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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Ultrasound-Guided Regional Anesthesia and Patient Safety
Update of an Evidence-Based Analysis

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Abstract: In 2010, the American Society of Regional Anesthesia and Pain Medicine's evidence-based medicine assessment of ultrasound (US)-guided regional anesthesia (UGRA) analyzed the effect of this nerve localization technology on patient safety. That analysis focused on 4 important regional anesthesia complications: peripheral nerve injury, local anesthetic systemic toxicity (LAST), hemidiaphragmatic paresis (HDP), and pneumothorax. In the intervening 5 years, further research has allowed us to refine our original conclusions. This update reviews previous findings and critically evaluates new literature published since late 2009 that compares the patient safety attributes of UGRA with those of traditional nerve localization methods. As with the previous version of this exercise, analysis focused on randomized controlled trials that compared UGRA with an alternative neural localization method and case series of more than 500 patients. The Jadad score was used to grade individual study quality, and conclusions were graded as to strength of evidence. Of those randomized controlled trials identified by our search techniques, 28 compared the incidence of postoperative nerve symptoms, 27 assessed LAST parameters, 7 studied HDP, and 9 reported the incidence of pneumothorax. The current analysis strengthens our original conclusions that US guidance has no significant effect on the incidence of postoperative neurologic symptoms and that UGRA reduces the incidence and intensity of HDP but does so in an unpredictable manner. Conversely, emerging evidence supports the effectiveness of US guidance for reducing LAST across its clinical presentation continuum. The predicted frequency of pneumothorax has grown smaller in tandem with increased experience with US-guided supraclavicular block. This evidence-based review summarizes both the power and the limitations of UGRA as a tool for improving patient safety.

What's New: Since the original 2010 publication of this analysis, evidence has continued to support the concept that ultrasound (US) guidance does not meaningfully affect the incidence of peripheral nerve injury (PNI) associated with regional anesthesia. Similar confirmatory evidence attests to US guidance reducing the incidence and intensity of hemidiaphragmatic paresis (HDP) but not eliminating it. Literature published since late 2009 reports the effective role of US guidance in reducing the incidence of local anesthetic systemic toxicity and allows calculation of a lower predicted frequency of pneumothorax associated with US-guided supraclavicular blocks.

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As part of the 2010 American Society of Regional Anesthesia and Pain Medicine's Evidence-Based Assessment of Ultrasound-Guided Regional Anesthesia and Pain Medicine, a critical analysis was undertaken to evaluate the effect of ultrasound (US) guidance on patient safety. As stated in the introduction to that exercise[1]: "Ultrasound-guided regional anesthesia (UGRA) is the latest in a series of tools designed to optimize localization of neural targets prior to the deposition of local anesthetic or other drugs. Because ultrasound can provide direct visualization of the target nerve, surrounding tissues, and injectate spread—advantages not present with any other method of nerve localization—it is logical to assume that these traits may lead to improvements in patient safety in the form of decreased nerve injury, local anesthetic systemic toxicity (LAST), or other complications. Because serious regional anesthesia–related complications are infrequent, proving that UGRA is truly safer than peripheral nerve stimulation (PNS), paresthesia-seeking, fluoroscopy, or other localization methods is difficult." The current update builds on previous knowledge by analyzing literature published since 2009 to further clarify the capability of UGRA to enhance patient safety as it relates to 4 major regional anesthetic complications—postoperative neurologic symptoms (PONS), LAST, HDP, and pneumothorax. The term *peripheral nerve injury* has henceforth been replaced by PONS, which better reflects the rarity of long-term or permanent nerve injury as compared with the transient and relatively common neurologic symptoms that present during the short-term postoperative period.

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METHODS

The methodology of the current update mirrors that used in 2010[1]: "Randomized controlled trials (RCTs) were sought that compared UGRA with another form of neural localization, such as PNS or transarterial techniques (Table 1); subsequent comparative analysis of UGRA safety was based only on those RCTs. Case series (>500 patients) were used to provide supplemental information regarding the frequency of complications (Table 2). Some complications are so rare as to have been described only in case reports or correspondence. This form of reporting was used to document the existence of complications but was not used to compare UGRA with other neural localization techniques. The relative quality of individual RCTs was graded using the Jadad score (0–5 points)."[51] Strength of evidence (Table 3) was based on the US Department of Health and Human Services Agency for Health Care Policy and Research Levels of Evidence construct.[52]

The updated literature search for this analysis was conducted for the 6-year period that encompassed 2009 through early 2015. As in 2010,[53] the search was conducted "using standard search engines, including the National Library of Medicine's PubMed, the Cochrane Database for Systematic Reviews, Ovid, Science Direct, and Google Search. Search terms included "ultrasound-guided regional anesthesia," "ultrasound + nerve injury," "ultrasound + local anesthetic toxicity," "ultrasound + diaphragmatic paresis," "ultrasound + pneumothorax," and "ultrasound + complications." English-language articles and articles with sufficiently detailed abstracts translated into English were identified. The bibliographies of identified articles were perused for sources not procured through the search engines."

RESULTS

Since the 2010 publication, 14 additional RCTs and 5 additional large case series have reported at least 1 aspect of patient safety fitting our inclusion criteria. Readers should recognize that

TABLE 1. RCTs of US Guidance Versus Other Nerve Localization Techniques

Author, Year	Jadad Score	Block	No. US	No. USNS	No. PNS	Vascular Puncture, n (%)	Paresthesia, n (%)	Nerve Injury, n (%)
Antonakakis et al, 2010[2]	4	Deep peroneal	18		18*		US 3; LM 3; Resolved at 1 wk	
Aveline et al, 2010[3]	4	Femoral catheter		92	92			USNS 1 paresthesia; Resolved at 5 d
Bendtsen et al, 2011[4]	3	Popliteal sciatic	50		50	No hematoma	None	
Brull et al, 2009[5]	5	Infraclavicular	52		51	US 0 (0); PNS 4 (8); ($P = 0.11$)	US 3 (6); PNS 22 (45); ($P < 0.001$)	
Casati et al, 2007[6]	3	Axillary	30		29			None at 24 h
Casati et al, 2007[7]	4	Femoral	30		30		0 US; 0 PNS at 24 h	
Chan et al, 2007[8]	5	Axillary	64	62	62	None	US 13 (20); USNS 9 (15); PNS 13 (21); Transient (<5 d)	None
Danelli et al, 2009[9]	3	Popliteal sciatic	22		22	US 0 (0); PNS 5 (22)	US 0 (0); PNS 5 (22)	None at 24 h
Danelli et al, 2012[10]	2	Interscalene catheter	25		25	US 0 (0); PNS 3 (30); ($P = 0.04$)	No difference	
Dingemans et al, 2007[11]	2	Infraclavicular	36	36		US 2 (6); PNS 1 (3)	US 1 (3); Transient (<7 d)	
Domingo-Triado et al, 2007[12]	3	Midfemoral sciatic		30	31			PNS 1 neuropathic pain; Resolved by 10 d
Dufour et al, 2008[13]	4	Popliteal sciatic		26	25			US 0; PNS 0
Fredrickson et al, 2009[14]	3	Interscalene catheter	43		39			US 3; PNS 3; (ns); PONS; day 10
Fredrickson et al, 2009[15]	3	Femoral catheter	21		24	None		
Fredrickson et al, 2009[16]	3	Continuous interscalene	41		40			US 1 (2); PNS 4 (10); Resolved by 8 wk (ns)
Gurkan et al, 2008[17]	3	Lateral sagittal infraclavicular	40		40	US 0 (0); PNS 3 (8)		
Kapral et al, 2008[18]	2	Interscalene	80		80	None	None	None
Liu et al, 2005[19]	2	Axillary	60		30	US 0 (0); PNS 3 (10)	US 0 (0); PNS 3 (10)	
Liu et al, 2009[20]	3	Interscalene	111		108			Confirmed PONS; At 1 wk: PNS 12 (11); US 9 (8); (ns); At 4–6 wk: PNS 8 (7); US 7 (6); (ns)
Macaire et al, 2008[21]	2	Median and ulnar nerves	30		30	None	None	None
Manassero et al, 2012[22]	4	Obturator	25	25		None		
Marhofer et al, 1997[23]	1	3-in-1	20		20	US 0 (0); PNS 3 (15)		
Marhofer et al, 1998[24]	2	3-in-1	20		40	US 0 (0); PNS 4 (10)		
Marhofer et al, 2004[25]	3	Infraclavicular	20		20	None		None

Continued next page

TABLE 1. *(Continued)*

Author, Year	Jadad Score	Block	No. US	No. USNS	No. PNS	Vascular Puncture, n (%)	Paresthesia, n (%)	Nerve Injury, n (%)
Mariano et al, 2009[26]	2	Infraclavicular catheter	20		20	US 0 (0); PNS 6 (30); ($P < 0.01$)		
Mariano et al, 2009[27]	2	Femoral catheter	20		20	US 0 (0); PNS 4 (20); ($P < 0.04$)		
Mariano et al, 2009[28]	3	Interscalene catheter	20		20	US 1 (5); PNS 5 (25); ($P < 0.18$)		
Mariano et al, 2009[29]	3	Continuous popliteal sciatic	20		20	US 0 (0); PNS 2 (10); (ns)		
Mariano et al, 2010[30]	3	Popliteal sciatic catheter	40		40	US 0 (0); PNS 5 (13); ($P = 0.02$)		
Oberndorfer et al, 2007[31]	4	Femoral/sciatic	23		23	None	None	None
Perlas et al, 2008[32]	4	Popliteal sciatic	37		33	US 0 (0); PNS 0 (0)		US 0 (0); PNS 0 (0); at 7 d
Redborg et al, 2009[33]	5	Tibial nerve ankle	18		18			1 Dysesthesia with US (improving after 2 mo)
Sauter et al, 2008[34]	3	Lateral sagittal infraclavicular	40		40	US 2 (5); PNS 13 (33); ($P = 0.001$)		
Sites et al, 2006[35]	3	Axillary	28		28†			None at 1–2 wk
Soeding et al, 2005[36]	1	Axillary and interscalene	20		20*	No seizure	US 1 (5); Landmark 5; (25); ($P = 0.012$)	None
Taboada et al, 2009[37]	3	Coracoid infraclavicular	35		35	US 1 (3); PNS 1 (3)		US 0; PNS 0; after block
Tedore et al, 2009[38]	3	US infraclavicular and transarterial axillary	111		109†		US 29 (26); TA 44 (40); ($P = 0.035$)	Dysesthesias at 10 d; US 2 (2); TA 3 (3); (ns)
Williams et al, 2003[39]	2	Supraclavicular		40	40			US 2 (5); PNS 1 (3); Paresthesia resolved at 2 wk
Willschke et al, 2005[40]	3	Ilioinguinal/ iliohypogastric	30		30‡	None		None
Yu et al, 2007[41]	3	Axillary	40	40		US 0 (0); PNS 16 (40); ($P < 0.001$)		

*Landmark based.

†Transarterial axillary.

‡Fascial click.

LE indicates lower extremity; ns, not significant; TA, transarterial; UE, upper extremity; USNS, ultrasound + nerve stimulation.

RCTs that address LAST and PONS include relatively few patients. Higher-level evidence from meta-analysis[54] or registry data[42,43,47,48,50] has better elucidated the effect of US on these specific complications.

Six new RCTs reported the occurrence of transient paresthesia or PONS (2 months' or less follow-up) as a secondary outcome. This brings to 28 the number of studies (2298 subjects) that compared PONS associated with UGRA (either UGRA alone or in combination with PNS) with other techniques for nerve localization—PNS (23 studies), transarterial (2 studies), surface landmark (2 studies), or fascial click (1 study). The median quality (Jadad score) of these studies was 3; range, 2 to 5. Nine RCTs reported "none" for neurologic complications, whereas 19 RCTs reported actual incidence with or without statistical significance (Table 1). Eight large case series (4 new since 2009) reported incidences of PONS from a combined total of at least 55,818 peripheral nerve blocks (PNBs) (Table 2).

Ten additional RCTs reported unintended vascular puncture as a secondary outcome, bringing the total to 27 RCTs (1867 subjects). Eight of these studies reported no observed vascular punctures; 18 provided actual incidence figures with or without statistical significance. One study each reported "no seizure" or "no hematoma." The median Jadad score of these studies was 3; range, 1 to 5 (Table 1). Seven case series of at least 500 subjects

TABLE 2. Large Case Series of UGRA With or Without Other Localization Techniques

Author, Year	Block	US, n (%)	USNS, n (%)	PNS, n (%)	Vascular Puncture, n (%)	LAST, n (%)	Nerve Injury, n (%)
Barrington et al, 2009[42]	Australasian Collaboration; 8189 peripheral blocks (early complications); 7156 peripheral blocks (late complications)	1065 (13)	4095 (50)	2457 (30)	Overall: 7.2/1000 (95% CI, 5.1–10.0/1000); US 5.1/1000 PNS 13.9/1000; ($P = 0.001$)	Overall: 0.98/1000; (95% CI, 0.42–1.9/1000); US vs PNS; (ns)	30/7156 (0.42); 27/30 not block related; 3/30 block related (<6, >6, <12 mo duration)—0.4/1000; (95% CI, 0.08–1.1/1000); PNS 2 injuries; USNS 1 injury; (ns)
Barrington and Kluger, 2013[43]	AURORA; 25,336 peripheral blocks; (includes a portion of 2009 data)		20,401 (81)	4745 (19)	Overall: 4.1/1000; USNS 83/20,401; 4.1/1000; (95% CI, 3.2–5.0); PNS 21/4745 4.4/1,000; (95% CI, 2.7–6.8); (ns)	Overall: 0.87/1000; (95% CI, 0.54–1.3); USNS 12/20,401; 0.59/1000; (95% CI, 0.30–1.03); PNS 10/4745; 2.1/1000 (95% CI, 1.0–3.9); ($P = 0.004$)	
Fredrickson and Kilfoyle, 2009[44]	1010; single and continuous blocks; Upper and lower extremity		1010				New, all-cause neurologic symptoms: Day 10, 8.2%; 1 mo, 3.7%; 6 mo, 0.6%
Lecours et al, 2013[45]	627; Single-injection infraclavicular blocks	627				2 (0.3); possible	Paresthesia 43/627 (7); Block-related PONS; 4/627; 0.8% (95% CI, 0%–2%)
Liu et al, 2010[46]	1169; Prospective registry of supraclavicular (654); and interscalene (515) blocks		1169				PONS; 5/1169 at 1 wk; 4/1000 (95% CI, 1–10); All resolved within 3 mo; 0% (95% CI, 0–0.3)
Orebaugh et al, 2009[47]	Retrospective Quality Assurance database; 5436 peripheral blocks		2146 (39)	3290 (61)		UE immediate seizures: USNS 0 vs PNS 4; ($P = 0.044$) LE immediate seizures: USNS 0 vs PNS 1 (ns); 5 seizures/5436 blocks = 0.09%	USNS 0 vs PNS 3; (ns); All documented with electromyography and nerve conduction studies; 2 of 3 improving
Orebaugh et al, 2012[48]	Retrospective Quality Assurance database; 14,498 peripheral blocks (includes 2009 data)		9062	5436		USNS 0/1000; (95% CI, 0.003–0.41); PNS 6/1000; (95% CI, 0.5–2.4); ($P = 0.006$)	6–12 mo; USNS 1/1000; (95% CI, 0.03–0.6); PNS 4/1000; (95% CI, 0.3–1.9); ($P = 0.13$); Over 12 mo USNS 0/1000; (95% CI, 0.003–0.41); PNS 3/1000; (95% CI, 0.2–1.6); ($P = 0.10$)
Perlas, 2009[49]	Supraclavicular (510 blocks)	510			2 (0.4); (95% CI, 0.1%–1.4%)		2 (0.4); (95% CI, (0.1%–1.4%); Transient numbness (several weeks)
Sites et al, 2012[50]	12,668 peripheral blocks	12,668			Venous; 0.6/1000; (95% CI, 0.2–1.2); Arterial 1.2/1000; (95% CI, 0.7–2.0)	Seizure; 0.08/1000; (95% CI, 0.0–0.3)	PONS more than 5 d; 1.8/1000 (95% CI, 1.1–2.7); PONS more than 6 mo; 0.9/1000; (95% CI, 0.5–1.7)

AURORA indicates Australian and New Zealand Registry of Regional Anesthesia; USNS, ultrasound + nerve stimulation.

TABLE 3. Strength of Evidence—The Effect of US Guidance on Patient Safety

Postoperative Neurologic Symptoms (III)
- Proving statistical differences in nerve injury as a function of nerve localization technique is likely futile
- Underpowered results from randomized controlled trials, 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 postoperative neurologic symptoms (Level III evidence)
- Ultrasound-guided regional anesthesia seems to be associated with postoperative neurologic symptoms at an incidence similar to historical reports of nerve injury associated with PNS (Level III evidence)

Local Anesthetic Systemic Toxicity (Ia and III)
- Compared with PNS, US guidance lowers the risk of unintended vascular puncture, a surrogate outcome for local anesthetic systemic toxicity (Level Ia evidence)
- Registry data provide strong support to the statement that US guidance reduces the incidence of local anesthetic systemic toxicity across its clinical continuum (Level III evidence)
- Ultrasound guidance does not completely eliminate the risk of local anesthetic systemic toxicity; therefore, practitioners should remain vigilant and use other preventive and/or diagnostic modalities as appropriate (Grade B recommendation)

Hemidiaphragmatic Paresis (Ib and IV)
- Randomized controlled trials confirm the ability of low-volume US guidance 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 US-guided supraclavicular approach (Level Ib evidence)
- No randomized controlled trials or case reports address the role of US-guided brachial plexus blockade in patients at risk for 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)

(4 new since 2009) reported the frequency of vascular puncture and/or LAST in at least 53,639 PNBs (Table 2).

The effect of US guidance on the frequency and severity of HDP was reported in 7 RCTs (4 new since 2009), totaling 239 UGRA patients.[55–61] The median Jadad score for these studies was 3.5. Absence of pneumothorax was mentioned in 7 studies of supraclavicular block (3 new since 2009)[34,39,46,49,50,57,62] and 1 new study of infraclavicular block[45] that together amassed 3466 patients. A large registry reported 1 pneumothorax in 2384 supraclavicular blocks.[63]

Since our previous report, a meta-analysis of technical failure associated with lumbar puncture and epidural catheter placement (secondary outcomes) reported that US guidance reduces the risk of traumatic procedures (risk ratio, 0.27; 95% confidence interval [95% CI], 0.11–0.67; $P = 0.005$).[64] A similar meta-analysis in this series[65] addresses the effect of US on neuraxial procedure safety.

