve localization, usually peripheral nerve stimulation (PNS). Direct comparison of outcomes between studies is difficult because of definition variability for outcomes such as block performance time or success. Since 2010, the number of studies comparing UGRA to another nerve localization method has waned. Instead, most contemporary studies have sought to compare the relative attributes of USG blocks by varying (1) the approaches to a nerve or plexus, (2) the volume of local anesthetic, (3) the number of injections, and/or (4) local anesthetic distribution around the target nerve. The latter 4 study methodologies were not used to infer any advantage or limitation of UGRA versus another form of nerve localization. What follows

TABLE 1. Statements of Evidence and Grades of Recommendations

Statements of Evidence	
Ia	Evidence obtained from meta-analysis of RCTs
Ib	Evidence obtained from at least 1 RCT
IIa	Evidence obtained from at least 1 well-designed controlled study without randomization
IIb	Evidence obtained from at least 1 other type of well-designed quasi-experimental study
III	Evidence obtained from well-designed nonexperimental descriptive studies, such as comparative studies, correlation studies, and case reports
IV	Evidence obtained from expert committee reports or opinions and/or clinical experiences of respected authorities
Grades of Recommendations	
A	Requires at least 1 prospective RCT as part of a body of literature of overall good quality and consistency addressing the specific recommendation (evidence levels Ia and Ib)
B	Requires the availability of well conducted clinical studies, but no prospective, randomized clinical trials on the topic of recommendation (evidence levels IIa, IIb, III)
C	Requires evidence obtained from expert committee reports or opinions and/or clinical experiences of respected authorities. Indicates an absence of directly applicable clinical studies of good quality (evidence level IV)

Source: United States Department of Health and Human Services Agency for Health Care Policy and Research.[10]

TABLE 2. Jadad Score

Study Characteristic	Score
• Was the study described as randomized (this includes words such as *randomly*, *random*, and *randomization*)?	0/1
• Was the method used to generate the sequence of randomization described and appropriate (table of random numbers, computer generated, etc)?	0/1
• Was the study described as double blind?	0/1
• Was the method of double blinding described and appropriate (identical placebo, active placebo, dummy, etc)?	0/1
• Was there a description of withdrawals and dropouts?	0/1
• Deduct 1 point if the method used to generate the sequence of randomization was described, and it was inappropriate (patients were allocated alternately, or according to date of birth, hospital number, etc).	0/−1
• Deduct 1 point if the study was described as double blind, but the method of blinding was inappropriate (eg, comparison of tablet vs injection with no double dummy).	0/−1

The first 5 items are indications of good study quality; a point is added for each criterion met. The last 2 items indicate poor study quality; a point is subtracted for each criterion met. The Jadad score therefore ranges from 0 to 5.[11]

is a block-specific summary of findings and recommendations. Further details can be found in the supporting articles and tables from which these topics are summarized.

Needle-to-Nerve Proximity

New to this iteration is a scoping review regarding needle-to-nerve proximity and UGRA[2] that analyzes the evidence base for the technical capabilities of US equipment and operator skills. Central to this analysis is the question: "Does UGRA accurately and reliably detect needle tip position relative to the target nerve?" The answer is critical both to assessing the effectiveness of UGRA and to its purported safety attributes. Abdallah et al[2] addressed this issue by examining the evidence for US machine accuracy and reliability in identifying needle and nerve and the operator's ability to interpret the resulting images accurately. Crucial to the purported benefits of USG is the presumption that real-time, accurate visualization of block needle and surrounding tissue facilitates precise deposition of local anesthetic near the nerve while avoiding needle-related complications. Yet research has shown that operators are not consistently accurate in acquiring and maintaining needle tip visibility, distinguishing artifacts, or optimizing image quality.[18–21] Moreover, maneuvers such as needle movement or hydrolocation are not validated surrogates of needle visibility. When operator limitations are combined with the US machine's technical limitations, which themselves can be underestimated or misunderstood by the operator, it is not surprising that unintended needle-to-nerve contact, vascular entry, or pleural trespass continues to be reported.

With regard to visualizing the needle tip accurately, current US machines emit an approximately 1-mm-thick beam that can easily identify a typical block needle's tip. A variety of technological advances such as echogenic needles, beam steering, image compounding, multidimensional scanning, needle guidance systems, and electromagnetic needle tracking systems have been developed to optimize ultrasonic presentation of the needle tip and shaft.[2] Many of these technologies have phantom- or cadaver-level evidence of efficacy, with evidence of actual clinical benefit limited to a few studies.[22–24] Indeed, the US machine's capability to present the needle tip accurately and reliably must be balanced against the operator's skill in optimizing and interpreting the image. A substantial body of evidence attests that training and experience are crucial to the attainment of these skills[18,25] and that a skill as basic as visualizing the needle tip during needle advancement may take up to 80 blocks to gain competency.[21] When needle visualization is difficult because of increasing depth or suboptimal angle of insonation, some operators use surrogate indicators of needle position, such as small needle tip movements or injecting small volumes of fluid (hydrolocation). Neither of these surrogates has been validated in humans or cadavers, as might be accomplished with radiologic confirmation or dissection, respectively.