DISCUSSION

Levels of evidence for each of the 4 major complications discussed in this review are presented in Table 3.

Postoperative Neurologic Symptoms

Of all the anticipated benefits of US guidance, perhaps the most optimistic was that it would reduce or eliminate PNI. Such an expectation was understandable because heretofore no nerve localization technique allowed the operator to directly observe the target tissue, its surrounding structures, and injectate spread. That US may be safer because it facilitates a needle-to-nerve relationship that ensures needle proximity without actual entry into the nerve is consistent with the then prevailing theory that the pathophysiology of PNI, at least in part, is associated with direct needle trauma. Although UGRA has not resulted in a meaningful reduction of PNI, nonetheless, it has revolutionized our understanding of the contribution of needle-to-nerve relationship to the pathophysiology of PNI.

Surrogate markers of PNI are often referred to as PONS to distinguish them from the true outcome of long-term or permanent nerve injury. One day after PNB procedures, neurologic symptoms such as paresthesia or residual blockade may be present in up to 19% of patients[66] and may persist in approximately 3% of patients during the first few months.[44,67] Long-term (6–12 months) PONS have an incidence of 2 to 4 per 10,000 PNBs[68,69] and are a common metric by which PONS is compared between US and other forms of nerve localization, most commonly PNS. Proving a statistically significant reduction of long-term nerve injury is unlikely to occur because it would require a controlled study of more than 70,000 subjects per group to demonstrate a 50% reduction from 4 to 2 injuries per 10,000 blocks ($\alpha = 0.05$, $\beta = 0.8$). Moreover, the rate of permanent injury (1 year or longer) is even lower, for example, only 1 permanent injury in 65,092 blocks was reported in the literature between 1995 and 2005.[67]

The 2010 version of this article concluded that US guidance does not reduce the incidence of PONS.[53] The primary support for this conclusion came from 2 large studies that reported no difference in the incidence of long-term PONS when US guidance (with or without supplemental PNS) was used to localize nerves versus PNS alone. The Australasian Collaboration[42] reported no differences in more than 7000 PNBs. Of the 30 instances of PNI, only 3 were judged anesthetic related after neurologic workup that included electrophysiologic testing—an incidence of 0.4 per 1000 PNBs (95% CI, 0.08–1.1). Similarly, the Pittsburgh quality assurance database of more than 5000 PNBs[47] found no difference in PNI as a function of nerve localization method. By adding 2 smaller studies of 510[49] and 1010[44] blocks each, our 2010 analysis was based on a combined 15,145 PNBs.[53] The calculated incidence of long-term PONS reported in these studies is similar to that reported in previous single-injection[69] and continuous perineural catheter[70] studies that used PNS as the primary nerve localization tool.

In the interim since 2010, additional registry data and case reports (Table 2) corroborate our initial interpretation that UGRA does not significantly reduce the incidence of PONS. A follow-up

report from the Pittsburgh quality assurance database once again found no difference in nerve injuries that lasted longer than 1 year when US was incorporated into nerve localization as compared with landmark/PNS techniques.[48] Two large registries and a case series reported varied incidences of long-term PONS. Higher than expected incidence was reported by the Dartmouth registry of 12,668 US-guided blocks (persistent at 6 months; 0.9/1000; 95% CI, 0.5–1.7)[50] and a case series of 627 US-guided infraclavicular blocks (short-term follow-up not specified; 8/1000; 95% CI, 0–20).[45] Conversely, the Hospital for Special Surgery registry of 1169 US-guided interscalene and supraclavicular blocks reported an incidence that was lower than expected (resolved by 3 months; 0/1000; 95% CI, 0–0.3).[46] Case reports of long-term and permanent nerve injury in the setting of US guidance have since emerged.[71–73]

In summary, the occurrence of PONS has been recorded from large registries and case series, totaling nearly 56,000 patients (Level III evidence). The use of US guidance for nerve localization has not reduced the incidence of PONS as compared with landmark/PNS guidance. Case reports and registry data report PNI despite US guidance. Indeed, if one were to analyze long-term nerve injuries from only the US groups of the 3 largest registries,[42,48,50] the 5/10,000 incidence is consistent with historic reports of long-term perioperative nerve injury when only PNS was used.[69]

Local Anesthetic Systemic Toxicity

The 2010 review[53] concluded that there was no firm evidence that UGRA reduced the incidence of LAST compared with other nerve localization methods. Although a meta-analysis[54] concluded that US reduced the incidence of unintended vascular puncture as compared with other methods, there was conflicting evidence whether or not this surrogate outcome resulted in fewer episodes of LAST. For instance, a 2009 publication by Barrington et al[42] found no difference in actual LAST as a function of localization technique. A quality assurance study by Orebaugh et al[47] noted a reduction in seizures after US-guided upper extremity procedures but no statistically significant difference compared with PNS techniques when all blocks were included. Both of these groups have subsequently published work that provides strong evidence that US guidance can indeed reduce the incidence of LAST (Table 2).

In a follow-up study by Orebaugh et al,[48] 6 of 5436 PNS/landmark blocks were associated with seizure, whereas no seizure occurred in 9062 US/PNS block patients ($P = 0.006$). In a follow-up study by Barrington and Kluger,[43] US guidance was associated with a reduced incidence of LAST throughout its clinical continuum from minor symptoms (n = 13) to seizure (n = 8) and cardiac arrest (n = 1). There were 12 LAST events in 20,401 US-guided techniques (0.59/1000; 95% CI, 0.30–1.03) versus 10 events in 4745 non-US techniques (2.1/1000; 95% CI, 1.0–3.9) ($P = 0.004$). When propensity analysis was used, the risk of LAST was reduced by more than 65% by the use of US guidance. Taken together, these 2 studies provide the strongest evidence to date that US improves patient safety as related to LAST prevention (Level III evidence).

If one were to analyze only those major LAST events (seizure or cardiac arrest) that occurred in the US groups of the 3 largest registries,[43,48,50] the resulting 2.6/10,000 incidence is less than historic norms.[74] Yet, LAST continues to be reported in isolation, including 2 patients with seizure after US-guided transversus abdominis plane blocks.[75] Practitioners are cautioned not to abandon vigilance when using potentially toxic doses of local anesthetics.[76]

Hemidiaphragmatic Paresis

Transient HDP is a universal side effect of non–US-guided interscalene approaches to the brachial plexus that typically use 20 mL or more local anesthetic.[66] The advent of UGRA not only facilitated more accurate deposition of local anesthetic but imparted increased practitioner confidence to use lower volumes.[43] The 2010 version of this article cited 3 studies of low-volume local anesthetic that aimed to reduce or eliminate HDP by limiting local anesthetic spread to the phrenic nerve during the interscalene and supraclavicular approaches. Those studies showed that reducing local anesthetic volumes to 5 to 10 mL indeed lowered the incidence and lessened the intensity of HDP associated with the interscalene approach and nearly eliminated it using the supraclavicular approach. However, these desirable effects are not predictable for an individual patient, which could be problematic for those patients who could most benefit from eliminating HDP, that is, those with severe pulmonary disease who require oxygen or long-term steroid therapy.[53]

In the interim 5 years, several new investigations of UGRA and HDP have been reported. These investigations both validate our previous conclusion and provide additional insight into the ability of low-volume local anesthetics to provide effective surgical blockade. Three new studies[58,59,77] report differing incidences of HDP during US-guided interscalene block. Sinha et al[60] reported the same incidence of HDP when 10 mL versus 20 mL ropivacaine 0.5% was deposited at the cricoid cartilage level. Using lower volumes, Lee et al[58] reported that 5 mL or 10 mL ropivacaine 0.75% produced equal analgesia, but that 5 mL reduced chest x-ray–diagnosed HDP from 60% to 33% ($P = 0.035$). Renes et al[59] further clarified the role of volume by determining the minimum effective volume (MEV) of ropivacaine 0.75% deposited adjacent to the C7 root: The MEV-50% was 2.9 mL, and the calculated MEV-95% was 3.6 mL. Importantly, there was no US-diagnosed HDP up to 2 hours after surgery, but ventilatory function and ipsilateral hemidiaphragmatic movement were reduced in all subjects after 24 hours of ropivacaine 0.2% at 6 mL/h.[59] These newer studies confirm previous observations that the incidence of HDP is most reduced when smaller volumes of less concentrated local anesthetic are deposited at more caudad cervical vertebral levels. Although others have confirmed observations that the brachial plexus can be anesthetized at the interscalene approach with remarkably low volumes of local anesthetic, there is also evidence that anesthetic block failure may increase at ropivacaine 0.75% volumes of 5 mL and less.[78,79]

A new RCT reported that 34% of 32 subjects who underwent US-guided supraclavicular blocks experienced at least 75% reduction in diaphragmatic excursion compared with 1 (3%) of 32 subjects ($P = 0.001$) in the US-guided infraclavicular group (both with 30 mL of 0.5% ropivacaine).[61] These results are consistent with previous landmark-based studies that demonstrate progressively fewer instances of HDP with more distal approaches to the brachial plexus[66] but still the potential for hemidiaphragmatic involvement. A case report documented HDP associated with infraclavicular block, even when a lateral approach was used.[80]

In summary, recent evidence corroborates our previous conclusion that low-volume (5–10 mL) local anesthetic upper extremity blockade indeed results in less frequent and less intense HDP but does so in an unpredictable manner (Level Ib evidence). There are no studies of low-volume upper extremity blockade in patients with chronic pulmonary disease who are the most likely to benefit, or be harmed, by these techniques. Importantly, even if HDP is absent or less intense immediately after surgery, practitioners are cautioned that, just as with landmark-based approaches,[81] HDP will likely occur when a postoperative infusion is used.[59]

Pneumothorax

As reported in 2010, there are no studies that specifically compared the incidence of pneumothorax from US guidance with

alternative localization methods. Historically, a supraclavicular block was associated with up to 6% incidence of pneumothorax, but these incidence data are from the original supraclavicular techniques[66,82] wherein the block needle, if it missed its neural target, was on a direct trajectory to the lung. Subsequent landmark-based techniques[83,84] likely reduced pneumothorax occurrence significantly, but data do not exist to confirm this clinical impression.

In our 2010 report, 1 large case series reported no pneumothorax after 510 US-guided supraclavicular blocks. This series plus 3 small RCTs allowed us to amass 575 reported US-guided supraclavicular blocks without a pneumothorax (calculated 5:1000 upper limit 95% CI).[53] In the interim, the International Registry of Regional Anesthesia reported 1 pneumothorax in 2384 US-guided supraclavicular blocks (point estimate, 0.4:1000; 95% CI, 0.01–2.3:1000).[63] This point estimate is comparable to an estimated 1:1000 upper 95% CI that results from combining "zero incidence data" from our 2010 report with 2 subsequent registries[46,50] and a small case series,[62] giving a total of 2839 blocks. In addition to supraclavicular block data, no pneumothorax was identified during an observational study of 627 US-guided infraclavicular blocks.[45]

Although the predicted incidence has decreased during the past 5 years, pneumothorax has been reported despite US guidance using the interscalene,[85] supraclavicular,[63,86] and infraclavicular[87] approaches. Although it seems that the incidence of pneumothorax associated with UGRA is substantially less than with the classic supraclavicular approaches, it is unclear if the incidence is less than that experienced during the 1980s and 1990s using landmark-based techniques that were developed to direct needle trajectory away from the lung. In summary, the incidence of pneumothorax associated with UGRA is low but may or may not be lower than with landmark-based techniques (Level III evidence).

Indirect Effects of UGRA on Patient Safety

Not all benefits of US are necessarily linked to direct visualization of target structures. The 2010 review[53] suggested that US may reduce some complications because the technique facilitates a different, perhaps safer, needle trajectory that might result in safety benefits unrelated to US per se. For example, the superficial posterolateral-to-anteromedial needle trajectory characteristic of the US-guided interscalene approach theoretically reduces the opportunity for unintended neuraxial deposition of local anesthetic, a complication that has been reported using the classic interscalene approach wherein the needle can be mistakenly directed toward the neuraxis. Several publications since 2009 refute this assumption. Two cases of epidural spread of local anesthetic—one delayed presentation associated with catheter use[88] and one presentation shortly after block placement[89]—have been reported with US-guided interscalene block. Furthermore, imaging or dissection of cadavers has shown that ultrasonically guided subepineurial needle placement and injection using the interscalene approach can result in epidural spread of dye.[89,90]

Limitations and Future Directions

The literature of UGRA has grown substantially since 2009, but its effect on our understanding with regard to patient safety has been variable. Despite a 4-fold increase in the number of patients for whom PONS has been reported, we are no closer to a statistically significant determination of whether or not UGRA results in fewer nerve injuries as compared with other localization techniques. Indeed, as detailed in our previous report,[1] the extreme rarity of long-term and permanent nerve injury associated with regional anesthesia makes statistical proof unlikely.[91] Conversely, the higher incidence of LAST (relative to PONS) combined with the power of large registry data has identified a positive role for US lowering the incidence of LAST. Nevertheless, the UGRA literature remains sparse with regard to those patient groups that are most at risk for complications and that might derive the most benefit from direct visualization of neural and surrounding tissues. These groups include patients at a higher risk for perioperative nerve injury (eg, diabetics or those with preexisting neurologic disease), LAST (small children or adults with cardiac comorbidities[92]), hematoma (anticoagulated patients), or postoperative pulmonary compromise (severe pulmonary disease).

Ultrasound guidance allows real-time visualization of the needle-to-nerve relationship, yet, as noted in 2010 and further elucidated in the interim,[93] practitioners must be aware of the technical limitations of US. For instance, US facilitates the early detection of a 0.5-mL intraneural injection into cadaveric sciatic nerve or supraclavicular plexus, as manifested by cross-sectional expansion of the nerve and echogenic changes.[94] However, although practitioners are excellent at recognizing extraneural injection, even experts fail to detect 1 in 6 intraneural injections,[95] a cadaveric finding that is similar to reported unintended intraneural injection in the clinical realm.[96–99] Furthermore, cadaveric studies of low-volume detection may not adequately mimic those clinical scenarios wherein nerve damage has likely occurred by the time a higher-volume injection has been detected.[100] Animal studies correlate worse functional outcome and more severe histologic damage with intrafascicular injection as compared with extrafascicular injection,[101–103] yet the resolution of current US machines is inadequate to detect intrafascicular needle placement.[104] Moreover, keeping the needle tip in full view during blocking procedures can be difficult based on artifact[105] and operator skill.[106] These points become relevant when one considers recent cadaver studies that describe how difficulty distinguishing deep cervical fascia from epineurium resulted in unintended subepineurial injection in 5 of 10 trials.[107] In addition to potential nerve injury, unintended intraneural injection in the interscalene region has been associated with cadaveric and human evidence of unintended epidural spread of injectate.[89,90] Recent clinical studies suggest that block effectiveness is not compromised by local anesthetic deposition a small distance from the nerve,[108,109] which argues that placing the needle as close as possible to the neural target may not always be beneficial, although these observations are likely to be block specific.

Previous and current analysis[1,110] has not found US to be inferior to more traditional nerve localization tools with regard to any reported outcome. During the past decade, US technology has become increasingly available throughout North America, and a generation of anesthesiology residents is now unfamiliar with alternative nerve localization methods. For 1 group of experienced investigators, the reported incidence of PONS seems to have decreased between studies, which suggests an adverse outcome reduction coincident with evolving skill and experience.[20,111] Nevertheless, the absence of US machines at all practice locations, the ongoing presence of anesthesiologists extremely experienced and proficient with non-US nerve localization techniques, and (with the possible exception of LAST) the absence of definitive scientific proof of US's superiority make it impossible to assert that US guidance has become the standard of care for nerve localization.

CONCLUSIONS

Since 2009, 19 additional RCTs or large case series that address issues of US guidance and patient safety have been published. These studies confirm and strengthen previous conclusions that UGRA does not have a meaningful impact on the incidence of PONS, and indeed permanent nerve injury has been reported despite its use. Similarly, the use of US reduces the incidence and severity of HDP, but its inability to do so consistently becomes problematic when considering interscalene brachial plexus blockade

in patients with severe pulmonary disease. The increased number of reported US-guided supraclavicular blocks has allowed calculation of a lower predicted incidence of pneumothorax overall, but the complication continues to be reported in individual patients. The greatest progress during the previous 5 years concerns LAST, where strong registry data show that US guidance can reduce the risk of LAST across its clinical presentation continuum by 65%.

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Evidence Basis for Ultrasound-Guided Block Characteristics Onset, Quality, and Duration

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Abstract: This systematic review summarizes existing evidence for superior onset, quality, and duration of block for ultrasound guidance versus other techniques for nerve localization. MEDLINE was systematically searched from 1966 to June 2013 for randomized controlled trials (RCTs) comparing ultrasound guidance to another technique for peripheral nerve blocks. Twenty-three RCTs were identified for upper-extremity peripheral nerve blocks and 17 for lower extremity. Jadad scores for quality of RCT ranged from 1 to 5 with a median of 3. For upper-extremity blocks, 11 (48%) of 23 RCTs reported faster onset of block, 9 (39%) of 23 reported better quality of block, and 1 (14%) of 7 reported longer duration of block with ultrasound. One RCT reported that ultrasound was inferior for onset of combined median and ulnar block. For lower-extremity blocks, 8 (80%) of 10 RCTs reported faster onset, 9 (56%) of 16 reported better quality, and 2 (33%) of 6 RCTs reported longer duration of blocks. One RCT reported that ultrasound was inferior for quality and duration for ankle block. There is level 1b evidence to make a grade A recommendation that ultrasound guidance provides a modest improvement in block onset and quality of peripheral nerve blocks, especially for lower extremity. Ultrasound is rarely inferior to other techniques.

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WHAT'S NEW?

Since the previous review in 2010, the number of identified randomized controlled trials (RCTs) for upper-extremity blocks has increased from 16 to 23 and for lower-extremity blocks from 8 to 17. Measurement outcomes are heterogeneous, but there is still level 1b evidence to make a grade A recommendation that ultrasound guidance provides a modest improvement in block onset and quality of peripheral nerve blocks, especially for lower extremity.