In addition to needle tip visualization, both machine and operator contribute to the optimal identification of target tissues, particularly neural structures. Nerves can take on a variety of ultrasonic appearances depending on size, ratio of neural to nonneural connective tissue, and the echogenicity of surrounding tissues. While US machines continue to improve and can generate beautiful sonograms, operators may misunderstand the machine's limitations with regard to acoustic resolution. The frequency range of US transducers (2.5–20 MHz) generally translates to presentation of structures of 1000 μm or greater, which means that small terminal nerves are not visualized with US. Indeed, much of peripheral nerve anatomy of anesthesiologist interest cannot be accurately and reliably imaged by US, whether the relatively large epineurium (200–3000 μm), still smaller nerve fascicles (100–1000 μm), or, perhaps most importantly, the protective perineurium (5–25 μm) that envelopes the fascicles.[2] Clinically, this can translate to about one-third of fascicles not being visible on a US image[26] or the inability to identify separately brachial plexus epineurium from deep cervical fascia at the interscalene level.[27] Even larger nerves can be difficult to image if their trajectory results in suboptimal angles of insonation or if surrounding tissues acoustically match the nerve's echogenicity. Ultrasound machine manufacturers have developed software and transducer technologies to improve image clarity, yet confirmatory human evidence that these technical advancements meaningfully improve nerve visualization is sparse, much less linked to improved clinical outcomes.

Even in the face of an ideally optimized image, there is no good understanding of what constitutes safe versus dangerous injection around neural tissue. While most,[28] but not all,[29] experts do not advocate intentional USG intraneural injection of local anesthetic, intraneural injections are not always easy to detect by nerve swelling[30,31] or hypoechoic halo formation around the target nerve.[32,33] These vagaries in our understanding of sonoanatomy and microanatomy in the context of UGRA have led some experts to call for implementation of more conservative USG nerve localization techniques that strive to "stay away" from the nerve rather than to place the needle tip as close to the target as possible.[34,35] These arguments are supported by limited evidence of equivalent block quality when the needle is placed intentionally a small distance (eg, ≥1.6 mm) from the nerve.[36,37]

In summary, despite continued technological advances in US machines and adjunctive devices, there is relatively little human evidence to support clinical efficacy and better outcomes as they relate to improved needle and nerve visualization. Many commonly used clinical techniques to improve needle visualization, such as hydrolocation or needle movement, have not undergone rigorous clinical validation. Research points to the common mistakes and prolonged learning curves of most operators and supports the effectiveness of various training tools (most of which use surrogates such as phantoms or cadavers, rather than human subjects). The evidence basis for the role of equipment and operators in determining needle-to-nerve proximity is summarized in Table 3.

Upper-Extremity Blocks

Since our original publications,[38,39] 22 new RCTs have been published with regard to USG upper-extremity block. This brings to 47 the total number of upper-extremity studies, 29 of which compare UGRA to another nerve localization technique and 18 of which compare 2 or more techniques specific to USG. The median Jadad score of these articles is 3 but varies widely and is slightly skewed toward lower-quality studies. As before, a study was considered "positive" if any UGRA block characteristic was statistically superior to the comparator, "negative" if the comparator was superior to US, or "no difference" if the characteristics showed no statistical difference or were split evenly between US and the alternative localization technique. This qualitative assessment is important in that it does not quantify the degree of difference, but rather leaves the individual clinician to decide if the difference is meaningful for his/her practice (eg, block onset time differences).

Comparison of USG Upper-Extremity Block to Another Nerve Localization Technique

Tables 4 and 5 summarize upper-extremity block characteristics. Twenty-two of 29 studies found UGRA superior to the comparator (usually PNS) in at least 1 measured outcome, and 5 reported no difference. Overall, studies favor US for reduced needle passes (χ^2 analysis, $P = 0.018$) and reduced vascular puncture ($P = 0.001$). Faster block performance time was supported by 14 of 23 studies ($P = 0.015$). The 3 negative studies used combination US-PNS guidance, which has been reported to increase procedure time, but not to improve block characteristics.[3] Six of 7 studies found no difference in block duration.

Faster block onset time (ranging from 4 to 22 minutes) versus no difference was reported by an equal number of studies.[4] When

TABLE 3. Evidence-Based Recommendations to Enhance Detection of Needle-to-Nerve Proximity

Needle Tip Presentation
- Needle-probe alignment and needle tip identification improve with operator competency (level IIa).
- Educational tools such as phantoms and simulation facilitate skill acquisition, needle-probe alignment, and needle tip detection (level IIa).
- Transducer manipulation improves needle tip visualization (level IIb).
- Needle manipulation to alter the angle of insonation can improve needle tip visibility (level III).
- Needle manipulation to alter bevel orientation improves needle tip visibility (level IIb).
- Larger needle gauge increases US beam reflectiveness and may facilitate needle tip detection (level III).
- Echogenic needles improve needle tip visibility (level IIa).
- Needle priming and pumping assist in needle and needle tip detection (level IIb).
- Needle guides assist in needle tip visualization (level IIb).
- Beam steering enhances needle tip visibility (level IIb).
- Image compounding technology enhances the sonographic presentation of block needles (level IIa).
- Needle recognition software facilitates identification of needle tip position (level IIb).
- Vibrating devices and Doppler effect permit estimation of needle tip position (level III).
- Coupling US with magnetic resonance imaging improves the accuracy of needle tip detection (level IIb).
- Needle-integrated optical fiber hydrophone can facilitate needle tip identification (level III).
- Photoacoustic tracking may facilitate needle and catheter detection (level III).
- Three-dimensional US imaging facilitates needle tip visualization (level IIb).
- Four-dimensional US imaging can facilitate needle tip tracking (level III).
- High definition US imaging improves needle tip visibility (level IIb).
- Robotic-assisted guidance can improve needle tip recognition (level III).

Needle Tip Interpretation
- Operator competency enhances needle tip recognition (level IIa).
- Tissue movement is a surrogate measure of needle tip position (level III).
- Hydrolocation is useful to estimate needle tip position (level IIb).
- Bubble injection can facilitate needle tip recognition (level III).
- Needle tracking assists in interpreting needle trajectory and needle tip recognition (level III).

Nerve Presentation
- Tissue harmonic imaging can enhance nerve visualization (level III).
- Spatial compound imaging can improve nerve presentation (level III).

Nerve Interpretation
- Nerve swelling is indicative of intraneural injection (level IIb).
- Development of concentric hypoechoic halo in the targeted nerve is indicative of intraneural injection (level IIb).

TABLE 4. Outcome Comparisons of USG Versus Other Nerve Localization Methods for Upper Extremity Regional Anesthesia

Outcome	Grade of Recommendation	No. of Studies Evaluating Outcome (Conclusive/Unclear/Negative)	*P*
Block performance time	A: Supportive of US	14/6*/3†	0.015
No. of needle passes	A: Supportive of US	4/0/0	0.018
Vascular puncture	A: Supportive of US	9/1/0	0.001
Procedure pain	I	6/5/0	0.060
Sensory onset	A: Supportive of US	12/6/1	0.008
Motor onset	I	4/1/0	0.074
Block success	I	9/15/0	0.001‡
Block duration	I	2/3/0	0.247

All studies are RCTs.

*Four studies demonstrated faster block performance time with US but did not define whether prescan time was included.

†Two of the negative studies compared PNS versus PNS and US.

‡*P* value for 3-way comparison; χ^2 for 2-way comparison between supportive/inconclusive, $P = 0.221$.

I indicates insufficient or conflicting evidence not allowing a recommendation for or against intervention

the entire upper-extremity data set was subjected to analysis of categorical variables (positive, negative, no difference), US was statistically superior in terms of sensory block onset time (χ^2 analysis, $P = 0.008$).[3] Although this latter statement is not based on meta-analysis, it is consistent with Cochrane analysis conclusions.[16] Of those 14 studies that reported sensory block onset at a predetermined time point, US was superior to the comparator (ranging from 75% vs 47% on the low side to 100% vs 77% on the high side, respectively). Overall, block onset as determined by anesthesia presence at a preset time point favored US (χ^2 $P = 0.001$).

Differences in block quality (defined as avoidance of rescue or supplemental anesthesia or complete block of all studied nerves) are more difficult to evaluate. The majority of studies found no difference in avoidance of rescue or supplementation (11 of 15 and 12 of 15 RCTs, respectively). Complete block success for all nerves studied is arguably the most relevant (ie, true outcome) comparison between US and other localization tools. For this characteristic, 7 of 12 studies reported no difference, whereas 5 of 12 reported greater success with US versus the comparator technique (range of complete block success 87% vs 27% to 100% vs 76%, respectively).

Comparison of Different USG Upper-Extremity Block Techniques

Our previous report noted 6 studies that compared various USG upper-extremity block approaches (supraclavicular, infraclavicular, axillary) and concluded that no technique was superior to the other.[38] The intervening years have produced 12 additional studies focused on various injection techniques (single vs double or double vs quadruple) for specific approaches. These investigations generally conclude that undertaking additional injections does not improve block quality substantially, but does increase performance time. For example, Bernuci et al[40] and Tran et al[41] reported that a 2-injection perivascular axillary block technique resulted in block success equivalent to a 4-injection technique, but did so with fewer needle passes and faster performance time.

In summary, while our 2010 analyses[38,39] supported only faster sensory block onset as a benefit of USG upper-extremity block, interval publications have provided level Ib evidence and grade A recommendations that USG modestly improves surrogates for block quality and performance, including faster sensory block onset, fewer vascular punctures, faster performance time, and fewer needle passes. Current evidence is indeterminate for upper-extremity block characteristics such as block success or duration, motor block onset, or procedure pain (Tables 4 and 5). These conclusions should be tempered by knowledge that they are based on relatively small heterogeneous RCTs. Factors contributing to these limitations include various nerve localization comparators (mostly PNS, but also paresthesia, perivascular, or fascial pop), investigators inexperienced in the comparator technique (including supervised trainees), and/or the use of less-than-ideal techniques for the comparator block. Our conclusions are consistent with those of 2 recent meta-analyses[13,14] and a Cochrane review.[16]

Lower-Extremity Blocks

Based on the 11 RCTs available in 2010, we concluded that level Ib evidence supported a grade A recommendation for positive effects of USG on the following attributes of lower-extremity regional anesthetic blocks: faster onset and higher success for sensory blockade, decreased local anesthetic requirement, and decreased block performance time.[39,42] In the interim 5 years, 34 additional high-quality (Jadad score ≥3) RCTs have been published, based on 2439 new subjects plus 64 volunteers. The trend of these studies has been to focus less on comparisons with other nerve localization techniques (PNS) and more on identifying the ideal block techniques (24 of 34 RCTs) as facilitated by USG

TABLE 5. Effect of USG on Upper- and Lower-Extremity PNB Characteristics

Statement	Level of Evidence	Grade of Recommendation	Comments
US improves onset of block	1b	A	
US improves quality of block	1b	A	Stronger evidence for lower-extremity blocks
US does not improve duration of block	1b	A	Few RCTs studied this outcome

(eg, optimal perineural local anesthetic distribution or continuous catheter placement).[8]