The National Library of Medicine's MEDLINE database was searched for the time period 1966 to April 2014. Search strategies included the terms "ultrasound guided" and "nerve block," limited by the terms "English," "human," and "randomized controlled trial." Only RCTs comparing ultrasound guidance to an alternative technique for nerve localization during peripheral nerve blocks were included. Information from individual RCTs on study characteristics and results regarding block onset, quality of nerve block, and duration were abstracted (Fig. 1). Definitions for these outcomes were per the original RCTs and were often quite different between RCTs. For the purposes of this review, onset was defined as either time until onset of sensory block or percentage of success rate of block at preset time measurement periods depending on individual RCT. Quality was defined as avoidance of rescue anesthesia, additional analgesic supplement, or complete block of all studied nerves depending on individual RCT. Duration was defined as either time until first request for analgesic or time until resolution of block depending on individual RCT. A Jadad score was used to grade each RCT for study quality. The Jadad scale is a 3-point score commonly used to rate the quality of a clinical trial. Two additional points may be added or deducted to the score, allowing a maximal score of 5.

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RESULTS

Twenty-three RCTs for upper-extremity blocks (Table 1)[1–23] and 17 RCTs for lower-extremity blocks (Table 2)[24–40] were identified that compared ultrasound guidance to an alternative technique. One additional RCT was identified that compared ultrasound to nerve stimulator for femoral nerve block.[41] However, this study's primary end point was to determine the minimal effective volume for nerve block with a planned failure rate of 50% in each group (ED_{50}). We excluded this study because of lack of clinical relevance. Since the previous review in *Regional Anesthesia and Pain Medicine*, 7 new RCTs were identified for upper-extremity blocks,[17–23] and 9 new RCTs were identified for lower-extremity blocks.[32–40] Jadad scores ranged from 1 to 5 with a median of 3. Multiple outcomes were often measured in the same RCT for onset, quality, or duration of block. Thus, an individual RCT was considered positive for ultrasound guidance onset, quality, or duration of block if any 1 suboutcome was statistically improved. Not all RCTs measured onset, quality, and duration of blocks; thus, denominators do not always equal 23 for upper-extremity RCTs and 17 for lower-extremity RCTs.

Onset of Block

For the upper-extremity RCTs, there was some evidence for hastened onset of block with ultrasound, as 11 of 23 RCTs reported a positive finding, 6 of 23 found no difference, and only 1 RCT reported slower onset with ultrasound.

- Time until onset of block: 9 of 23 RCTs reported this outcome. Four of 9 reported faster onset by 4 to 22 minutes, 4 of 9 reported no difference, and 1 of 9 reported slower onset by 2 minutes.
- Percent successful block at preset timepoints: 14 of 23 RCTs reported this outcome. Nine of 14 reported greater success rates of 75% to 100% with ultrasound versus 47% to 77% with control technique, and 5 of 14 reported no difference.

For the lower-extremity RCTs, there was good evidence for hastened onset of block with ultrasound, as 8 of 10 RCTs reported a positive finding, 2 of 10 found no difference, and no RCT reported slower onset with ultrasound.

- Time until onset of block: 7 of 17 RCTs reported this outcome. Three of 7 reported faster onset by 5 to 14 minutes, and 2 of 7 reported no difference.
- Percent successful block at preset timepoints: 6 of 17 RCTs reported this outcome. All 6 RCTs reported greater success rates of 17% to 89% with ultrasound versus 0% to 61% with control technique.

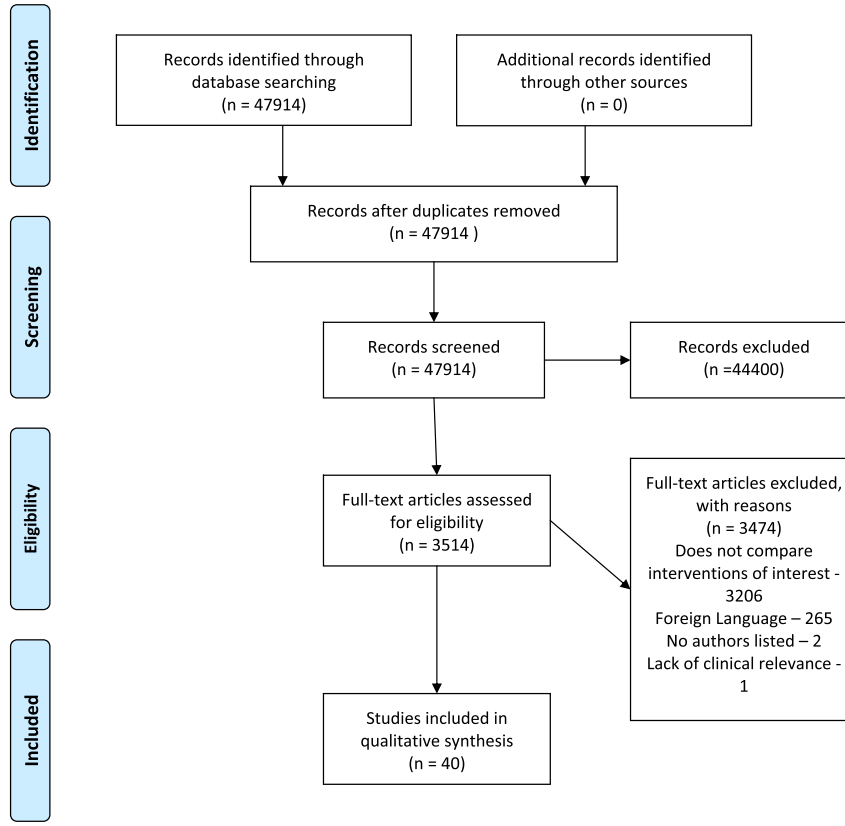

FIGURE 1. PRISMA 2009 flow diagram.

Quality of Block

For the upper-extremity RCTs, there was some evidence for improved quality of block with ultrasound, as 9 of 23 RCTs reported a positive finding, and 13 of 23 found no difference with ultrasound. The 9 RCTs that reported better quality with ultrasound compared this technique to conventional block, nerve stimulator, and transarterial injection.

- Need for rescue anesthetic: 15 of 23 RCTs reported this outcome. Four of 15 RCTs reported greater success rates of 83% to 100% with ultrasound versus 55% to 91% with control technique.
- Need for supplemental analgesia: 15 of 23 RCTs reported this outcome. Three of 15 reported greater success rates of 92% to 96% not requiring supplemental analgesia with ultrasound versus 64% to 82% with control technique, and 12 of 15 reported no difference.
- Complete block of all studied nerves: 12 of 23 RCTs reported this outcome. Five of 12 reported greater success rates of 87% to 100% with ultrasound versus 27% to 76% with control technique.

For the lower-extremity RCTs, there was good evidence for improved quality of block with ultrasound, as 9 of 17 RCTs reported a positive finding, 7 of 17 found no difference, and only 1 RCT reported lower quality with ultrasound for ankle block with use of less volume of local anesthetic for the ultrasound group.

- Need for rescue anesthetic: 5 of 17 RCTs reported this outcome. All reported no difference.
- Need for supplemental analgesia: 8 of 17 RCTs reported this outcome. Four of 8 reported greater success rates with of 50% to 85% with ultrasound versus 30% to 80% with control technique.
- Complete block of all studied nerves: 12 of 17 RCTs reported this outcome. Seven of 12 reported greater success rates of 94% to 100% with ultrasound versus 71% to 79% with control technique.

Duration of Block

Few RCTs evaluated duration of block. For the upper-extremity RCTs, there was minimal evidence for prolonged duration of block with ultrasound, as 1 of 7 RCTs reported a positive finding, whereas 6 of 7 found no difference with ultrasound.

- Time until first request for analgesia: 3 RCTs reported this outcome and reported no difference.
- Time until resolution of block: 4 RCTs reported this outcome. One reported 220-minute greater duration with ultrasound, whereas the other RCTs reported no difference.

For the lower-extremity RCTs, there was little evidence for prolonged duration of block with ultrasound, as 2 of 6 RCTs reported a positive finding, 3 of 6 RCTs found no difference, and 1 of 6 RCTs reported shorter duration of block with ultrasound for ankle block per above.

- Time until first request for analgesia: 4 RCTs reported this outcome. Two of 4 reported greater duration of 240 to 510 minutes with ultrasound, 1 of 4 reported shorter duration, and 1 reported no difference.
- Time until resolution of block: 3 RCTs reported this outcome. One reported 12-minute greater duration with ultrasound, whereas the 2 of 3 RCTs reported no difference.

TABLE 1. Summary of RCTs Comparing Ultrasound Guidance Versus Alternative Technique for Upper-Extremity Nerve Block

Study		Williams et al,[1] 2003	Liu et al,[2] 2005	Soeding et al,[3] 2005	Sites et al,[4] 2006
Jadad score		2	2	1	3
Groups (n: technique)		Supraclavicular block	Axillary block	Interscalene and axillary block upper-limb surgery	Axillary block
		Distal arm, forearm, or hand surgery	Forearm and hand surgery	20: ultrasound guidance (US) (13: interscalene, 7: axillary)	Hand surgery
		40: US + NS (US) 40: NS	30: US single injection (US) 30: US double injection (UD) 30: NS double injection (ND)	20: Landmark-based (11: interscalene, 9: axillary)	28: Transarterial (TA) 28: 3 injection (US)
		1:1 Bupivacaine 0.5% + lidocaine 2% with 1:200,000 epinephrine	0.5 mL/kg 1.5% Lidocaine with 5 μg/kg epinephrine	3 mg/kg Ropivacaine	10 mL 1.5% lidocaine + 5 μg/mL Epinephrine
Primary outcome		N/A	Powered to detect a 20% difference in the rate of adverse outcomes	Powered to detect a 20% improvement in the completeness of upper-limb anesthesia	Powered to detect a 20% difference in the rate of failed blocks
Onset time	Time of onset	N/A	N/A	N/A	N/A
	Success at set timepoints	Similar rate of partial or complete sensory block in all nerve territories after 30 min. Group US vs group NS: 95% vs 85%	Similar efficacy in all 3 groups in blocking all 7 sensory and motor nerves after 40 min. Groups US and ND vs group UD: 70% vs 73%	More complete sensory and motor block at 10 and 20 min postblock with US ($P = 0.011$ for sensory block, $P = 0.003$ for motor; no other numbers reported—graphs show that sensory and motor scores were better on average for US vs NS)*	Similar rate of complete sensory block between US vs TA at all intervals (5–30 min) Similar rate of complete motor block between US vs TA at all intervals except at 15 and 25 min where there is a significant difference*
	Time necessary to perform block, min	Significantly faster in group US vs NS: 5.0 ± 2.4 vs 9.8 ± 7.5 min* End point for performance: interval between 1st needle insertion and final needle withdrawal	Significantly faster in groups UD and US vs group ND: 6.7 ± 1.3 and 6.5 ± 1.3 vs 8.2 ± 1.5 min* End point for performance: time from needle puncture or US application on skin to the completion of the LA injection	N/A	Significantly faster in group US vs group TA: 7.9 ± 3.9 vs 11.1 ± 5.7 min* End point for performance: time from completion of the sterile preparation to the withdrawal of the needle
Quality	Not needing rescue anesthesia, %	No significant difference between US vs NS (100% vs 92%)	No significant difference between US vs UD vs ND (97% vs 100% vs 100%)	No significant difference between US vs landmark (95% vs 90%)	Significant difference between US vs TA (100% vs 86%) Fewer overall failures in US vs TA: 0% vs 28%*
	Not needing analgesic supplement, %	No significant difference between US vs NS (85% vs 78%)	No significant difference between US vs UD vs ND (87% vs 90% vs 90%)	N/A	No difference between US vs TA (82% for both)
	Complete block of all examined nerves, %	No significant difference between US vs NS at 30 min (55% vs 65%)	No significant difference between US and ND vs UD at 40 min (70% vs 73%)	N/A	N/A
Duration	Duration of block, min	N/A	N/A	Similar duration for group US vs group landmark (10.3 vs 11.2 h)	N/A
	Time to 1st analgesic, min	Similar duration for group US vs NS: 846 ± 531 vs 652 ± 473 min Defined as interval between block completion and ingestion of the 1st postoperative analgesic	N/A	N/A	N/A

(Continued next page)

TABLE 1. *(Continued)*

Study		Casati et al,[5] 2007	Chan et al,[6] 2007	Dingemans et al,[7] 2007	Sauter et al,[8] 2008
Jadad score		3	5	2	3
Groups (n: technique)		Axillary block	Axillary block	Infraclavicular block	Lateral sagittal infraclavicular block
		Forearm, wrist, and hand surgery	Hand surgery	Hand, forearm, and distal arm surgery	Elective hand or forearm surgery
		30: 4 Nerve branches, injection US	64: 3 Injection US	36: US-guided perivascular (US)	40: NS
		30: 4 Nerve branches, injection NS	62: 3 Injection NS		40: US
			62: 3 Injection combined USNS		Presurgery: oral paracetamol 1.5 g, IV alfentanil 0.5 mg, midazolam 1 mg
		20 mL 0.75% Ropivacaine	42 mL 2% Lidocaine + 0.5% bupivacaine	36: single injection US-guided NS (NS) 0.5 mL/kg (maximum of 40 mL) of 1:3 0.5% bupivacaine, 2% lidocaine with 1:200,000 epinephrine	During: 0.6 mL/kg mepivacaine 15 mg/mL with epinephrine 2.5 μg/mL
Primary outcome		Powered to detect a 5 min difference in the onset of nerve blockade	Powered to detect increase in rate of successful block from 80% to 95%	Powered to detect a difference of 1.6 min in performance between the 2 techniques	Powered to detect a difference of 5 min between 2 techniques
Onset time	Time of onset	Sensory onset faster for US vs NS: 14 ± 6 vs 18 ± 6 min* but no difference in onset of motor block: 24 ± 8 vs 25 ± 8 min	N/A	N/A	No significant difference in onset time for US vs NS: 13.9 ± 5.8 vs 13.7 ± 6.6 min
	Success at set timepoints	N/A	More complete sensory block for US and USNS vs NS at 30 min (83% and 81% vs 63%)*	More complete sensory and motor blocks for US vs NS at 30 min (86% vs 57%)	Similar rate of complete sensory block between US vs NS at 30 min (95% vs 85%)
			Similar rate of complete motor block btw US and USNS vs NS at 30 min	In group US, no. injections (single vs multiple did not affect rate of complete block)	
	Time necessary to perform block, min	N/A	Significantly faster in group US vs group NS vs group USNS: 9.3 ± 4.0 min vs 11.2 ± 4.4 min vs 12.4 ± 4.8 min*	Significantly faster in group US vs group NS: 3.1 ± 1.6 vs 5.2 ± 4.7 min*	No significant difference between group US vs group NS: 4.1 ± 1.3 vs 4.3 ± 1.3 min
			End point for performance: time from palpation of axillary artery (NS) or ultrasound application (US) to the end of local anesthetic injection	End point for performance: interval between skin puncture and withdrawal of the needle after injection	End point for performance: time from needle insertion until finished local anesthetic injection. In group US, the prescan time was included in performance time
Quality	Not needing rescue anesthesia, %	No difference between US vs NS (100% for both)	No significant difference between US vs NS vs USNS (98% vs 95% vs 98%)	No difference between US vs NS (100% for both)	No significant difference between US vs NS (100 vs 95%)
	Not needing analgesic supplement, %	No significant difference between US vs NS (97% vs 94%)	No significant difference between US vs NS vs USNS (95% vs 86% vs 92%)	Significant difference between US vs NS (92% vs 74%)*	No significant difference between US vs NS (95% for both)
	Complete block of all examined nerves, %	N/A	N/A	N/A	N/A
Duration	Duration of block, min	N/A	N/A	N/A	N/A
	Time to 1st analgesic, h	N/A	N/A	Similar duration for group US vs group NS (7 ± 3 vs 8 ± 5 h)	N/A

Study		Gürkan et al,[9] 2008	Macaire et al,[10] 2008	Kapral et al,[11] 2008	Dhir and Ganapathy,[12] 2008
Jadad score		2	2	2	2
Groups (n: technique)		Lateral sagittal infraclavicular block	Combined median and ulnar nerve block	Interscalene brachial plexus block	Infraclavicular brachial plexus block using nonstimulating catheter
		Hand, wrist, and forearm surgery	Endoscopic carpal tunnel release	Trauma-related upper-arm surgery	Elective hand surgery
		40: NS	30: NS	80: NS	22: Traditional nerve stimulation (TR)
		40: US	30: US	80: US	22: Stimulating catheter (ST)
					22: Ultrasound guidance (US)
		20 mL levobupivacaine 5 mg/mL + 20 mL lidocaine 20 mg/mL with 5 μg/mL epinephrine	Premedication with alprazolam 0.5 mg, 4 mL plain mepivacaine 1.5% for each nerve	Premedication with 1 mL subcutaneous lidocaine 1% 20 mL of ropivacaine 0.75%	Titration of fentanyl (50–150 μg) and midazolam (1–3 mg), 40 mL of 15mgl/mL mepivacaine with 2.5 μg/mL adrenaline
Primary outcome		Powered to detect a score of 12 for sensory evaluation at 20 min with a statistical power of 0.9	Powered to detect at least 20-s reduction in block performance time in the US group	Powered to detect the duration of sensory blockade could be prolonged from 700 (NS) to 800 (US) min	Powered to detect that ultrasound guidance would increase success rate from 60% to 95%
Onset time	Time of onset	No significant difference in onset time for US vs NS: 20 vs 20 min	Slower onset of median block for US vs NS: median (range) 371 (252–465) vs 254 (210–300) s*	Faster onset time for US vs NS: median (range): 10 (6–13) vs 22 (11–28) min	N/A
			Slower onset of ulnar block for US vs NS: 368 (246–430) vs 241(210–310) s*		
	Success at set timepoints	Similar efficacy of block at 30 min for group US vs group NS (95% vs 92.5%)	N/A	Significantly better sensory and motor block quality at 30 min for US vs NS*	Significantly better sensory and motor block quality after 20 min for US and ST vs TR*
	Time necessary to perform block, min	Significantly slower in group US vs group NS: 7.2 ± 1 vs 6.4 ± 1 min*	Significantly faster for median and ulnar block in group US vs group NS: 55 vs 100 s and 58 vs 80s*	N/A	N/A
		End point for performance: N/A	End point for performance: time between beginning of specific procedure (median, ulnar nerve block) and end of local anesthetic injection		
Quality	Not needing rescue anesthesia, %	No significant difference between US vs NS (100% vs 95%)	N/A	Significant difference between US vs NS (99% vs 91%)*	Significant difference between US vs TR and ST (96% vs 59% and 58%)*
	Not needing analgesic supplement, %	No significant difference between US vs NS (95% vs 98%)	N/A	N/A	N/A
	Complete block of all examined nerves, %	Similar efficacy of complete block at 30 min for group US vs group NS (95% vs 92.5%)	Same efficacy of complete block for group US vs group NS (93%)	Similar rate of success for group US vs group NS (99% vs 91%)	Significantly better in group US and group ST vs group TR at 30 min (87% and 68% vs 27%)*
Duration	Duration of block, min	N/A	N/A	Longer block duration for US vs NS: 899 (611–1020) vs 679 (417–968) min*	Similar duration for US vs ST vs TR: 246.2 ± 50 vs 247.5 ± 49.6 vs 261.6 ± 54.3
	Time to 1st analgesic, min	N/A	N/A	N/A	N/A