Evidence for US affecting positively the characteristics of all lower-extremity blocks and techniques (eg, femoral, sciatic, single injection, catheter) is somewhat stronger than that for upper-extremity block. Lower-extremity studies were considered positive for US if any outcome was superior to the comparator technique. Three of 4 RCTs reported faster sensory block onset with US (1 reported no difference); time savings varied from 5 to 20 minutes. It is important to recognize that these lower-extremity regional techniques were intended for analgesia, not surgical anesthesia—a distinction that tends to minimize the importance of faster block onset. Six of 10 RCTs reporting block success rate found greater effectiveness with US localization versus the comparator (3 reported no difference). When complete blockade of all studied nerves was reported, USG resulted in greater success in 4 of 6 RCTs (2 found no difference). For complete sensory blockade, US success rates varied from 72% to 100%, whereas the comparator success rates varied from 21% to 61%. Ultrasound guidance has little effect on block duration.[4]

The results of studies published since 2009 have strengthened previous Ib level evidence to support grade A recommendations regarding nerve localization technique. Ten new studies compared USG to PNS, 4 of which combined US with PNS. These studies support US as the preferred nerve localization tool for increasing lower-extremity sensory block success and decreasing block performance time, block onset time, and local anesthetic volume. Those studies that combined US with PNS for nerve localization (compared with US alone) failed to show benefit to the practice, but did document increased block performance time. As for studies involving femoral perineural catheter techniques, 2 RCTs demonstrated that incorporating USG decreased block performance time as compared with a PNS-directed stimulating catheter, but no differences in analgesic efficacy were found.[43,44] Conversely, adding USG to nonstimulating catheter placement resulted in decreased block performance time plus improved analgesia qualities, as measured by opioid and/or local anesthetic requirements, and analgesia scores.[45] With regard to popliteal sciatic catheters, the use of USG resulted in similar pain scores while using less local anesthetic infusion[46] and improved sensory blockade.[47]

The majority of new lower-extremity studies have evaluated techniques to optimize USG. Fourteen new studies investigated the ideal spread of local anesthetic around the target nerve. A volunteer study of continuous femoral nerve block showed that placing the catheter anterior to the femoral nerve resulted in slightly improved sensory block without affecting motor strength[48]; it is unclear how these results might apply to a clinical setting such as total knee arthroplasty. As for saphenous nerve blockade, recent studies have reported similar block characteristics whether low-volume injections (5–8 mL) were performed using the adductor canal versus the subsartorial approaches.[49,50] With regard to the sciatic popliteal approach, recent investigations consistently demonstrate improved block characteristics (onset time and/or performance time) when the local anesthetic is deposited within the subparaneural compartment (the paraneurium is a sheath deep to the epimysium that surrounds muscle tissue and superficial to the nerve's epineurium).[8,51,52]

In summary, an abundance of new lower-extremity studies (mostly level Ib evidence) has served to reinforce our previous grade A recommendation that US improves block characteristics (onset time, performance time, and rate of complete sensory blockade) as compared with PNS techniques. Importantly, US was never found to be inferior to the comparator technique, regardless of the primary outcome studied. Studies published in the previous 5 years have further refined our understanding of the ideal techniques associated with local anesthetic injection patterns and lower-extremity perineural catheter placement. Table 6 presents recommendations for lower-extremity block.

Truncal Blocks

Truncal blocks include paravertebral, intercostal, transversus abdominis plane (TAP), rectus sheath, and ilioinguinal/iliohypogastric (II/IH) blocks. We have also included in this iteration analysis of evidence for newer truncal blocks—PECS, quadratus lumborum, and transversalis fascia—all of which have been described in limited case reports or technical descriptions without comparison to alternative techniques or with insufficient subject numbers to adequately ascertain complication rates or major outcomes.[7] Our 2010 review[53] concluded that limited RCT evidence supported USG as the preferred technique for rectus sheath and II/IH blocks, but evidence was insufficient to make recommendations regarding other blocks. The interval 5-year period has produced a number of anatomic (primarily cadaver based), pharmacokinetic, injectate spread, and feasibility studies, but relatively few studies that compared UGRA with other localization techniques or that assessed complications.

With regard to paravertebral blocks, although investigators continue to produce cadaver-based studies that further our understanding of the basics, relatively few studies in the past 5 years have evaluated outcomes and complications in a comparative manner. Several recent case series document improved early outcomes as compared with placebo,[54] and one study has shown that thoracic paravertebral blocks provide similar analgesia with improved hemodynamic stability after open thoracotomy as compared with thoracic epidural analgesia.[55] Despite the use of USG, there have been reports of pleural puncture with intrathoracic catheter placement.[56] Based on level IIb evidence, we make a grade B recommendation for the use of US with paravertebral blocks.

TABLE 6. Summary Statements Comparing USG to an Alternative Peripheral Nerve Localization Technique for Lower-Extremity Regional Anesthesia

Primary Outcome	Grade of Recommendation	Level of Evidence
Decreased block performance time (vs PNS)	A: Supportive of USG	Ib
Decreased block onset time	A: Supportive of USG	Ib
Decreased local anesthetic requirements	A: Supportive of USG	Ib
Addition of concurrent PNS to USG	A: Not supportive of benefit for addition of concurrent PNS to USG	Ib
Increased block success (rate of complete sensory block)	A: Supportive of USG	Ib
Improved postoperative analgesia for perineural catheters	A: Not supportive of benefit for USG	Ib

New cadaveric and volunteer studies have better defined relevant anatomy, pharmacology, and analgesic attributes of TAP blocks.[7] The most important of these studies demonstrated that a 2-injection technique was required to block the entire (unilateral) anterolateral abdominal wall in 8 volunteers.[57] Several meta-analyses in the last 5 years have evaluated the role of TAP blocks in various surgeries, including cesarean delivery.[58–60] These analyses in general found that TAP blocks reduced nausea and vomiting and morphine requirements as compared with placebo, but did not improve analgesia. For cesarean delivery, USG TAP reduced pain and nausea for 24 hours as compared with intrathecal morphine, but did not affect other outcomes.[58] These meta-analyses are somewhat difficult to interpret because they commingle landmark-based and US-based TAP blocks. When taken together, level Ia evidence from meta-analyses suggests a grade A recommendation that the benefits of TAP blocks are relatively limited (reduced nausea and vomiting without consistent improvement in analgesia) as compared with alternative forms of analgesia.