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TABLE 1. *(Continued)*

Study		Fredrickson et al,[13] 2009	Liu et al,[14] 2009	Taboada et al,[15] 2009	Tedore et al,[16] 2009
Jadad score		2	3	3	2
Groups (n: technique)		Interscalene catheter	Interscalene block	Coracoid infraclavicular brachial plexus block	TA axillary block
		Shoulder surgery	Shoulder arthroscopy	Hand and forearm surgery	Infraclavicular block
		41: US	115: US	35: US	Upper-extremity surgery at or distal to the elbow
		40: NS	115: NS	35: NS	111: US
		5–10 mL 1% lidocaine with epinephrine 1:200,000			109: TA
		30 mL ropivacaine 0.5%	1.5% Mepivacaine with 1:300,000 epinephrine and $NaCO_3$	Premedication with 1–2 mg midazolam, 40 mL 1.5% mepivacaine	1.5% Mepivacaine with 1:200,000 epinephrine, bicarbonate 1 mEq/10 mL
Primary outcome		Powered to detect a mean difference of 1.5 points on the numerical rating pain score	Powered to detect a difference in risk of postoperative neurological symptoms (4% vs 16%) between techniques	Powered to detect a 5-min difference in onset time between techniques	Powered to detect a reduction in dysesthesias from 19% to 5.7% using a 2-sided *t* test
Onset time	Time of onset	N/A	N/A	No significant difference in onset time for complete block between US vs NS: 17 (8) vs 19 (9) min	N/A
	Success at set timepoints	N/A	More complete motor block in the biceps for US vs NS at 5 min*	Similar efficacy of sensory and motor block at 30 min for group US vs group NS (91% for both, 89% vs 91%)	Similar efficacy of motor block at 5 and 10 min for US vs TA. Similar efficacy of sensory block at 5 min. Significantly better quality sensory block at 10 min for US vs TA (75% vs 47%)*
		Significantly faster in group US vs group NS: 78 (65–101) vs 108 (94–129) s*	No significant difference between group US vs group NS: 5 ± 3 min for both	Significantly faster in group US vs group NS: 3 (1) vs 6.2 (2.4) min*	
	Time necessary to perform block, min	End point for performance: time from the moment the needle tip penetrated the skin until exiting the skin over the interscalene catheter	End point for performance: time from needle insertion to final needle withdrawal	End point for performance: interval between needle insertion and its removal at the end of the local anesthetic injection	No significant difference between group US vs group TA: 7 ± 4 vs 7 ± 3 min
Quality	Not needing rescue anesthesia, %	N/A	No significant difference between US vs NS (100% for both)	No significant difference between US vs NS (97% vs 100%)	No significant difference between US vs TA (99% vs 99%)
	Not needing analgesic supplement, %	No significant difference between US vs NS	N/A	No significant difference between US vs NS (94% vs 91%)	No significant difference between US vs TA (93% vs 86%)
	Complete block of all examined nerves, %	N/A	N/A	Similar efficacy of sensory and motor block for group US vs group NS (91% for both, 89% vs 91%)	N/A
Duration	Duration of block, min	N/A	N/A	Similar duration for group US vs group NS (237 ± 45 vs 247 ± 57 min)	N/A
Time to 1st analgesic, min		N/A	N/A	N/A	N/A

Study		Ponde and Diwan,[19] 2009	Fredrickson et al,[21] 2009	Mariano et al,[20] 2009	McNaught et al,[22] 2011
Jadad score		2	4	3	5
Groups (n: technique)		Infraclavicular brachial plexus block	Interscalene catheter placement	Infraclavicular brachial plexus catheter placement	Interscalene brachial plexus block
		Hand surgery	Shoulder surgery	Distal upper-extremity surgery	Shoulder arthroscopy
		25: US	43: US	20: US	20: US
		25: NS	40: NS	20: NS	20: NS
			5–10 mL 1% lidocaine with epinephrine 1:200,000		
		0.5 mL/kg of 0.5% bupivacaine	30 mL ropivacaine 0.5%	40 mL of solution containing 1.5% mepivacaine and 2.5–5.0 μg/mL epinephrine	0.5% Ropivacaine, up-down sequential dosing method with starting volume of 10 mL and testing interval of 1 mL
Primary outcome		Powered to detect an increase in success rate from 66% in NS group to 100% in US group	Powered to detect a 0.9 difference of supplemental ropivacaine bolus demands	Powered to detect a 5-min difference in time for catheter placement Sample size calculation powered to detect a minimum detectable difference of 2.5 mL (SD of 2 mL)	Primary outcome: pain score 30 min after entry to the recovery room. Successful block defined as verbal rating score of 0 out of 10
Onset time	Time of onset	N/A	N/A	N/A	N/A
	Success at set timepoints	N/A	N/A	N/A	N/A
			Significantly faster in group US vs group NS: median (quartile) 49 (41–55) vs 97 (81–135) s*	Significantly faster in group US vs group NS: median (10th–90th percentile) 9.0 (6.0–13.2) vs 15.0 (4.9–30.0) min*	Significantly lower minimum effective analgesic volume of 0.5% ropivacaine in group US vs group NS: 0.9 mL (95% CI, 0.3–2.8 mL) vs 5.4 (95% CI, 3.4–8.9 mL)*
	Time necessary to perform block, min	N/A	End point for performance: time from the moment the needle tip penetrated the skin until it exited the skin over the interscalene catheter	End point for performance: time from the moment the US probe or catheter placement needle tip 1st touched the skin until its removal	End point for performance: N/A
Quality	Not needing rescue anesthesia, %	N/A	N/A	N/A	N/A
	Not needing analgesic supplement, %	Significant difference between US vs NS (96% vs 64%)*	Significant difference between US vs NS in supplemental bolus (81% vs 56%) and oral analgesic consumption (95% vs 82%) on POD1	N/A	N/A
	Complete block of all examined nerves, %	Significantly higher block success rate in US vs NS (96% vs 64%)*	N/A	Significantly higher success rate in US vs NS (100% vs 70%)*	N/A
Duration	Duration of block, min	N/A	N/A	N/A	N/A
	Time to 1st analgesic, min	No significant difference between US vs NS	N/A	N/A	N/A

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TABLE 1. *(Continued)*

Study		Strub et al,[17] 2011	Danelli et al,[18] 2012	Trabelsi et al,[23] 2013
Jadad score		2	4	1
Groups (n: technique)		Axillary brachial plexus block	Interscalene brachial plexus block	Infraclavicular brachial plexus block
		Hand surgery	Shoulder surgery	Upper limb
		70: Ultrasound block (US)	25: US	30: US
		71: Conventional block (CB)	25: NS	30: NS
		Mixture of bupivacaine hydrochloride (5 mg/mL) with 0.5% epinephrine and mepivacaine hydrochloride (10 mg/mL) in a ratio of 1:1	20 mL of 1% ropivacaine	15 mL 0.5% bupivacaine
Primary outcome		Powered to detect difference in the no. of successful block (effect size of 0.25)	Powered to detect a 5-min difference in readiness for surgery (block onset time)	Powered to detect 10-min difference in onset of sensory block
Onset time	Time of onset	Time to complete onset of anesthesia significantly faster for US vs CB: median (range) 8 (4–60) vs 30 (4–110) min*	No significant difference between US vs NS: 15 ± 9 vs 18 ± 7 min	Significantly faster onset for all 4 nerves (median 10 vs 14 min for US)*
	Success at set timepoints	N/A	N/A	Significantly greater success rate for all 4 nerves at 15 min after block*
	Time necessary to perform block, min	No significant difference between US vs CB: median (range) 7.5 (5–16) vs 7 (4–20) min	Significant difference between US vs NS: 5 ± 3 vs 8 ± 5 min*	No difference (mean 220 s US vs 281 s NS)
		End point for performance: N/A	End point for performance: time interval between the 1st US scan (US group)/identification of anatomical landmarks (NS group) and needle removal at the end of the block	
Quality	Not needing rescue anesthesia, %	Significant difference between US vs CB (83% vs 55%)*	N/A	N/A
	Not needing analgesic supplement, %	No significant difference between US vs CB (96% vs, 92%)	No significant difference between US vs NS (72% vs, 76%)	N/A
	Complete block of all examined nerves, %	Significantly higher success rate in US vs CB for all examined nerves: median (96% vs 76%),* radial (89% vs 73%),* ulnar (96% vs 73%),* and musculocutaneous (90% vs 72%)*	No significant difference in sensory/motor mean [SD] block onset times between US vs NS for axillary (14 [7]/13 [7] vs 15 [6]/14 [8]), radial (16 [9]/20 [7] vs 16 [6]/25 [7]), musculocutaneous nerves (14 [7]/17 [9] vs 17 [6]/17 [9])	100% success for all 4 nerves for US vs 73%–100% for NS*
Duration	Duration of block, min	N/A	N/A	N/A
	Time to 1st analgesic, min	N/A	N/A	N/A

*Statistically significant.

CI indicates confidence interval; LA, local anesthetic; NS, nerve stimulator; POD, postoperative day; US, ultrasound.

TABLE 2. Summary of RCTs Comparing Ultrasound Guidance Versus Alternative Technique for Lower-Extremity Nerve Blocks

Study		Marhofer et al,[24] 1997	Marhofer et al,[25] 1998	Domingo-Triado et al,[26] 2007	Perlas et al,[27] 2008
Jadad score		1	2	3	4
Groups (n: technique)		3-in-1 block Hip surgery after trauma 20: US 20: NS 20 mL 0.5% bupivacaine Spinal anesthesia	3-in-1 block Hip surgery after trauma 20: US (group A) 20 mL 0.5% bupivacaine 20: NS (group B) 20 mL 0.5% bupivacaine 20: NS (group C) 30 mL 0.5% bupivacaine Spinal anesthesia	Sciatic block at midfemoral level Foot and ankle surgery 30: US NS (group US) 31: NS only 34 mL 0.5% ropivacaine	Sciatic block at popliteal fossa Major elective food or ankle surgery 33: NS 37: US 15 mL 2% lidocaine with 1:200,000 epinephrine 15 mL 0.5% bupivacaine
Primary outcome		N/A	N/A	Powered to detect 25% difference in no. of attempts to perform technique	Powered to detect increase in success rate from baseline 70% to 95%
Onset time	Time of onset	Significantly faster onset for US vs NS: 16 ± 14 vs 27 ± 16 min*	Significantly faster onset for US vs NS: 13 ± 16 (A) vs 27 ± 12 (B) and 26 ± 13 (C) min*	No significant difference in onset time between US vs NS	Significantly faster onset for US vs NS at 10 min and every 5 min afterwards*
	Success at set timepoints	More successful block from 30 to 60 min for US vs NS: sensation at 15% ± 10% vs 27% ± 14% of initial value*	More successful block during 1st hour for group A vs group B and C: final sensation at 4% ± 5% of initial value vs 21% ± 11% and 22% ± 19%, respectively*	N/A	Significantly higher block success rate at 30 min for US vs NS: 89.2% vs 60.6%*
	Time necessary to perform block, min	N/A	N/A	No significant difference in time to perform block between US vs NS: 5 (5–15) min for both End point for performance: time from the 1st needle insertion to successful nerve location (NS) or from the beginning of ultrasound technique to successful nerve location (US)	No significant difference in block procedure time between US vs NS: 8.1 ± 3.3 vs 8.3 ± 5.6 End point for performance: time interval from ultrasound probe preparation (US) or start of landmark palpation (NS) until completion of local anesthetic injection
Quality	Not needing rescue anesthesia, %	N/A	N/A	No significant difference between US vs NS for spinal anesthesia (97% vs 93%)	No significant difference between US vs NS (92% vs 76%)
	Not needing analgesic supplement, %	No significant difference between US vs NS (95% vs 90%)	No significant difference between group A (95%), Group B (90%), and group C (95%)	N/A	N/A
	Complete block of all examined nerves, %	No significant difference in complete 3-in-1 block (sensation at <30% initial value) observed in US vs NS (95% vs 85%) Better quality of block at period 30 to 60 min after for US vs NS: sensation at 15% ± 10% vs 27% ± 14% of initial value*	No significant difference in complete 3-in-1 block (sensation at <30% initial value) observed in group A vs group B and C (95% vs 80% for both) Quality of block better in A vs B and C during 1st hour: final sensation at 4% ± 5% of initial value vs 21% ± 11% and 22% ± 19%, respectively*	Quality of sensory block and tolerance to tourniquet better in US vs NS (96.7% vs 71% achieved complete sensory block; 93.3% vs 48.4% tolerated the tourniquet without sedation)*	N/A
Duration	Duration of block, min	N/A	N/A	No significant difference in duration between US vs NS: Sensory: 17.5 (9–25) vs 17 (6–24) h Motor: 20 (7–24) vs 17 (11–24) h	N/A
	Time to 1st analgesic, min	N/A	N/A	N/A	N/A

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TABLE 2. *(Continued)*

Study		Dufour et al,[28] 2008	van Geffen et al,[29] 2009	Mariano et al,[30] 2009	Redborg et al,[31] 2009
Jadad score		4	3	3	2
Groups (n: technique)		Popliteal sciatic nerve block Foot surgery 25: NS only (NS) 26: US + NS (US) Premedication with hydroxyzine 50 mg 1 h before arrival in operating room. 10 mL of levobupivacaine 0.5% administered separately on the tibial and common peroneal nerves (20 mL total)	Distal sciatic block at popliteal fossa Foot or ankle surgery 20: NS 20: US Premedication with IV midazolam 2 mg. Up to 40 mL lignocaine 1.5% with epinephrine 5 μg/mL (dose-response study)	Popliteal-sciatic perineural catheter Foot or ankle surgery 20: Electrical stimulation (ES) 20: NS 40 mL 1.5% mepivacaine with epinephrine 2.5 to 5.0 μg/mL	Tibial nerve block Ankle surgery 18: US 18: Landmark (LM) 5 mL 3% chloroprocaine
Primary outcome		Powered to detect a reduction in block time by 25% with US	Powered to detect a reduced amount of 10 mL of local anesthetic	Powered to detect a 5-min difference in the time for catheter placement	Powered to detect a success rate of 95% in group US and 50% in group LM
Onset time	Time of onset	N/A	No significant difference in onset of sensory of motor block for US vs NS: median (interquartile range) 10 (11) vs 12.5 (10) min; 10 (9) vs 15 (19) min	N/A	N/A
	Success at set timepoints	More successful sensory and motor block at 30 min for US vs NS (85% vs 32%; 65% vs 16%)*	N/A	N/A	More successful sensory and motor block at 30 min for US vs LM (72% vs 22%, 17% vs 0%)*
	Time necessary to perform block, min	No significant difference in time between US vs NS: 304 ± 94 vs 261 ± 75 s End point for performance: interval between the 1st needle insertion and its removal at the end of the block	No significant difference between US vs NS: 6 ± 1.9 vs 7.6 ± 3.7 min End point for performance: interval between the 1st needle insertion (NS) or the start of visualization of the distal sciatic nerve (NS) until the removal of needle at the end of the injection of local anesthetic	Significantly faster in group US vs group ES: 5.0 (3.9–11.1) vs 10.0 (2.0 vs 15.0) min* End point for performance: time from when the US probe (US) or catheter-placement needle (ES) 1st touched the patient to when the catheter placement needle was removed	Significantly slower in group US vs group LM: 158 (110–242) vs 79 (39–131) s End point for performance: For Group US, time elapsed between transducer placement on the skin and the needle removal after block completion. For Group LM, time elapsed between insertion of needle and its final removal after injection
Quality	Not needing rescue anesthesia, %	No difference between US vs NS (100% for both)	N/A	N/A	N/A
	Not needing analgesic supplement, %	N/A	N/A	N/A	N/A
	Complete block of all examined nerves, %	N/A	Higher success rate with US vs NS (100% vs 75%)*	Similar rate of success between US vs NS	At all times, proportion of complete blocks higher in group US vs LM*
Duration	Duration of block, min	N/A	No significant difference for sensory or motor block between US vs NS: Sensory: 240 (113) vs 240 (105) min Motor: 210 (90) vs 210 (165) min	N/A	N/A
	Time to 1st analgesic, min	No significant difference in time to 1st analgesic for US vs NS: 16.6 ± 2.9 vs 17.1 ± 3.7 min	N/A	N/A	N/A