Our previous analysis noted that trainees averted peritoneal puncture during pediatric rectus sheath block as compared with a loss-of-resistance technique.[61] There is no evidence that USG rectus sheath block improves analgesia after umbilical hernia repair in adults as compared with surgeon infiltration of local anesthetic[62] (level Ib evidence). Similar evidence supports a grade A recommendation regarding the superiority of USG II/IH blocks in children as compared with a landmark-based technique.[63]

In summary, the evidence basis for UGRA related to truncal blocks remains limited, particularly in terms of clinically relevant comparison to standard alternatives such as thoracic epidural analgesia or surgeon infiltration. The majority of investigations have evaluated the efficacy of truncal block versus either placebo or a standard analgesic routine (eg, intrathecal morphine for cesarean delivery). Indeed, studies rarely evaluate US versus an alternative nerve localization technique, likely because most modern truncal blocks are US based. Overall, our conclusions from 2010 remain largely the same[53]—there is limited evidence to support US improving rectus sheath block safety and II/IH block outcomes; there is insufficient evidence to compare US to alternative nerve localization methods for other truncal blocks. More so than for other regional anesthesia applications, the evidence for the role of US in truncal blocks is mixed. Some outcomes are clearly improved, for example, the decreased risk of unintentional abdominal organ puncture, whereas other outcomes may be worse, as exemplified by possible increased risk of epidural spread with USG paravertebral block. Nonetheless, future comparative studies are unlikely, considering the high acceptance of USG truncal approaches by many practitioners. Table 7 summarizes recommendations for US-guided truncal blocks.

TABLE 7. Evidence-Based Recommendations for USG Truncal Block

Block	Grade of Recommendation	Level of Evidence
Thoracic paravertebral	B	IIb-III
PECS	A	Ib-III
Intercostal	C	III
TAP	A	Ia-IIb
Rectus sheath	A	I
Transversalis fascia	B	III
II/IH	A	Ib-IIb

Note that levels of evidence for paravertebral, intercostal, TAP, rectus sheath, and II/IH blocks are derived in part from comparison with alternative landmark-based techniques. The remaining blocks are typically performed using only USG.

Neuraxial Blocks

The literature of neuraxial US for spinal and lumbar epidural anesthesia has expanded significantly since 2010, including studies of patient populations at risk of difficult block placement, such as obesity, previous spine surgery, or spinal deformities. The literature that met criteria for inclusion in this analysis consists of 31 clinical trials, a meta-analysis,[15] and additional meta-analytical information from the supporting article itself,[6] all of which dealt with the concept of US-assisted (ie, preprocedural) lumbar neuraxial anesthesia. The quality of these studies is generally good, with only a few manifesting more than 1 risk factor for high bias. Because published evidence is limited or the techniques are considered experimental, we did not address adjunct thoracic neuraxis US or real-time USG adult neuraxial procedures. Three questions compromise the focus of this update and are addressed individually:

Does Neuraxial US Accurately Identify a Given Lumbar Interspace?

Eight studies addressed this topic, 5 of which failed to verify the US-determined interspace level against a reference imaging modality. The 3 studies that used radiologic verification compared the accuracy of US-determined landmarks with plain x-ray,[64] magnetic resonance imaging,[65] and computed tomography.[66] These studies showed that the accuracy of US ranged from 68% to 76% as compared with radiologic imaging and was never more than a single interspace removed from the reference interspace. These findings compare quite favorably to palpation of the vertebral spine, which was inaccurate in up to 70% of subjects and erred by more than 1 interspace over half of the time (level IIa evidence). Of note, novices may require up to 36 trials before they become 90% accurate with US-assisted determination of lumbar interspaces.[66]

Does Neuraxial US Accurately Predict Needle Insertion Depth to Target?

This topic was addressed by 13 generally high-quality studies conducted in a variety of clinical settings (obstetric, surgical, and diagnostic lumbar puncture). These studies consistently showed a high correlation between the US-measured midline depth to the epidural space and the needle-measured depth (pooled Pearson product-moment correlation coefficient, 0.91; 95% confidence interval [CI], 0.87–0.94). Actual needle insertion-to-target depths were mostly within 3 mm or less of the preliminary US measurement (level Ia evidence).

Does Neuraxial US Improve Efficacy or Safety of Neuraxial Techniques?

Fourteen RCTs and 5 prospective cohort studies (nearly 2000 subjects obtained from a variety of orthopedic, obstetric, and diagnostic indications) reported technical failure, number of needle passes, and/or safety outcomes (the latter was always an underpowered secondary outcome). The overall quality of these studies was reasonable, but many suffered from lack of blinding, which is an inherent limitation with these types of studies.

Meta-analysis from the supporting article[6] demonstrated that neuraxial US assistance reduced the risk of technical failure (combined risk ratio, 0.51; 95% CI, 0.32–0.80) and the number of needle passes required to successfully reach the needle target intrathecal or epidural space (−0.86; 95% CI, −1.12 to −0.60).

Another meta-analysis[15] has reported similar findings, including a 79% reduction in the risk of failed lumbar puncture or epidural catheterization, fewer needle redirections, and a 73% reduction in visible blood or cerebrospinal fluid red blood cell count. Although block-related trauma and excessive needle passes have been associated with neurologic complications, the small number of patients studied and the rarity of neurologic complications such as postmeningeal puncture headache or spinal hematoma (none of which occurred in these studies) make it impossible to offer recommendations specific to US-assisted neuraxial procedures and patient safety (level III evidence).