Study		Fredrickson and Danesh-Clough,[32] 2009	Mariano et al,[33] 2009	Antonakakis et al,[34] 2010	Mariano et al,[35] 2010
Jadad score		4	2	4	2
Groups (n: technique)		Femoral nerve catheter placement Major knee surgery 21: US 24: NS	Femoral perinueral catheter insertion Knee surgery 20: US 20: NS	Deep peroneal nerve block Volunteers without surgery US: 18 Landmark (LM): 18 Each subject received both block types and thus served as his/her own control	Popliteal sciatic perineural catheter insertion Foot and/or ankle surgery 40: US 40: NS
		Premedication with oral paracetamol 1.0 g, diclofenac SR 75 mg, omeprazole 20 mg. 5–10 mL 1% lidocaine with epinephrine (1:200,000). 30 mL of ropivacaine 0.5% or ropivacaine 0.375%	40 mL solution containing mepivacaine 1.5% and epinephrine 2.5–5.0 μg/mL	5 mL of 3% 2-chloroprocaine	40 mL solution of 1.5% mepivacaine with epinephrine 2.5–5.0 μg/mL
Primary outcome		Powered to detect at least a 2-point shift in mean postoperative pain score on a scale of 0–10	Powered to detect a 5-min difference in catheter placement time	Powered to detect a success rate of 95% in US group and 50% in LM group	Powered to detect a difference of 1.25 on the numeric rating pain scale (0–10) during the 1st 24 postoperative hours
Onset time	Time of onset	N/A	N/A	US had significantly better temperature sensation and motor block than LM at 10 min postinjection of LA* No significant difference in temperature sensation and motor block between US vs LM at 20 to 60 min postinjection of LA	N/A
	Success at set timepoints	N/A	N/A	N/A	N/A
	Time necessary to perform block, min	Significantly faster in US vs NS: median (quartiles) 58 (51–76) vs 120 (95–178) s*	Significantly faster in US vs NS: median (10th–90th percentiles) 5.0 (3.9–10.0) vs 8.5 (4.8–30.0) min*	Significantly slower in US vs LM: median (range) 143 (77–243) vs 81 (44–144) s*	Significantly faster in US vs NS: mean (95% CI) 7.0 (4.0–14.1) vs 11.0 (5.0–30.0) min*
		End point for performance: time from the needle-tip penetrating the skin until exiting the skin over the catheter	End point for performance: time from the ultrasound transducer (US group)/catheter insertion needle (NS group) 1st touched the patient until its removal after catheter placement	End point for performance: time elapsed between transducer placement on the skin (US) or needle insertion to raise a skin wheel (LM) and removal of needle	End point for performance: time when the US transducer(US)/ catheter placement needle (NS) 1st touched the patient until its removal following catheter placement
Quality	Not needing rescue anesthesia, %	No significant difference between US vs NS (52% vs 58%)	N/A	N/A	No significant difference between US vs NS on POD0: median (10th–90th percentile) 100 (0–250) vs 50 (0–250) μg
	Not needing analgesic supplement,%	No significant difference between US vs NS on POD1 (57% vs 46%) and POD2 (71% vs 50%)	N/A	N/A	No significant difference between US vs NS on POD1: 20 (0–40) vs 20 (5–45) mg
	Complete block of all examined nerves, %	N/A	No significant difference between US vs NS (100% vs 85%; $P = 0.086$)	N/A	Significantly higher block success rate with US vs NS (98% vs 78%)*
Duration	Duration of block, min	N/A	N/A	N/A	N/A
	Time to 1st analgesic, min	N/A	N/A	N/A	N/A

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TABLE 2. *(Continued)*

Study		Aveline et al,[36] 2010	Faraoni et al,[37] 2010	Fredrickson et al,[38] 2011	Bendtsen et al,[39] 2011
Jadad score		4	2	4	4
Groups (n: technique)		Femoral nerve block	Dorsal penile nerve block	Ankle block	Popliteal sciatic nerve block
		Total knee arthroplasty	Circumcision	Foot surgery	Major foot and ankle surgery
		46: US	20: US	37: Low-volume ultrasound (LVUS)	50: US
		46: NS	20: LM	35: Standard volume landmark (SVL)	48: NS
		Premedication with 1 mg alprazolam	Premedication with 0.2 mg/kg midazolam	Premedication with acetaminophen 1 g and (IV parecoxib 40 mg) or (oral diclofenac SR 75 mg with omeprazole 20 mg)	
		20 mL of 5 mg/mL levobupivacaine	Ropivacaine 0.75%	Up to 30 mL of ropivacaine 0.5%	30 mL of ropivacaine 0.75%
Primary outcome		Powered to detect a difference of 25 mL in total local anesthetic dose on POD2	Powered to detect a difference of 200 min between the mean values of time to 1st administration of the analgesic drug	Powered to detect a 1-point shift in the 11-point numerical rating pain scale (0–10) during the 1st 24 postoperative hours	Powered to detect a 20% increase in success rate of sensory blockade from 75% with NS to 95% with US
Onset time	Time of onset	Significantly faster sensory and motor block onset time for US vs NS: median [25–75th percentile] 11 [6–17] vs 16 [11–23] min*	N/A	N/A	N/A
	Success at set timepoints	N/A	N/A	N/A	N/A
	Time necessary to perform block, min	Significantly slower in US vs NS: 9 ± 4 vs 6 ± 3 min*	N/A	Significantly slower in LVUS vs SVL: median [range] 5 [4.6–6.2] vs 3 [2.7–4] min*	N/A
		End point for performance: elapsed time from the US probe preparation (US) or stimulating needle insertion (NS) until catheter placement		End point for performance: N/A	
Quality	Not needing rescue anesthesia, %	N/A	N/A	N/A	N/A
	Not needing analgesic supplement, %	Significantly lower cumulative LA consumption over 48 h (299 ± 45 vs 333 ± 48 mL)* and cumulative oral analgesic dose until POD2 (20 [0–40] vs 40[20–60]) for US vs NS	Significant difference between the US vs LM: 85% vs 30%*	Significant difference between LVUS vs SVL: 50% vs 80%*	Significantly lower analgesic consumption over 1st 48 h for US vs NS: median [range] 18 [0–159] vs 34 [0–152] mg*
	Complete block of all examined nerves, %	N/A	Similar block success between US vs LM: 100% vs 90%	No significant difference in block success rate between LVUS vs SVL in the recovery room: 89% vs 80%	Significantly higher success rate of sensory block with US vs NS: 94% vs 79%*
Duration	Duration of block, min	N/A	Significantly longer for US vs LM: median [range] 41.5 [35–50] vs 30 [26–39] min*	N/A	N/A
	Time to 1st analgesic, min	Significantly longer for US vs NS: 11 [7–13] vs 7 [4–12]h*	Significantly longer for US vs LM: 570 [360–860] vs 60 [30–300] min*	Time to 1st dose: Significantly reduced in LVUS group: Kaplan-Meier curves; hazard ratio [95% CI], 3.0 [1.3–7.3]; $P = 0.009$*	N/A

Study		Sala-Blanch et al,[40] 2012
Jadad score		4
Groups (n: technique)		Popliteal sciatic nerve block Hallux valgus repair surgery US: 25 NS: 26 20 mL of mepivacaine 1.5%
Primary outcome		Powered to detect a difference of 40% in proportion of patients with complete block at 15 min
Onset time	Time of onset	N/A
	Success at set timepoints	Significantly higher success rate of sensory and motor blocks with US vs NS at: 10 min postinjection: 28% vs 4% and 40% vs 4%, respectively* 15 min postinjection: 80% vs 4% and 60% vs 8%, respectively*
	Time necessary to perform block, min	N/A
Quality	Not needing rescue anesthesia, %	N/A
	Not needing analgesic supplement, %	N/A
	Complete block of all examined nerves, %	No difference in block success rate after 30-min injection between US vs NS (100% vs 100%)
Duration	Duration of block, min	N/A
	Time to 1st analgesic, min	N/A

*Statistically significant.

CI indicates confidence interval; LA, local anesthetic; NS, nerve stimulator; POD, postoperative day; US, ultrasound.

TABLE 3. Summary of Advantages of Ultrasound Guidance for Onset, Quality, and Duration of Blocks

End Point	RCT Group	US Better Than NS	US Same as NS	US Worse Than NS
Onset	Upper-extremity RCTs	11 Soeding et al,[3] 2005; Sites et al,[4] 2006; Casati et al,[5] 2007; Chan et al,[6] 2007; Dingemans et al,[7] 2007; Kapral et al,[11] 2008; Dhir and Ganapathy,[12] 2008; Liu et al,[14] 2009; Tedore et al,[16] 2009; Strub et al,[17] 2011; Trabelsi et al,[23] 2013	6 Williams et al,[1] 2003; Liu et al,[2] 2005; Sauter et al,[8] 2008; Gürkan et al,[9] 2008; Taboada et al,[15] 2009; Danelli et al,[18] 2012	1 Macaire et al,[10] 2008
	Lower-extremity RCTs	8 Marhofer et al,[24] 1997; Marhofer et al,[25] 1998; Perlas et al,[27] 2008; Dufour et al,[28] 2008; Redborg et al,[31] 2009; Antonakakis et al,[34] 2010; Aveline et al,[36] 2010; Sala-Blanch et al,[40] 2012	2 Domingo-Triado et al,[26] 2007; van Geffen et al,[29] 2009	0
Quality	Upper-extremity RCTs	9 Sites et al,[4] 2006, Dingemans et al,[7] 2007, Dhir and Ganapathy,[12] 2008, Kapral et al,[11] 2008, Ponde and Diwan,[19] 2009; Fredrickson et al,[21] 2009; Mariano et al,[20] 2009; Strub et al,[17] 2011, Trabelsi et al,[23] 2013	13 Williams et al,[1] 2003; Liu et al,[2] 2005; Soeding et al,[3] 2005; Casati et al,[5] 2007; Chan et al,[6] 2007; Sauter et al,[8] 2008; Gürkan et al,[9] 2008; Macaire et al,[10] 2008; Fredrickson[21] 2009; Liu et al, 2009; Taboada et al,[15] 2009; Tedore et al,[16] 2009; Danelli et al,[18] 2012	0
	Lower-extremity RCTs	9 Marhoffer 1997; Marhoffer 1998; Domingo-Triado et al,[26] 2007; van Geffen et al,[29] 2009; Redborg et al,[31] 2009; Mariano et al,[35] 2010; Aveline et al,[36] 2010; Faraoni et al,[37] 2010; Bendtsen et al,[39] 2011	6 Perlas et al,[27] 2008; Dufour et al,[28] 2008; Mariano et al,[30] 2009; Fredrickson and Danesh-Clough,[32] 2009; Mariano et al,[33] 2009; Antonakakis et al,[34] 2010; Sala-Blanch et al,[40] 2012	1 Fredrickson et al,[38] 2011
Duration	Upper-extremity RCTs	1 Kapral et al,[11] 2008	6 Williams et al,[1] 2003; Soeding et al,[3] 2005; Dingemans et al,[7] 2007; Dhir and Ganapathy,[12] 2008; Taboada et al,[15] 2009; Ponde and Diwan,[19] 2009	0
	Lower-extremity RCTs	2 Aveline et al,[36] 2010; Faraoni et al,[37] 2010	3 Domingo-Triado et al,[26] 2007, Dufour et al,[28] 2008, van Geffen et al,[29] 2009	1 Fredrickson et al,[38] 2011

Table 3 summarizes the tally of RCTs that reported superiority, equivalence, and inferiority for onset, quality, and durations of block with ultrasound.

DISCUSSION

Overall, RCTs comparing ultrasound guidance to another technique are small and diverse in terms of type of block, anesthetic agents, and comparative control techniques. Most RCTs compared ultrasound with nerve stimulator, but other techniques included fascial pops, transarterial, surface landmarks, and ultrasound combined with nerve stimulator. A further confounding factor for review was diversity in number of injections used for both ultrasound and control techniques. Previous studies with nerve-stimulator–guided peripheral nerve blocks have demonstrated increased efficacy with either multiple injections or specific multinerve motor responses,[42] yet not all RCTs used multiple injections or multinerve stimulation for the control groups and may have thus artificially reduced the efficacy of the control technique. Finally, most RCTs were performed at institutions with high proficiency with ultrasound, and results may differ with less expert practitioners. Table 4 summarizes recommendations, levels of evidence, and grade of recommendation.

Does Ultrasound-Guidance Improve Onset of Block?

For the upper and lower extremity, use of ultrasound resulted in faster initial onset of block. Ultrasound may have produced faster onset of block because of closer needle approximation and

TABLE 4. Levels of Evidence and Recommendations

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

local anesthetic distribution to the target nerves. Time savings from faster onset of block are difficult to categorize, as RCTs used varied outcome measures. A previous Cochrane Systematic Review (2011) also concluded ultrasound improved onset of nerve block.[45]

- There is level 1b evidence for a grade A recommendation that ultrasound increases onset of block.

Does Ultrasound Improve Quality of Block?

Randomized controlled trials from upper-extremity blocks offer modest evidence for superior quality of block as only 9 of 23 upper RCTs reported superiority in at least 1 measure of block quality. Evidence for improved quality was stronger for lower-extremity RCTs, as 9 of 16 RCTs reported better quality of some measure. Again, ultrasound was never inferior to control groups for upper-extremity RCTs and rarely inferior (1/16 RCTs) for lower-extremity RCTs. It may be that lower-extremity nerves are more difficult to anesthetize because of typically larger size (eg, sciatic nerve), and thus ability of ultrasound to allow closer targeting of nerves provided more obvious advantage than that for upper-extremity RCTs. Two previous systematic reviews of RCTs comparing ultrasound-guided nerve blocks to a different guidance technique also concluded that ultrasound increased quality or success of block.[44,45] A meta-analysis from 2013 comparing ultrasound to nerve stimulator guidance for placement of peripheral nerve catheters also noted improved success with use of ultrasound.[46]

- There is 1b level of evidence for a grade A recommendation that ultrasound may modestly improve quality of block, especially for lower extremities.

Does Ultrasound Prolong Duration of Block?

Duration was infrequently measured, and only 3 of 13 RCTs noted prolonged duration for ultrasound. Again, ultrasound was never inferior to control groups for upper-extremity RCTs and rarely inferior (1/6 RCTs) for lower-extremity RCTs. A recent systematic review from 2011 also concluded that there was insufficient information to determine an effect of ultrasound on duration of block.[43]

- There is level 1b evidence for a grade A recommendation that ultrasound does not increase duration of block, although RCTs are few.

CONCLUSIONS

Since the previous review in *Regional Anesthesia and Pain Medicine*, 7 new RCTs were identified for upper-extremity blocks,[17–23] and 9 new RCTs were identified for lower-extremity blocks.[32–40] These additional RCTs maintain support for level 1b evidence to make a grade A recommendation that ultrasound guidance provides a modest improvement in block onset and quality, especially for lower extremity. Three other systematic reviews in 2011 have reached the same conclusions for onset and quality. The variety of study techniques makes meta-analysis difficult. Importantly, ultrasound is rarely inferior to control techniques. Reasons for the modest separation between ultrasound and control techniques may be the currently high published success rates with nerve stimulator in expert hands (90%–99%)[42] and typically small sample sizes of current RCTs. However, evidence for advantages for ultrasound guidance may increase because of increased training exposure, continuing evolution of curriculum, and simulation for teaching ultrasound.[47,48]

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The Requisites of Needle-to-Nerve Proximity for Ultrasound-Guided Regional Anesthesia

A Scoping Review of the Evidence

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Abstract: This scoping review examines the literature to determine whether the position of the needle tip relative to the target nerve is accurately and reliably detected during ultrasound (US)–guided regional anesthesia. The requisites for successful and safe needle tip positioning relative to the target nerve include accurate and reliable needle presentation by the machine, needle interpretation by the operator, nerve presentation by the machine, and nerve interpretation by the operator. Failure to visualize the needle tip is a common occurrence, frequently prompting operators to use needle and probe maneuvers, which are not necessarily based on evidence. Needle tip interpretation often relies on surrogate indicators that have not been validated. The acoustic resolution of modern portable US machines limits the extent to which nerve microanatomy can be reliably presented. Finally, our interpretation of the sonographic end points for local anesthetic injection that best balance success and safety for US-guided regional anesthesia continues to evolve.

What's New: In order to determine whether or not the position of the needle tip relative to the target nerve is accurately and reliably detected during US-guided regional anesthesia, the available literature is reviewed and interpreted to address the following 4 questions:

1. Is the presentation of needle tip by the ultrasound machine accurate and reliable?
2. Is the interpretation of the needle tip image by the operator accurate and reliable?
3. Is the presentation of the nerve by the ultrasound machine accurate and reliable?
4. Is the interpretation of the nerve image by the operator accurate and reliable?

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The introduction of real-time ultrasound (US) guidance is the most important advance in regional anesthesia practice of the new millennium. Compared with traditional nerve localization techniques, US increases overall block success, hastens block onset, and allows a lower volume of local anesthetic to be used.[1–4] Importantly, US also reduces serious complications such as vascular puncture and local anaesthetic toxicity.[1,5] These procedure-related advantages of US are believed to stem from reliable, real-time visualization of needle tip positioning relative to the target nerve and surrounding tissues. Indeed, when compared with US, traditional nerve localization techniques such as mechanical elicitation of paresthesias and peripheral nerve stimulation are limited by their low sensitivity in discriminating the position of the needle tip relative to the target nerve.[6] Accordingly, another purported advantage of real-time US guidance is the potential to avoid hazardous mechanical trauma to the nerve by the needle. While sound in theory, the concept of improved safety with respect to nerve injury has not translated into practice.[7–9] There are now numerous reports of inadvertent intraneural injection despite the use of real-time US guidance,[10–13] with subsequent nerve injury in some cases, presumably due to unrecognized placement of the needle tip inside the target nerve. Indeed, unlike many radiographic still imaging techniques, the quality of real-time sonographic imaging reflects both the intrinsic capacity of the machine's technology as well as the skills of the operator. Therefore, the objective of this literature review was to determine whether the position of the needle tip relative to the target nerve is accurately and reliably detected during US-guided regional anesthesia.

METHODS

Literature Search

Two of the authors (F.W.A. and R.B.) independently searched the US National Library of Medicine database, MEDLINE; the Excerpta Medica database, EMBASE; Cochrane Database of Systematic Reviews; CINAHL; and Cochrane Central Register of Controlled Trials databases. The medical subject headings "ultrasound" and "nerve block" alone and coupled with the results of the search for the keywords "nerve" OR "needle" combined by the Boolean operator AND with the keywords "localization" OR "visualization" OR "detection" OR "identification" OR "recognition" OR "presentation" OR "interpretation" were queried. Gray literature and the bibliographies of included articles were also searched for additional reports that met the inclusion criteria.

Eligibility Criteria

Reports of qualitative and quantitative studies involving both humans and animals were considered, and the search was limited to reports published between January 1960 and March 2014. Only reports published in the English language were included. We sought and retrieved full reports that examined the effects of various interventions, techniques, maneuvers, or technologies on the presentation and interpretation of both needle and targeted nerve during US-guided regional anesthesia. Reports describing research related to any intervention that may facilitate the recognition of needle-to-nerve proximity and/or the impact of this intervention on the success and/or efficacy and/or safety of the US-guided intervention were selected. The review was not limited to randomized controlled trials, and all levels of evidence[14] were considered. Studies examining US-guided procedures for chronic pain management were excluded as these were recently addressed elsewhere.[15]

Two of the authors (F.W.A. and R.B.) reviewed the retrieved reports; the decision to include qualifying reports was based on relevance rather than level of evidence and was reached by consensus.

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Disagreements were resolved by a voting process that involved all 3 authors.

Data Analysis

A standardized data extraction form was used to review and evaluate the results of included reports. Two of the authors (F.W. A. and R.B.) independently charted the included reports; assessed their design, interventions, and outcomes; and assigned a level of evidence using the US Department of Health and Human Services Agency for Health Care Policy and Research Levels of Evidence.[14]

Study Design

The literature examining the reliability and accuracy of needle tip positioning relative to the nerve during US-guided regional anesthesia is emerging or evolving and comprises a diverse array of research methodologies. To address our objective for the present study, we therefore decided a priori that a scoping design would be more appropriate than a traditional systematic review, which has a very limited focus and is directed by a finite study question.[16] The aim of a scoping review is 2-fold: (i) to comprehensively explore the nature, relevance, and size of existing evidence and (ii) to specify the research question(s) that will further develop the knowledge base and guide future focused research.[17–19] To that end, the guidelines for conducting a scoping review described by Arksey and O'Malley[20] were followed in the preparation of this manuscript. Accordingly, we identified any recurring themes related to the requisites of needle-to-nerve proximity addressed in these reports. The final levels of evidence as well as the themes addressed were designated by consensus, and the included reports were classified according to these recurring themes. In keeping with guidelines for conducting a scoping review,[20] the authors also consulted with Prof. Vincent W. Chan, a leading authority on US-based regional anesthesia, for his opinion regarding the identification of recurring themes, the classification of retrieved reports according to these themes, and the validity of the conclusions derived by the authors.

RESULTS

Our search yielded 14,847 citations; 13,279 abstracts were identified after duplicate citation removal. From these, 12,991 did not meet the inclusion criteria and were excluded. We reviewed a total of 288 full-text articles and included 106 of these articles in this review (Fig. 1).

The review identified 4 recurring themes representing elements that must be in synchrony for accurate and reliable positioning of the needle tip relative to the target nerve during US-guided regional anesthesia, namely, (i) the machine's sonographic presentation of the needle tip, (ii) the operator's interpretation of the needle tip image, (iii) the machine's sonographic presentation of the nerve, and (iv) the operator's interpretation of the nerve image. Based on these themes, herein we interpret the available literature in an attempt to address the following 4 questions:

(1) Is the presentation of needle tip by the US machine accurate and reliable?
(2) Is the interpretation of the needle tip image by the operator accurate and reliable?
(3) Is the presentation of the nerve by the US machine accurate and reliable?
(4) Is the interpretation of the nerve image by the operator accurate and reliable?

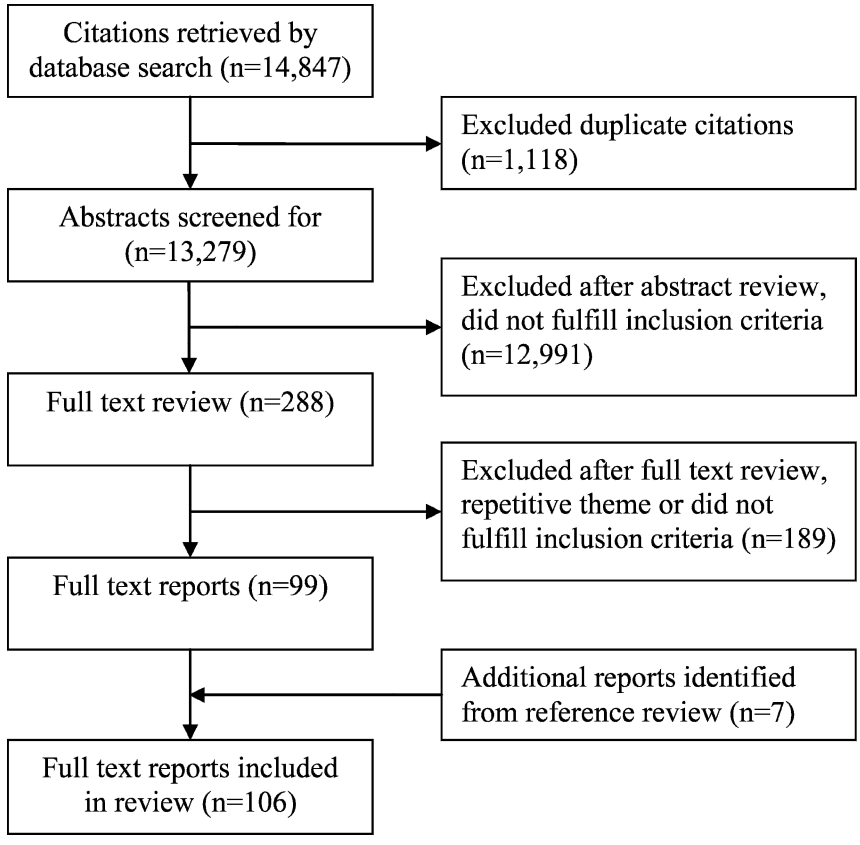

FIGURE 1. Selection process. Flowchart summarizing the study selection process and depicting retrieved, included, and excluded studies.

Table 1 categorizes the various maneuvers, techniques, and technologies identified through the literature search that may facilitate recognition of needle-to-nerve proximity according to the themes identified and summarizes the corresponding level of evidence.

Needle Tip Presentation

Visualizing the needle tip during US-guided regional anesthesia, and indeed other US-guided procedures, can be challenging.[21] Poor needle tip visibility is responsible for failure rates as high as 3.7% for thyroid,[22] 4.5% for liver,[23] and 7.5% for breast US-guided needle biopsies.[24] Similarly, the failure of first cannulation attempt during US-guided central venous access procedures is reported to be 9.8%,[25] whereas failure of the first amniocentesis attempt during the third trimester is reported to be 9%.[26] In the context of regional anesthesia, the importance of accurate needle tip presentation cannot be overstated as evidenced by several reports of serious complications following inadvertent injection of local anesthetic inside blood vessels and nerves despite the use of US-guidance in the hands of skilled operators.[8,27–29]

TABLE 1. Evidence-Based Recommendations to Enhance Detection of Needle-to-Nerve Proximity, Assessed Using the US Department of Health and Human Services Agency for Health Care Policy and Research Levels of Evidence[14]

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)

Regardless of whether the needle approach is in-plane or out-of-plane with respect to the US beam, the quality and accuracy of the needle tip presentation depend on proper alignment of the 1-mm-thick US beam with the needle tip, which is considerably less than 1 mm in diameter for most regional anesthesia needles. While some nonclinical studies suggest that visualization of a needle tip is easier using the in-plane approach,[30] contemporary recommendations do not advocate 1 needle approach—in-plane versus out-of-plane—over the other as both have advantages and limitations.[31] Indeed, the risk of misinterpreting the needle shaft for the needle tip persists irrespective of the needle approach. Operator training increases the likelihood of needle tip visualization. Although no evidence-based guidelines exist indicating the number of procedures required to master needle tip visualization during peripheral nerve blockade,[31,32] data from Sites and colleagues[33] suggest that at least 80 US-guided blocks may be required before novices can consistently visualize the needle tip during needle advancement. The use of educational tools such as phantoms and practical simulation has been demonstrated to improve needle probe alignment and needle tip presentation.[34–39]

Both transducer and needle manipulation by the operator are commonly used to optimize needle tip presentation. Transducer rotating, tilting, and sliding[40] as well as the "walk down,"[41] a maneuver whereby the needle is inserted at a distance from the target to permit easier needle tip identification with shallow angles of insonation before progressively moving to steeper angles, are popular maneuvers used to improve needle tip presentation for the in-plane and out-of-plane techniques, respectively, although evidence supporting enhanced needle tip visibility with these maneuvers is lacking. Modifying the angle of insertion to vary the needle-US beam angle of insonation[42,43] and altering the bevel orientation[43,44] have been described to enhance needle tip visibility, albeit the extent of improvement has not been systematically quantified. Although these techniques may improve the presentation of the needle shaft, they are not necessarily effective in visualizing the needle tip.[45]

Technical nonoperator factors also influence the sonographic presentation of the needle tip. Large-gauge needles possess a greater reflective surface that can enhance visualization[43] but are not routinely used in regional anesthetic practice. The use of echogenic needles is gaining popularity.[46] By reflecting a larger proportion of the incident US beam,[47,48] echogenic needles have been shown to improve needle visibility in phantoms[49] and cadavers,[50] particularly in deeper blocks requiring steeper needle trajectories, although evidence of a clinical benefit is scant at present.[48] Priming the needle,[43] pumping the stylet by performing a repetitive in-and-out movement inside the needle[51,52] while using a motion detection algorithm,[53] and using larger gauge needles[43,54] and some devices such as mechanical[55,56] and optical needle guides[57] have been suggested to improve needle visibility, but again, their clinical utility has not been definitively demonstrated. Ultrasound machine features, such as beam steering technology,[58] image compounding,[59] and needle recognition software (SonoSite, Bothell, Washington; GE Healthcare, Waukesha, Wisconsin), are thought to improve needle tip and shaft presentation. Color Doppler coupled with

needle vibrating devices,[60–64] magnetic resonance imaging coupled with US imaging,[65] needle-integrated optical fiber hydrophones,[66] photoacoustic tracking,[67] and 3-dimensional,[68] 4-dimensional,[69] and high-definition[70] US imaging are further promising technologies whose utility in needle tip presentation during nerve blocks has yet to be demonstrated. Most recently, the use of robotic assistance for US-guided nerve blocks has been reported in order to ensure consistent alignment between the US beam and needle tip and, as such, reliable needle tip presentation.[71,72]

Needle Tip Interpretation

Accurate and reliable presentation of the needle tip by the US machine is only useful if the needle tip can be interpreted as such by the provider. Evidence suggests that operator competency, achieved through education, training, and practice, facilitates acquisition of the necessary needle tip identification and interpretation skills and improves overall block success rates.[34–39]

Using B-mode US, the needle tip is most often presented as a hyperechoic dot on an image composed of millions of other white dots. Ultrasound beam attenuation and a decline in resolution with an increasing depth of targeted nerves further complicate needle tip interpretation. Whether an in-plane or an out-of-plane approach is used, the diversity of surrogate indicators used to facilitate needle tip interpretation and their routine use in daily practice underscores the challenges of needle interpretation. Tissue movement when the needle is advanced or jiggled[73] may help the provider estimate the position of an otherwise obscure needle tip. Similarly, hydrolocation by injection of small volumes (0.5–1 mL) of fluid may serve the same purpose by creating a dark anechoic pocket and accentuating the needle tip.[74] Injection of microbubbles, a variant of hydrolocation, can facilitate recognition of the needle tip but may also result in deterioration of the image quality.[75,76] Importantly, however, none of these surrogate indicators of needle tip position have been validated radiographically in live subjects or by anatomical dissection in cadaver studies. More recently, novel electromagnetic needle tracking systems such as the SonixGPS (Ultrasonix, Richmond, British Columbia, Canada)[77] and the eTRAX Needle Guidance System (CIVCO, Kalona, Iowa)[78] have been introduced. Much like global positioning system devices commonly used in motor vehicles, these electromagnetic needle tracking systems detect the actual needle tip position and display the projected needle trajectory on the US screen. Such applications may prove especially useful to indicate the needle tip position when performing deep peripheral nerve blocks or neuraxial procedures, but the current supporting evidence is limited to case series.[79,80]

Nerve Presentation

The sonographic presentation of the target nerve varies depending on its size, internal architecture (ie, echotexture),[81] and the echogenicity of the surrounding tissues.[76,82–84] The connective tissue inside nerves appears hyperechoic, whereas the neural components (fascicles) appear hypoechoic, and this connective tissue intertwined with neural components contributes to the distinctive honeycomb appearance of most peripheral nerves.[85]

In order to reliably interpret what is presented on the US screen during nerve imaging, the operator must first understand what cannot be presented by US. Most modern clinical-grade US machines operate in the 2.5- to 20-MHz frequency range, which generally permits presentation of structures greater or equal to 1000 μm.[86–93] In order for a tissue structure to be presented as a discrete and distinct image on the US screen, the machine's intrinsic acoustic resolution must be greater than the actual size of target structure. As such, US is seldom sufficient to accurately and reliably present the small terminal nerve branches that innervate the tissue of interest. Indeed, it is these small terminal nerve branches that are often the indirect yet ultimate target for sensory blockade, prompting some operators to use US to guide local anesthetic infiltration of large volumes of local anesthetic solution adjacent to readily visible bony tissue or in between anatomical fascial planes rather than target the larger, visible, and possibly mixed motor/sensory nerves upstream.

Similarly, US cannot accurately and reliably present the fine connective tissue layers and neural components inside a peripheral nerve. Most nerve fascicles[81,94] (size = 100–1000 μm)[95] and the perineurium (size = 5–25 μm),[96] the epineurium[97] (size = 200–3000 μm),[83,98,99] and the recently described paraneural sheath[82,84] of peripheral nerves are smaller than the machine's capacity for lateral resolution. Indeed, this limitation of US resolution has been illustrated in a cadaveric study by Orebaugh and colleagues,[100] wherein conventional US resolution failed to identify the epineurium of the brachial plexus at the interscalene level. In addition, Silvestri and colleagues[101] noted that only a third of the total number of fascicles in a peripheral nerve may be presented using US and attributed this to both the limited lateral resolution of US as well as the inability of US to present fascicles unless their trajectory is perpendicular to the incident beam. Finally, changes in nerve trajectory or angulation, malpositioning of the neural structure on the US screen,[33] the absence of identifiable sonographic landmarks that can aid in target identification,[102] the presence of fat whose echogenic properties matches that of nerves around the targeted nerve,[81] and the lack of acoustic mismatch between the nerve and its surrounding tissue in general[103–105] are all factors that can hinder nerve presentation irrespective of its size. Tissue harmonic imaging,[106] spatial compound imaging,[107] and adaptive processing are technologies available on many modern portable US machines and may be combined to improve picture clarity by reducing artifacts and speckle; however, no definitive evidence exists to support their efficacy in visualizing nerve tissue in particular.

Nerve Interpretation

The sonographic characteristics of the target nerve and resultant local anesthetic distribution that reliably predicts a successful block following injection have not been defined. While circumferential injection may be required for some nerves, such as the sciatic nerve[108,109] and median nerve,[110,111] it has not been shown to be a requirement for other nerves. Similarly, as with our understanding of sonographic nerve structure[112] and its associated connective tissue layers,[113] the sonographic characteristics of a safe versus dangerous injection are not known.[114] While experts agree that intraneural injection should be avoided,[115,116] it has been suggested that a 9%[117] or even 15%[118] increase in the cross-sectional area of a nerve may be required before an operator is even able to accurately interpret an intraneural needle tip position. Bigeleisen performed deliberate intraneural injection at the axillary[114] and supraclavicular[119] levels of the brachial plexus without any electrophysiological or clinical sequelae and designated the development of a "hypoechoic halo" and nerve swelling as end points indicative of intraneural injection. Sala-Blanch et al[13] performed sciatic nerve blocks at the level of the popliteal fossa and designated local anesthetic injection that produces a "hypoechoic halo around the nerve" or "concentric hypoechoic area around the nerve 2 to 3 cm proximal to the injection site"[118] as subepineural and did not detect any evidence of nerve injury. While nerve swelling is reliably indicative of intraneural injection[120–122] and may potentially be associated with nerve injury, the exact needle tip position that produces the "halo" and the "concentric hypoechoic" signs is controversial. More recently, Andersen and colleagues[84] described the paraneural sheath enveloping the sciatic nerve and proposed that the aforementioned pattern of spread, which had

previously been interpreted as subepineural,[13,118,123] was in fact subparaneural[124] and not intraneural. Nevertheless, an alarming rate of paresthesias,[84,125] nerve swelling,[70,84] and even long-term neurological sequelae[84] has still been reported with deliberate subparaneural injection. Such controversies underscore the nascent stage of our collective understanding of sonographic neurological microanatomy in the context of regional anesthesia practice.[13,118]

DISCUSSION

Based on our scoping review of the literature, we found that very few of the strategies and tools commonly used to position the needle tip in close proximity to the target nerve during routine US-guided regional anesthesia practice are soundly based in evidence. Techniques such as hydrolocation and the elicitation of tissue movement that are used regularly to infer the position of the needle tip have not been validated. Fundamental practical considerations such as the quality of needle tip presentation and interpretation for in-plane compared with out-of-plane needle approaches and the operator learning curves that support an accurate and reliable needle-nerve relationship during in-plane compared with out-of-plane approaches remain undefined. Moreover, the numerous technologies and devices recently developed to assist with needle and nerve presentation and interpretation suggest that these requisites can be challenging to achieve, are largely undiscovered, or may even be misunderstood. Indeed, Dr Alon Winnie's[126] timeless dictum, "When there are problems with any regional technique, look for the cause first on the proximal end of the needle," resonates still in the modern era of US-guided nerve blocks. There is sound evidence that operator training improves the reliability and accuracy of both the presentation and interpretation of the needle tip and its position. Finally, the optimal sonographic relationship between the needle tip position and the target nerve is unknown. One distinct advantage that US may offer over other nerve localization techniques is the ability to estimate how far the needle tip is from the targeted nerve, rather than how close it is. Indeed, more conservative US-guided "stay-away" nerve block techniques are beginning to populate the literature,[127,128] including injection into muscles, along fascial planes, or perivascularly instead of perineurally.[129] As our understanding and appreciation of the possibilities and limitations of US guidance for regional anesthesia continue to evolve, our present goal must be to determine the location where the needle tip can be accurately and reliably positioned relative to the target nerve in order to achieve successful and safe peripheral nerve blockade within a reasonable time.