Since our 2010 reviews,[17,67] the literature of neuraxial US has expanded beyond the primarily obstetric populations that were the subject of early investigations, has included more studies of special patient populations at increased risk of technically difficult blocks, and has incorporated meta-analysis. Level Ia evidence supports grade A recommendations that neuraxial US has a role in improving the efficiency of lumbar neuraxial anesthesia (including technically difficult patients) and in accurately predicting depth-to-target. Level IIa evidence supports a grade B recommendation that neuraxial US aids in identification of interspace level more accurately than palpation, but not as good as radiologic imaging. Level III evidence based on small subject numbers supports a role for neuraxial US in reducing surrogate markers of potential neurologic injury, but evidence is inadequate to assess its effect on safety outcomes. Recommendations for neuraxial block are summarized in Table 8.

Pediatric Blocks

In the interim since our 2010 review,[68] 39 additional pediatric UGRA studies have been published, a greater than 150% increase. This growth in scientific inquiry mirrors the growth of US utilization in pediatric anesthesia practice.[69,70] Overall study quality has improved (median Jadad score, 3; range, 1–4), with more recent literature being composed of RCTs and prospective observational trials. This expanded evidence base tends to support our original conclusions that pediatric UGRA results in faster block onset, higher PNB success rate, and the ability to perform regional anesthesia using less local anesthetic volume. However, much like adult evidence, these differences, although statistically significant, are often relatively small in size and likely to be of variable importance to individual practitioners.

The evidence basis for USG and pediatric regional anesthesia is more robust for PNB than for neuraxial blockade, and that trend has held steadily over the interim. Previous evidence suggested that US improves the success rate for pediatric truncal blocks, but not upper-extremity PNBs.[68] Ultrasound offers modestly faster block performance time as compared with PNS, but not landmark techniques. For instance, USG pediatric axillary block performance was slightly faster compared with PNS (14.6 ± 3.0 vs 16.1 ± 2 minutes, respectively, $P = 0.035$),[71] but when USG was compared with a landmark-based penile block, performance time was longer by an average of 75 seconds[72] (level Ib evidence). Two new RCTs reported increased block success with US as compared with PNS for infraclavicular[73] and femoral sciatic blocks,[74] but no difference with axillary block[71] (level Ib evidence). When block success was assessed by opioid consumption, there was no difference between US and PNS. The use of US does result in less postoperative opioid use in children as compared with landmark techniques, but these studies compare block types (eg, USG rectus sheath block vs local infiltration for pediatric inguinal herniorraphy) rather than compare different nerve localization techniques within identical block types (level IIb evidence). There is no evidence that US offers superior pain relief in children as compared with alternative localization methods. One study supported increased lower-extremity block duration as compared with PNS,[74] whereas 3 other studies found no difference[9] (level Ib evidence).

With regard to pediatric neuraxial anesthesia, our previous report identified no studies that addressed neuraxial block characteristics. A new USG thoracic epidural study[75] reported shorter needling time after a prescanning procedure, but longer overall block time. A caudal anesthesia study[76] also reported shorter needling time, but did not report scan duration. The same studies noted that prescanning increased the success rate of the first needle pass (ie, resulted in fewer needle passes), but not overall block success (level Ib evidence). Consistent with our previous report, additional studies support the concept that US aids in visualizing catheters during neuraxial block in children and accurately predicts the distance from skin-to-epidural space, dura, or sacral hiatus[9] (level III and Ib evidence, respectively).

In summary, while the number of studies of USG regional anesthesia in children has grown exponentially, our recommendations remain largely unchanged from 2010 (Table 9). Ultrasound guidance can lead to modest improvement in some PNB characteristics, but these effects are likely of variable significance in individual practice settings and are inconsistently present for specific block types. For neuraxial blocks, US prescanning predicts skin-to-target distances accurately and reduces total needle passes, but these advantages have not translated into more successful blocks or increased safety. In very young children, neuraxial US allows real-time observation of needle and catheter placement and local anesthetic spread.

Patient Safety

In the interim since our 2010 publication,[17] 14 new RCTs and 5 additional large cases series have been published that address USG and patient safety as it relates to 4 major complications—PONS, LAST, HDP, and pneumothorax. Overall study quality is good (median Jadad score, 4). In addition, several meta-analyses that include safety issues have been published.[6,12,16] Safety issues related to neuraxial anesthesia were addressed previously in that section.

In this iteration of our evidence-based analysis, we chose to use "PONS" to emphasize the transient nature of most perioperative neurologic symptoms and distinguish them from extremely rare long-term nerve injuries (approximately 4 per 10,000 blocks at 6–12 months).[28,77] Eight large case series to date (each reporting at least 500 patients) have reported incidences of PONS from a combined total of at least 55,818 PNBs. These data support our previous conclusion that US does not reduce the incidence of PONS as compared with other nerve localization techniques

TABLE 8. Evidence-Based Recommendations for US-Assisted Neuraxial Block

Outcome	Grade of Recommendation	Level of Evidence
Increased accuracy of lumbar interspace identification	B	IIa
Accurate measurement of the depth of the epidural and intrathecal space	A	Ia
Improved efficacy of neuraxial anesthesia	A	Ia
Improved safety of neuraxial anesthesia	B	III

TABLE 9. Evidence-Based Recommendations for USG Pediatric Regional Anesthesia

Outcomes	Statement of Evidence	Grade of Recommendation
PNBs		
Block performance time		
• US-guided blocks are quicker to perform than blocks using the nerve stimulation technique*	Ib	B
• US-guided blocks may require more time to perform when compared with landmark-based* techniques	Ib	B
Block onset		
• No evidence found	N/A	N/A
Block success		
• Block success is higher with USG compared with the nerve stimulation technique	Ib	A
• Block success with USG is not higher than landmark-based techniques†	Ib	B
Block quality		
• Opioid consumption is less in USG blocks compared with general anesthesia alone	Ib	A
• Opioid consumption is less when comparing USG to the landmark technique*	Ib	B
• Analgesia consumption is not different when comparing USG blocks to nerve stimulation*	Ib	C
• US guidance prolongs block duration when compared with the landmark technique,	Ib	A
nerve stimulation technique, and local anesthetic wound infiltration	Ib	A
• US guidance provides excellent pain relief compared with the landmark technique	Ib	A
• US guidance provides excellent pain relief compared with local anesthetic wound infiltration	Ib	A
• US guidance may not be superior to nerve stimulation with respect to pain relief†	Ib	C
Local anesthetic spread	III	B
• Local anesthetic spread can be visualized with USG		
Local anesthetic dose		
• There is no correlation between local anesthetic dose and no. of dermatomes blocked for TAP blocks‡	III	C
Visualization of anatomical structures, needle, and catheter		
• US guidance allows for visibility of anatomical structures, needle, and catheter	Ib	A
Neuraxial blockade		
Block performance time		
• Neuraxial needling time is shorter when US is used	Ib	A
Block success		
• US imaging of neuraxial structure allows the operator to perform blocks more easily, but does not necessarily increase block success§	Ib	B
Local anesthetic spread		
• US imaging allows real-time visualization of local anesthetic spread in neuraxial blockade	Ib	A
• Caudal spread of local anesthetic has an inverse relationship with regard to physical characteristics (age, height, and weight)	III	B
Visualization of anatomical structures and catheter		
• US imaging can detect variations in anatomical structure and visualize the catheter	III	B
• US imaging can predict epidural depth	Ib	A
Block quality		
Epidural blocks are sufficient at providing analgesia	III	B
Pediatric regional anesthesia		
Safety and complications		
• Pediatric regional anesthesia has a low incidence of adverse events and complications‖	IV	B

*Grade of recommendation reduced because of conflicting or inconsistent evidence.

†Grade of recommendation reduced because of nonsignificant difference between techniques.

‡Grade of recommendation reduced because of potential confounding factors in data interpretation.

§Grade of recommendation reduced because of lack of evidence supporting increase in overall block success with USG.

‖Grade of recommendation raised because evidence is supported by large-scale, multicenter prospective studies with good data.

(most commonly PNS). Indeed, the incidence of long-term injury calculated from the 3 largest registries is 5 per 10,000 PNBs, nearly identical to the historic incidence figures associated with PNS-guided blocks.[5] Case reports have emerged that describe long-term and permanent peripheral nerve injury despite the use of USG[78–80] (level III evidence).

Prior to 2010, the evidence base regarding LAST was indeterminate. A meta-analysis clearly showed that US reduced the

incidence of unintended vascular puncture (a surrogate outcome for LAST) as compared with PNS, but registry data found no overall difference in the incidence of local anesthetic-induced seizure.[81,82] Subsequent registry data[83,84] from the previously cited groups plus an additional set of single-institution registry data[85] provide the best evidence to date that US reduces the incidence of LAST throughout its clinical continuum of symptoms, including serious manifestations such as seizure or cardiac arrest. Propensity analysis shows that US use reduces the risk of LAST by 65%.[83] Despite this positive finding, the risk of serious LAST is approximately 2.6 per 10,000 PNBs even with US, which leads to the recommendation that practitioners continue to maintain vigilance when using potentially toxic doses of local anesthetic[5] (level III evidence).

Several new RCTs have further refined our understanding of how US-enabled low-volume brachial plexus blockade affects HDP. Three studies[86–88] of interscalene block reaffirm that US-facilitated low-volume block reduces the incidence and intensity of HDP (as compared with PNS) and that these benefits are most effective when less concentrated local anesthetic is injected in smaller volumes at a more caudad cervical vertebral level. Nevertheless, these maneuvers do not reduce the incidence of HDP to zero, nor is the effect predictable from patient to patient. A recent study reported that the supraclavicular approach was associated with HDP in 34% of subjects as compared with a lower (3%) but still present risk with the infraclavicular approach.[89] Importantly, evidence suggests that HDP may occur in all subjects after a 24-hour infusion of ropivacaine 0.2% at 6 mL/h[87] (level Ib evidence). There are no studies that address the effect of low-volume upper-extremity UGRA in patients specifically at risk of pulmonary compromise.

The risk of pneumothorax associated with upper-extremity regional blockade may be less than that for modern landmark-based PNS or paresthesia techniques, but direct comparisons are absent. Nevertheless, the number of patients who underwent USG supraclavicular block in published studies without an incident of pneumothorax totals 2839 (calculated upper limit 95% CI, 1 per 1000 blocks).[5] This compares favorably with a point estimate 0.4 per 1000 blocks (95% CI, 0.01–2.3 per 1000) that was derived from 1 pneumothorax diagnosed after 2384 USG supraclavicular blocks reported from the International Registry of Regional Anesthesia.[90] Despite these somewhat reassuring numbers, pneumothorax has been reported after USG interscalene, supraclavicular, and infraclavicular approaches[5] (level III evidence).