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Evidence for the Use of Ultrasound Imaging in Pediatric Regional Anesthesia
A Systematic Review

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Abstract: An earlier review to evaluate the quality and outcomes of studies assessing ultrasound imaging in regional anesthesia for the pediatric population considered articles published from 1994 to 2009 and showed some evidence in support of block-related outcomes (block onset, success, duration) and process-related outcomes (performance time, local anesthetic dose, and spread). At that time, strong evidence in the form of randomized controlled trials and well-designed prospective observational studies was limited, leading to a call for additional research. The current systematic review (2009–2014) compares and updates the evidence for ultrasound-guided pediatric regional anesthesia published since our last review. Using the MEDLINE and EMBASE databases, we included in this review studies examining ultrasound imaging for nerve localization in the pediatric population between 2009 and March 2014 (meta-analyses, systematic reviews, randomized controlled trials, controlled studies without randomization, observational studies, comparative studies, and case series involving at least 10 patients). In the current review, we identified 24 and 13 articles evaluating peripheral nerve blocks and neuraxial anesthesia, respectively.

What's New: Studies in the current review provide stronger evidence and have addressed a number of outcomes that were previously inconsistent or lacked strength in evidence. In the current systematic review, we identified more studies in a shorter period compared with the previous review, and these studies contain higher levels of evidence compared with what we previously found. Randomized controlled trials and well-designed prospective observational studies have replaced case series. Stronger evidence from the literature suggests that ultrasound-guided peripheral blocks decrease block performance time when compared with nerve stimulation (but take longer than the landmark technique), increase block success, and increase block quality (as measured by analgesic consumption, block duration, and pain scores). Ultrasound guidance in neuraxial blocks improves needling time, predicts epidural depth, allows visualization of the catheter and local anesthetic spread, and improves block quality. Furthermore, we identified 2 large-scale prospective studies describing the incidence of adverse events and complications in pediatric regional anesthesia. The increase in evidence presented in this review reflects the efficacy and prevalent use of ultrasound imaging in pediatric regional anesthesia.

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Since the introduction of ultrasound imaging for regional anesthesia in adults, its use in the pediatric population has followed. Because the vast majority of pediatric regional anesthesia is conducted after administration of general anesthesia, close monitoring and careful consideration must be given in this specific population. Children have neurodevelopmental differences, including anatomical, physiological, and pharmacological differences, that preclude the generalization of results from adult studies to the pediatric population. Ultrasonography can be an asset in this population because anatomical structures are in proximity and the vertebral column may not be fully ossified. Given the increasing popularity of ultrasound-guided regional anesthesia in the pediatric population, evaluation of the evidence in this area seems appropriate.

Our previous evidence-based review of the use of ultrasound imaging in pediatric regional anesthesia (1994–2009) highlighted important trends,[1] yet available evidence was far from comprehensive. At the time, strong evidence in the form of randomized controlled trails and well-designed prospective observational studies was limited. The use of ultrasound to guide peripheral nerve blockade seemed to hasten the onset of upper extremity blocks, improve intraoperative and early postoperative analgesia for surgery at the anterior trunk, prolong analgesia after blockade of the extremities, and minimize anesthetic requirements. There was some evidence reporting the ability of ultrasound imaging in neuraxial anesthesia to visualize the dura mater and ligamentum flavum, predict the depth to loss of resistance (LOR), visualize the needle for epidural blocks in neonates, confirm catheter position after injection of fluid or air, and limit bone contact during thoracic epidural placement.

The purpose of the current review is to compare and update the evidence for ultrasound imaging in pediatric regional anesthesia between 1994 to 2009 and 2009 to 2014. A systematic review was performed to evaluate and compare the evidence for the use of ultrasound imaging in pediatric regional anesthesia since our last review.

METHODS

Criteria for Selection of Included Studies

A systematic review of the medical literature (MEDLINE and EMBASE) was performed using a search strategy for studies examining ultrasound imaging for nerve localization in the pediatric population between 2009 and March 2014 (see Appendix). PRISMA guidelines were followed for the identification, screening, and inclusion of articles for analysis (Fig. 1).

Types of Included Studies

We included meta-analyses, systematic reviews, randomized controlled trials (RCTs), controlled studies without randomization, observational studies, comparative studies, and case series involving at least 10 patients. Case series involving fewer than 10 patients, case reports, letters to editors, and expert reviews were excluded. Landmark imaging studies were used only to demonstrate the feasibility of ultrasonography but not to evaluate evidence for the use of ultrasound in regional anesthesia.

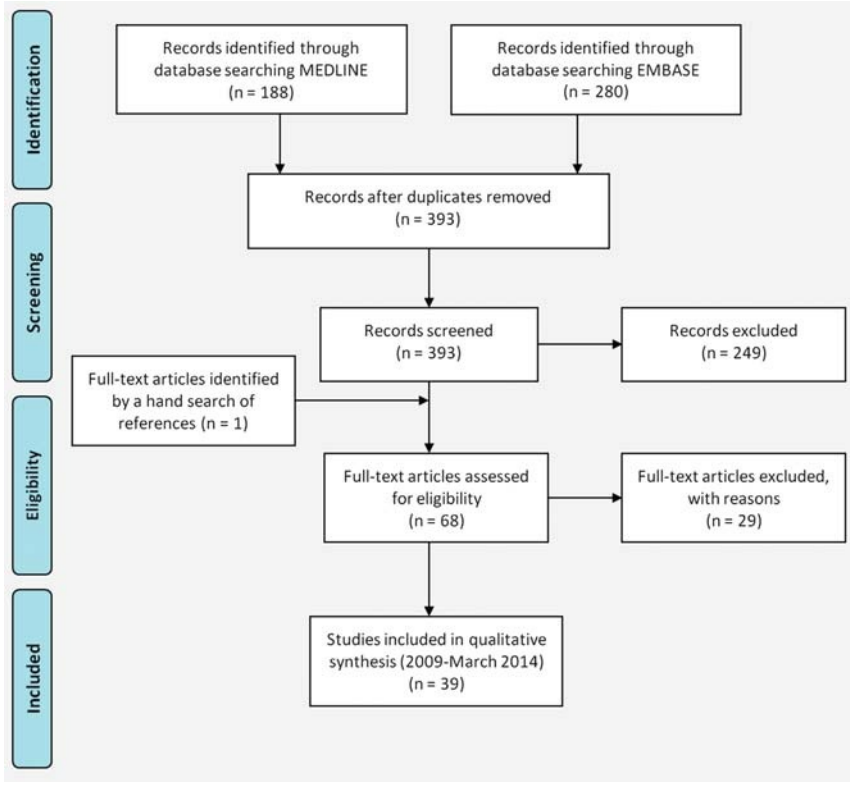

FIGURE 1. PRISMA flow diagram of study selection for the current review (2009–2014).

Outcome Measures

Relevant full-text articles were separated into type of regional anesthesia (peripheral or neuraxial blockade) and subsequently reviewed. For each article, data pertaining to block-related outcomes (block onset, block success, block duration), process-related outcomes (block performance time, local anesthetic dose, local anesthetic spread), and safety-related outcomes (incidence of complications) were extracted and entered into a database (Microsoft Excel, Microsoft Corp, Redmond, Washington). Articles describing the feasibility of ultrasound for visualizing anatomical structures and the needle/catheter were also included.

Methods of the Review

Two reviewers independently screened all abstracts obtained from the searches for potential relevant articles, and the full text of these articles was retrieved for critical appraisal. References of all review articles and full-text articles were examined to ensure that no original research studies were missed. Relevant full-text articles were reviewed independently in duplicate. Any disagreements relating to inclusion of articles was resolved by discussion between the 2 reviewers.

To evaluate the evidence from the full-text articles, Statements of Evidence and Grades of Recommendation (Table 1) developed by the US Department of Health and Human Services Agency for Health Care Policy and Research[2] were assigned to each study. Furthermore, RCTs included in the current review were numerically scored (from 0 to 5) with Jadad scores[3] to assess scientific quality.

RESULTS

A total of 393 abstracts were retrieved from the MEDLINE and EMBASE databases from the initial search, and 67 were

TABLE 1. Statements of Evidence and Grades of Recommendation

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 Recommendation	
A	Requires at least 1 prospective, randomized, controlled trial 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: US Department of Health and Human Services, Agency for Health Care Policy and Research.

TABLE 2. Characteristics of Studies Included in Analysis for Peripheral Nerve Block and Neuraxial Anesthesia

Study	Study Design	Jadad Score	Population	Control Group	Study Group
Peripheral Nerve Blocks					
Alsaeed et al[26]	Case series	N/A	Umbilical hernia repair (n = 22)	N/A	Ultrasound-guided rectus sheath block
Boretsky et al[21]	Retrospective study	N/A	Abdominal or thoracic surgery (n = 22)	N/A	Ultrasound-guided paravertebral perineural catheter placement
De Jose Maria et al[14]	Prospective observational study	N/A	Elective or emergent orthopedic or trauma surgery (n = 85)	N/A	Ultrasound-guided peripheral nerve catheter placement
Dillow et al[19]	Prospective observational study	N/A	Lower limb surgery (n = 19)	N/A	Ultrasound-guided parasacral sciatic nerve block
Dingeman et al[12]	RCT	3	Umbilical hernia repair (n = 52)	Local anesthetic infiltration	Ultrasound-guided bilateral rectus sheath block
Elnour et al[4]	RCT	3	Forearm and hand surgery (n = 40)	Nerve stimulator axillary brachial plexus block	Ultrasound-guided axillary brachial plexus block
Elshaikh et al[5]	RCT	3	Major abdominal surgery for intra-abdominal malignancies (n = 30)	Systemic opioid analgesia	Ultrasound-guided TAP block
Faraoni et al[6]	RCT	2	Male circumcision (n = 40)	Landmark-based dorsal penile nerve block	Ultrasound-guided dorsal penile nerve block
Ford et al[15]	Prospective observational study	N/A	Healthy children undergoing day case surgery (n = 127 ultrasound scans)	N/A	Ultrasound of ilioinguinal and iliohypogastric nerves
Gurnaney et al[7]	RCT	4	Umbilical hernia repair (n = 52)	Local anesthetic infiltration	Ultrasound-guided rectus sheath block
Hong et al[16]	Prospective observational study	N/A	Inguinal surgery (n = 200)	N/A	Ultrasound of ilioinguinal and iliohypogastric nerves
O'Sullivan et al[8]	RCT	4	Male circumcision (n = 64)	Landmark-based dorsal penile nerve block	Ultrasound-guided dorsal penile nerve block
Palmer et al[17]	Prospective observational study	N/A	Abdominal surgery (n = 27)	N/A	Ultrasound-guided TAP block
Ponde et al[9]	RCT	3	Foot surgery (n = 60)	Nerve stimulator sciatic and femoral nerve block	Ultrasound-guided sciatic and femoral nerve block
Ponde et al[10]	RCT	2	Hand surgery (n = 50)	Nerve stimulator infraclavicular brachial plexus block	Ultrasound-guided infraclavicular brachial plexus block
Ponde et al[22]	Case series	N/A	Foot surgery (n = 45)	N/A	Ultrasound-guided sciatic nerve block
Ponde et al[23]	Case series	N/A	Foot surgery (n = 40)	N/A	Ultrasound-guided sciatic perineural catheter placement
Ponde et al[18]	Prospective observational study	N/A	Children aged 2 d to 60 mo (n = 75)	N/A	Ultrasound of paravertebral space
Sahin et al[13]	RCT	2	Inguinal hernia repair (n = 57)	Local anesthetic infiltration	Ultrasound-guided TAP block
Sandeman et al[20]	Retrospective study	N/A	Male circumcision (n = 101)	Landmark-based dorsal penile nerve block	Ultrasound-guided dorsal penile nerve block
Sandeman et al[11]	RCT	4	Laparoscopic appendectomy (n = 93)	Systemic opioid analgesia	Ultrasound-guided TAP block
Sola et al[24]	Case series	N/A	Cleft palate repair (n = 25)	N/A	Ultrasound-guided suprazygomatic maxillary nerve block
Van Geffen et al[25]	Case series	N/A	Lower limb surgery (n = 45)	Ultrasound-guided proximal sciatic nerve block	Ultrasound-guided distal sciatic nerve block
Neuraxial Blockade					
Brenner et al[27]	RCT	3	Penile, anal, or inguinal surgery (n = 75)	N/A	Ultrasound assessment of cranial spread during caudal blockade
Hong et al[32]	Prospective observational study	N/A	Urologic surgery (n = 20)	N/A	Ultrasound assessment of arterial flow after caudal blockade

Continued next page

TABLE 2. *(Continued)*

Study	Study Design	Jadad Score	Population	Control Group	Study Group
Kim et al[36]	Prospective observational study	N/A	Inguinal surgery (n = 80)	N/A	Ultrasound assessment of central anatomy for caudal blockade
Koo et al[33]	Prospective observational study	N/A	Urologic surgery (n = 326)	N/A	Ultrasound assessment of central anatomy for caudal blockade
Koo et al[34]	Prospective observational study	N/A	Children with urogenital anomalies (n = 259)	N/A	Ultrasound assessment of lumbosacral region
Lundblad et al[35]	Prospective observational study	N/A	Subumbilical surgery (n = 50)	N/A	Ultrasound assessment of caudal blockade
Shin et al[28]	RCT	3	Urologic surgery (study 1, n = 317; study 2, n = 162)	Study 1: N/A Study 2: Ultrasound-guided caudal blockade at sacral hiatus	Study 1: Ultrasound assessment of central anatomy for caudal blockade; Study 2: Ultrasound-guided caudal blockade at S2-S3 interspace
Tachibana et al[29]	RCT	1	Nuss procedure (n = 20)	Caudal blockade without ultrasound visualization	Ultrasound visualization before caudal blockade
Triffterer et al[30]	RCT	3	Subumbilical surgery (n = 50)	Ultrasound assessment of cranial spread of caudal blockade (0.25 mL/s)	Ultrasound assessment of cranial spread of caudal blockade (0.5 mL/s)
Tsui et al[37]	Prospective observational study	N/A	Any surgical, urological, or orthopedic procedure, or ongoing chemotherapy regimen (n = 41)	N/A	Color flow Doppler ultrasound assessment of caudal blockade
Ueda et al[39]	Case series	N/A	Cardiac surgery (n = 13)	N/A	TEE to visualize central anatomy and for placement of epidural catheter
Wang et al[31]	RCT	3	Inguinal surgery (n = 140)	Caudal blockade without ultrasound visualization	Ultrasound-guided caudal blockade
Willschke et al[38]	Prospective observational study	N/A	Pyloromyotomy (n = 20)	N/A	Ultrasound-guided thoracic caudal blockade

selected for full-text review. One additional study was identified from a manual hand search of references from relevant full-text and review articles, leaving a total of 68 abstracts for full-text review. Twenty-nine of these were excluded because they did not meet the inclusion criteria; this left 39 full-text articles for inclusion in the review (Fig. 1).

There were 23 and 13 articles reporting quality and outcomes of ultrasound imaging for the pediatric population in peripheral and neuraxial blockade, respectively (Table 2). From the peripheral nerve block (PNB) set, there were 10 RCTs,[4–13] 6 prospective observational studies,[14–19] 2 retrospective studies,[20,21] and 5 case series[22–26] (Fig. 2). From the neuraxial blockade set, there were 5 RCTs,[27–31] 7 prospective observational studies,[28,32–37] 1 retrospective study,[38] and 1 case series[39] (Fig. 3). One of these articles in the neuraxial blockade set featured both an RCT as well as a prospective observational study.[28] In comparison, our previous review of the use of ultrasound imaging in pediatric regional anesthesia yielded 12 studies each for peripheral and neuraxial anesthesia.[1] We also identified 2 multi-institutional studies evaluating the outcomes of both peripheral and neuraxial regional anesthesia.[40,41] Randomized controlled trials were scored with the Jadad scale; we obtained 1 score of 1, 3 scores of 2, 9 scores of 3, and 3 scores of 4. No RCT had a score of 5 out of 5.

DISCUSSION

Summaries of the outcomes of interest found in the current review are found in Table 2. Statements of Evidence and Grades of Recommendation for each evaluated outcome in the current study are also listed in detail (Tables 3, 4).

Peripheral Nerve Blocks

Block performance time: Ultrasound-guided blocks are quicker to perform than blocks using the nerve stimulation technique (Statement of Evidence Ib, Grade of Recommendation B) *but may require more time to perform when compared with landmark-based techniques* (Statement of Evidence Ib, Grade of Recommendation B).

Our previous report did not identify any studies that compared performance time for ultrasound-guided block placement versus other techniques.[1] Since 2009, there have been an abundance of studies documenting performance time of ultrasound-guided techniques. These likely emerged to evaluate the feasibility and efficacy of the use of ultrasound imaging for pediatric regional anesthesia given its widespread use. There has been a mix of studies reporting both shorter and longer block performance times with the use of ultrasound. Elnour et al[4] compared the use of ultrasound imaging with nerve stimulator for axillary brachial plexus blocks in children listed for forearm and hand surgery and found a significantly shorter block performance time in the ultrasound-guided group (14.55 ± 3.39 vs 16.1 ± 2.24 minutes; $P = 0.035$). Faraoni et al[6] found the combined median time for dorsal penile nerve block and surgery in circumcisions to be significantly shorter in the ultrasound-guided group when compared with the classical landmark method (41.2 [35–50] vs 31.8 [26–39] minutes; $P = 0.001$); however, the block performance time was not measured in isolation. In contrast, O'Sullivan et al[8] found that ultrasound-guided dorsal penile nerve blocks were slower compared with the landmark method (115 [100–136] vs 40 [40–45] seconds; $P < 0.001$) in children listed for circumcision. An RCT comparing the use of ultrasound-guided transversus abdominis plane (TAP)

block to a control group (no TAP block) for laparoscopic appendectomy found the combined mean duration of the procedure (from commencement of anesthesia to arrival in recovery) to be longer in the ultrasound-guided TAP block group (111 vs 97 minutes; $P = 0.03$) because of the time required to perform the block.[11]

These studies suggest that ultrasound guidance hastens block performance time compared with nerve stimulation, but the evidence comparing ultrasound to the landmark method is unclear. The prolonged performance time of ultrasound-guided blocks relative to other means of nerve localization may be confounded by the initial learning effect and the availability (or lack thereof) of anesthesia assistants to help with the blocks. In a study involving a simple phantom, de Oliveira Filho et al[42] reported on subjects requiring 37 and 109 trials to achieve a 95% estimated success rate for maintaining needle visibility and injecting fluid around a simulated target, respectively. Another study by Kim et al[43] reported that, after only 5 trials, there was significant improvement in the quality of injection and the time to successful injection was significantly shortened. This study also found that 50% maximum quality was achieved after 3.6 trials and a plateau in quality after 8.5 trials. In 2 other studies that used olives to mimic cysts, Sites et al[44] reported improved success and accuracy after 6 trials, whereas Baranauskas et al[45] reported subjects requiring only 37 seconds for a successful injection without mistakes after 2 hours of practical training. Niazi et al[46] studied 20 anesthesia residents during their 3-week-long ultrasound-guided regional anesthesia block and found that trends of success were seen earlier in residents who received a 1-hour session on needling and proper hand-eye coordination in addition to didactic lectures compared with residents who received didactic lectures alone (5 vs 7 block attempts). Most studies using simple models suggest that the learning curve for ultrasound-guided blocks is quick but, in true clinical practice, this may not necessarily be the case because different blocks vary in difficulty.