In summary, new evidence since 2009 strengthens our original conclusions with regard to 2 aspects of patient safety: (1) UGRA does not reduce the incidence of PONS compared with other nerve localization techniques, and (2) UGRA reduces but does not eliminate the incidence and intensity of HDP and does so in an unpredictable manner. The predicted frequency of pneumothorax is now lower than what we originally had calculated for USG supraclavicular block. Finally, strong evidence from registry data supports significant reduction in the incidence of LAST throughout its clinical continuum. The level of evidence and recommendations for these statements are found in Table 10.

Concluding Comments

A quarter century has passed since visionary physicians first reported the possibilities of using US as a nerve localization tool.[91–93] Observation and experience suggest that US has become the predominant modality for regional anesthesia in North America, where an ever-increasing number of hospitals provide the technology, and a generation of anesthesiologists have been trained in its use exclusively. Ultrasound has revolutionized regional anesthesia utilization by empowering those anesthesiologists previously uncomfortable using it with a newfound confidence based on direct visualization of the target and at least the perception of increased success. When performed by investigators expert in both US and PNS,[94,95] UGRA does not appear to significantly increase the success rate for surgical anesthesia (ie, the true outcome), but the literature is silent with regard to the utilization and successfulness of US-inspired techniques among practicing anesthesiologists who previously shied away from regional anesthesia. Regardless, the panel opines that US is rapidly becoming the default nerve localization technique. Consequently, it seems unlikely that a third iteration of this evidence-based exercise will be relevant in the future.

TABLE 10. Strength of Evidence—The Effect of USG on Patient Safety

PONS (III)
- Proving statistical differences in nerve injury as a function of nerve localization technique is likely futile
- Underpowered results from RCTs, registries, and large case series find no difference in surrogate markers of nerve injury, such as paresthesia during or immediately after block placement or transient PONS (level III evidence)
- UGRA appears to be associated with PONS at an incidence similar to historical reports of nerve injury associated with PNS (level III evidence)

LAST (Ia and III)
- Compared with PNS, USG lowers the risk of unintended vascular puncture, a surrogate outcome for LAST (level Ia evidence)
- Registry data provide strong support to the statement that USG reduces the incidence of LAST across its clinical continuum (level III evidence)
- US guidance does not completely eliminate the risk of LAST, therefore practitioners should remain vigilant and use other preventive and/or diagnostic modalities as appropriate (grade B recommendation)

HDP (Ib and IV)
- RCTs confirm the ability of low-volume USG to reduce (but not eliminate) the incidence and severity of HDP using the interscalene approach. The incidence of HDP ranges from nearly 0% to 34% with the USG supraclavicular approach (level Ib evidence)
- No RCTs or case reports address the role of USG brachial plexus blockade in patients at risk of pulmonary compromise from underlying severe pulmonary disease. Because HDP can still occur unpredictably, caution is warranted in any patient unable to withstand a 25% diminution of pulmonary function (grade C recommendation)

Pneumothorax (III)
- No adequately powered studies directly address the risk of pneumothorax with US-guided regional anesthesia
- Registry data and case reports describe the occurrence of pneumothorax despite the use of UGRA (level III evidence)

The evidence base for US has expanded substantially over the past 5 years. With this expansion has come a shift of focus, from comparing US with alternative nerve localization tools to redefining basic block techniques specific to the options that US affords the practitioner. These options include how best to vary local anesthetic volume and distribution around the target nerve, how best to image the needle or catheter, and how best to refine techniques that have gained popularity in the US era, such as TAP block.

Recent literature has strengthened our previous conclusions with regard to block characteristics and localization tool comparisons. In general, the use of US indeed hastens the onset of sensory and (less so) motor blocks, often decreases performance time, and results in fewer needle passes. Although statistically valid, the clinical importance of these advantages varies with block type (eg, more pronounced with lower- than with upper-extremity blocks) and by practice setting (eg, the relative importance of 4-minute faster block onset). As one focuses directly on true outcomes such as readiness for surgery or block success as defined by no need for supplementation, the differences between USG and other localization tools become less pronounced. As for patient safety, recent literature solidifies our previous conclusion that US does not reduce the incidence of PONS, and that although US indeed lessens the incidence and severity of HDP, it does so unpredictably. Conversely, US has now been shown to reduce the incidence of LAST across its clinical continuum. The literature is incontrovertible in its assessment that US has not been found inferior to comparator techniques in any outcome studied to date.

As for the future, we humbly offer predictions and challenges. Further investigations that compare US with other forms of nerve localization will likely be limited and provide increasingly less relevant information. Conversely, the expansion of institution-specific and large international regional anesthesia registries provides hope that new insights will be gained into the role of UGRA in rare complications and evolving practice patterns. Ultrasound has been a major research tool in broadening our understanding of needle-to-nerve relationships and the pathophysiology of peripheral nerve injury; we expect this trend to continue. Similarly, there will be continued opportunity for investigation into the technical nuances of UGRA for years to come, similar to past investigations of the nuances of PNS or paresthesia-seeking techniques. We again challenge investigators to study the contributions of US in special patient populations for whom there is at least the possibility for enhanced patient safety, such as patients at increased risk of nerve injury (diabetes or preexisting neurologic disease), block-related bleeding (patients taking anticoagulants), or postoperative pulmonary complications (steroid or oxygen-dependent pulmonary disease).

In closing, the past quarter century has been an amazing time of discovery and change in the world of regional anesthesia. The skills of practitioners and investigators alike have become ever more sophisticated. While we believe it unlikely that a third evidence-based assessment of UGRA will be justified, we nevertheless foresee a bright future of discovery as US technology improves, practitioners become more skilled, and investigators find new ways to use this remarkable tool.

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