The time potentially saved with the use of ultrasound for PNBs compared with the nerve stimulator technique may be clinically insignificant, especially if absolute differences in block performance time are only a couple of minutes. If time is not clinically relevant, nerve localization should be the method that yields the most favorable outcomes. Although there is some evidence that points toward lengthened overall operating room times with the use of ultrasound-guided blocks, improved patient outcomes with the use of ultrasound-guided blocks must be taken into consideration before dismissing its use. Another point worth mentioning is that regardless of the method of nerve localization, it is evident that PNBs require time to perform. Although this can prolong the patient's perioperative experience, hospitals with a dedicated regional anesthesia block area can reduce overall operating room times by streamlining the operating room flows.

Block onset: There is no new evidence to support that ultrasound-guided blocks reduces the time to onset of sensory anesthesia in all related nerves. Since our last review, we did not identify any new studies that investigated the outcome of reduced onset of sensory block in children.

Block success: Block success is higher with ultrasound guidance compared with the nerve stimulation technique (Statement of Evidence Ib, Grade of Recommendation A) *but is not higher than landmark-based techniques* (Statement of Evidence Ib, Grade of Recommendation B).

Previously, we found that ultrasound guidance does not improve block success rates in upper extremity PNBs when compared with nerve stimulation guidance but does improve the intraoperative block success for truncal PNBs.[1] The current review identified a multitude of studies reporting higher block success rates with ultrasound guidance compared with other conventional techniques. Success with ultrasound guidance was higher than with nerve stimulation guidance for infraclavicular brachial plexus (96% vs 64%; $P = 0.005$)[10] and sciatic and femoral nerve (97% vs 76%; $P = 0.026$) blocks.[9] Elnour et al[4] documented a higher block success in ultrasound guidance compared with nerve stimulation (85% vs 75%) for axillary brachial plexus blocks; however, this difference was not statistically significant ($P = 0.43$). Furthermore, in a prospective observational study of 45 children undergoing foot surgery, it was shown that the success of ultrasound-guided sciatic nerve blocks did not depend on the ability to elicit a motor response using nerve stimulation.[22] In another prospective observational study for 19 children undergoing lower limb surgery, the success rate of an ultrasound-guided parasacral approach to sciatic nerve blockade was 100%.[19] In children listed for circumcision, Faraoni et al[6] reported a 100% block success with ultrasound guidance for dorsal penile nerve blocks compared with a 90% success rate using the landmark technique ($P = 0.5$). In a case series of 40 children receiving an ultrasound-guided sciatic perineural catheter for congenital talipoequinovarus surgery,[23] block success was 97.5%, with only 1 child with inadequate pain relief requiring postoperative rescue analgesia.

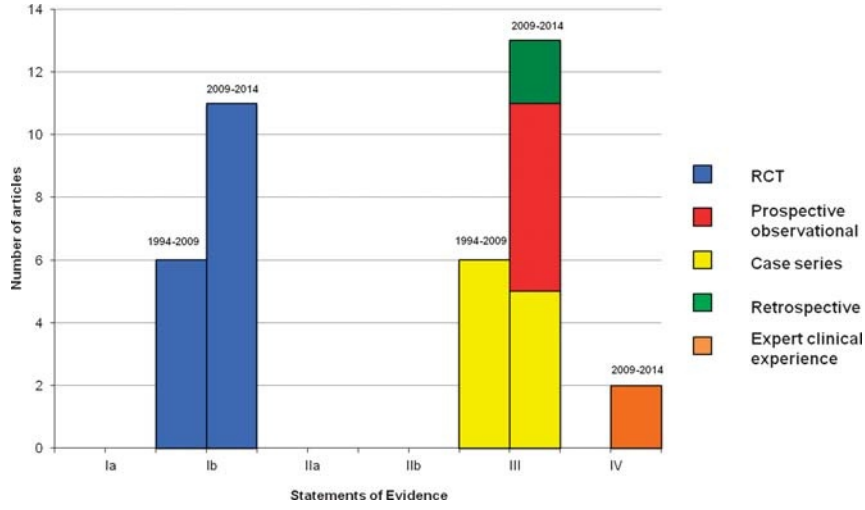

FIGURE 2. Evidence identified from the literature for peripheral nerve blocks.

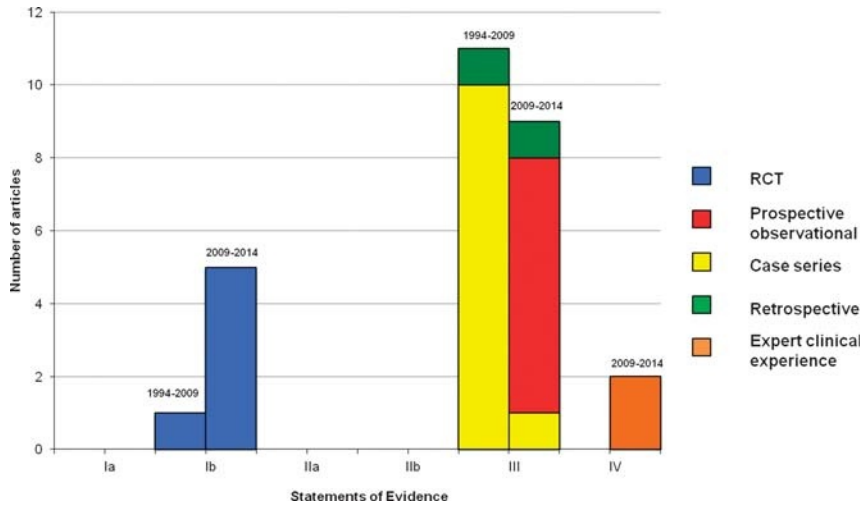

FIGURE 3. Evidence identified from the literature for neuraxial blocks.

Evidence pointing toward increased block success in upper extremity PNBs has emerged, with multiple studies supporting ultrasound guidance compared with nerve stimulation techniques. In addition, new studies have reinforced the use of ultrasound for truncal blocks, and ultrasound is starting to be used in novel situations such as sciatic perineural catheter placement. When regional anesthesia was introduced to the pediatric population, ultrasound-guided blocks were still in an immature stage, and operators were likely relatively inexperienced, as suggested by inconclusive evidence with respect to block success in our previous review.[1] A possible explanation is that operators today have gained experience performing blocks under ultrasound guidance, and these blocks are much more reproducible, resulting in a consistent high rate of success.

Improves block quality (analgesia consumption): Opioid consumption is less in ultrasound-guided blocks when compared with general anesthesia alone (Statement of Evidence Ib, Grade of Recommendation A) *when compared with the landmark technique* (Statement of Evidence Ib, Grade of Recommendation B) *and when compared with local anesthetic wound infiltration* (Statement of Evidence Ib, Grade of Recommendation A). *Analgesia consumption is not different when comparing ultrasound-guided blocks to nerve stimulation* (Statement of Evidence Ib, Grade of Recommendation C).

Intraoperative opioid consumption was significantly less with ultrasound-guided TAP blocks compared with standard care (no TAP block) for children receiving major abdominal surgeries for intra-abdominal malignancies (11.3 ± 17.7 vs 29.7 ± 18.8 μg/kg; $P = 0.01$).[5] When comparing ultrasound-guided dorsal penile nerve blocks, landmark-based dorsal penile nerve blocks, and caudal epidural analgesia in 216 circumcisions, there was a difference in the percentage of patients requiring intraoperative opiates (5.5%, 63%, and 1.7%, respectively; $P < 0.0001$), suggesting less ultrasound-guided block patients required intraoperative opiates compared with the landmark method group (5.5% vs 63%) but similarity to the caudal epidural group (5.5% vs 1.7%).[20] O'Sullivan et al[8] found no difference in the number of patients requiring fentanyl during the intraoperative period and immediately postoperatively when comparing the ultrasound-guided dorsal penile block group with the landmark technique group (29.4% vs 37.5%; $P = 0.663$).

Postoperative opioid consumption in ultrasound-guided blocks was less compared with the landmark method in both dorsal penile nerve blocks (5.9% vs 37.5% requiring codeine; $P = 0.005$)[8] and circumcisions (0.5 ± 2.7 vs 16.9 ± 39.2 μg/kg; $P = 0.0001$).[20] Gurnaney et al[7] documented a trend toward less postoperative opioid consumption in ultrasound-guided rectus sheath block compared with local anesthetic infiltration for umbilical hernia repairs (0.07 mg/kg vs 0.1 mg/kg), but this was not statistically significant ($P = 0.09$). However, there was significantly less opioid consumption in ultrasound-guided rectus sheath blocks compared with local anesthetic infiltration for umbilical hernia repairs during the entire perioperative period (0.07 mg/kg vs 0.13 mg/kg; $P = 0.008$). A case series of children receiving rectus sheath block for umbilical hernia repair also supports a limited need for postoperative opioid consumption—only one of the 22 children required morphine in the postanesthesia care unit (PACU).[26] Multiple RCTs comparing the use of ultrasound-guided PNBs with local anesthetic wound infiltration reported decreased postoperative analgesic consumption after hernia repair in those who received an ultrasound-guided block.[12,13] One of these RCTs reported that children receiving an ultrasound-guided bilateral rectus sheath block for umbilical hernia repair required fewer doses of both opioid and nonopioid medications in PACU when compared with local anesthetic infiltration as a pain control measure.[12] The other RCTs reported less analgesic doses (1.3 ± 1.2 vs 3.6 ± 0.7; $P < 0.001$) and less acetaminophen consumed (19.7 ± 2.8 vs 53.0 ± 6.4 mg/kg; $P < 0.001$) in the first 24 hours in children who received a ultrasound-guided TAP block when compared with wound infiltration for inguinal hernia repair.[13] The only study evaluating analgesia consumption that compared ultrasound guidance with nerve stimulation for infraclavicular brachial plexus blocks for children undergoing radial club hand repair found no difference in analgesia consumption in the 10 hours after surgery.[10] Sandeman et al[11] compared TAP block with no block and found no difference in the proportion of patients requiring more than 200 μg/kg of PCA morphine (69% vs 69%; $P = 0.99$), median morphine consumption between 0 and 8 hours postoperatively ($P = 0.52$), or median morphine consumption between more than 8 and 16 hours postoperatively ($P = 0.19$). The total number of postoperative boluses was less in the ultrasound group compared with the control group (4.7 ± 1.9 vs 1.9 ± 1.3; $P < 0.05$), and total morphine consumed postoperatively was less (3.7 ± 0.9 vs 1.3 ± 0.4 mg; $P < 0.05$).[5]

With respect to analgesia consumption, the use of ultrasound-guided blocks decreases the need for analgesia compared with general anesthesia alone or local anesthetic wound infiltration, but its

TABLE 3. Summary of Evidence for Peripheral Nerve Block Outcomes

Outcome	Block Region/Studies	Key Findings*	Statement of Evidence	Grade of Recommendation
Block performance time	Upper extremity: Elnour et al[4]	• Significantly shorter time compared with NS for axillary block	Ib	B (US vs NS)
	Trunk: Faraoni et al,[6] O'Sullivan et al,[8] Sandeman et al[11]	• US may or may not increase time compared to landmark method for penile block.		B (US vs landmark method)
Visibility of anatomy/ needle/catheter	Facial: Sola et al[24] Lower extremity: Dillow et al,[19] Ponde et al,[23] Van Geffen et al[25] Trunk: Alsaeed et al,[26] Boretsky et al,[21] Ford et al,[15] Hong et al,[16] Ponde and Desai[18]	• Subcutaneous structures, including anatomy, needle, and catheter are generally well visualized under US.	Ib	A (visualization of anatomical structures, needle, and catheter
Local anesthetic spread	Facial: Sola et al[24] Trunk: Palmer et al[18]	• US allows good visualization of local anesthetic spread around nerves and may predict a successful block.	III	B (visualization of local anesthetic spread)
Local anesthetic dose	Trunk: Palmer et al[18]	• No correlation between local anesthetic dose and dermatome level for US-guided TAP block.	III	C (local anesthetic dose and dermatome level)
Block success	Upper extremity: Elnour et al,[4] Ponde and Diwan[10]	• In general, US confers higher block success rates compared to NS.	Ib	A (US vs NS)
	Lower extremity: Dillow et al,[19] Ponde et al, [9,22,23] Trunk: Faraoni et al[6]	• For sciatic nerve blocks, the success of US-guided block does not depend on ability to elicit motor response with NS.		B (US vs landmark method)
Block quality (duration)	Upper extremity: Ponde and Diwan[10] Lower extremity: Ponde et al[9] Trunk: Elkshaikh et al,[5] Faraoni et al,[6] Gurnaney et al,[7] Sahin et al,[13] Sandeman et al,[11,20]	• Time to first analgesia is longer with US-guided blocks.	Ib	A (US vs landmark method, NS, local infiltration)
Block quality (pain)	Upper extremity: Elnour et al[4]	• In general, US-guided blocks provide excellent pain relief (lower Visual Analogue Scale scores) compared to landmark and local infiltration methods.	Ib	A (US vs landmark method, local infiltration)
	Lower extremity: Van Geffen et al[25] Trunk: Dingeman et al,[12] Elkshaikh et al,[5] Faraoni et al,[6] O'Sullivan et al,[8] Palmer et al,[17] Sahin et al,[13] Sandeman et al[11]	• No significant difference in analgesic effect between US and NS for axillary block.		C (US vs NS)
Block quality (opioid consumption)	Upper extremity: Ponde and Diwan[10]	• In general, intraoperative opioid consumption is less with US-guided blocks compared to landmark method and local infiltration.	Ib	A (US vs GA; US vs local infiltration)
	Trunk: Alsaeed et al,[26] Dingeman et al,[12] Elkshaikh et al,[5] Gurnaney et al[7]	• In general, US-guided blocks provide adequate postoperative pain control, but whether it is		B (US vs landmark method)
	O'Sullivan et al,[8] Sahin et al,[13] Sandeman et al[11,20]	superior to NS or landmark methods for certain blocks.		C (US vs NS)

*GA indicates general anesthesia; NS, nerve stimulation; US, ultrasound.

effect on analgesia consumption relative to the landmark technique is not entirely clear. Both ultrasound guidance and the landmark technique may be comparably effective with respect to block quality.

Improves block quality (duration): Ultrasound guidance prolongs block duration when compared with the landmark technique, nerve stimulation technique, and local anesthetic wound infiltration (Statement of Evidence Ib, Grade of Recommendation A).

TABLE 4. Summary of Evidence for Neuraxial Anesthesia Outcomes

Outcome	Studies	Key Findings*	Statement of Evidence	Grade of Recommendation
Block performance time	Tachibana et al,[29] Wang et al[31]	• Needling time shortened when US is used but may extend overall block performance time.	Ib	A (needling time)
Visibility of anatomy/needle/catheter	Kim et al,[36] Koo et al,[33,34] Shin et al,[28] Tachibana et al,[29] Ueda et al[39]	• US allows good visualization of neuraxial structures and age-, weight-, and height-dependent anatomical variations.	III (visualization of anatomical structures and catheter)	B (visualization of anatomical structures and catheter)
		• US can be used to predict skin-to-target distances.	Ib (prediction of epidural depth)	A (prediction of epidural depth)
Local anesthetic spread	Brenner et al,[27] Lundblad et al,[35] Triffterer et al,[30] Tsui et al,[37] Ueda et al[39]	• US allows good visualization of local anesthetic spread, and relationships between cranial spread and factors such as patient age, weight, height, and injection volume/speed can be made.	Ib (visualization of spread)	A (real-time visualization of local anesthetic spread)
		• Methods such as Doppler US and TEE can be used to gain more information about local anesthetic spread.	III (relationship of spread to physical characteristics)	B (correlation of local anesthetic spread and patient physical characteristics)
Block success	Shin et al,[28] Tachibana et al,[29] Wang et al[31]	• US improves success rate of first puncture but not overall success.	Ib	B (US vs LOR)
		• US prescanning may make the block easier to perform.		
Block quality	Willschke et al[38]	• Blocks performed under US guidance provide adequate postoperative pain control.	III	B (sufficient postoperative analgesia)

*LOR indicates loss of resistance; TEE, transesophageal echocardiography; US, ultrasound.

The duration to first analgesia is significantly higher with ultrasound-guided sciatic and femoral nerve blocks compared with nerve stimulation (8.6 ± 0.66 vs 7.6 ± 0.57 hours; $P < 0.001$),[9] but there was no difference in infraclavicular brachial plexus blocks when the 2 techniques were compared.[10] Time to first analgesia was longer with ultrasound-guided TAP block compared with no block (14.1 ± 4.9 hours vs 1.3 ± 1.1 hours; $P < 0.05$),[5] ultrasound-guided TAP block compared with wound infiltration (17 ± 6.8 hours vs 4.7 ± 1.6 hours; $P < 0.001$),[13] and ultrasound-guided dorsal penile nerve blocks compared with the landmark-based technique (570 [360–860] minutes vs 60 [30–300] minutes; $P < 0.0001$).[6]

Other studies were inconclusive and did not demonstrate superiority when using ultrasound for nerve localization. The mean time to first analgesia after ultrasound-guided dorsal penile nerve block compared with the landmark method was not significantly different (132 ± 68 minutes vs 90 ± 76 minutes; $P = 0.2$), but when comparing ultrasound guidance with caudal epidural anesthesia, mean time to first analgesia was shorter for ultrasound guidance (132 ± 68 minutes vs 179 ± 89 minutes; $P = 0.08$).[20] One study involving children receiving laparoscopic appendectomy showed no significant differences in median time to first PCA use between ultrasound-guided TAP block and no block (control) (50 vs 26 minutes, respectively; $P = 0.32$) or mean time to first non-PCA analgesia (483 ± 486 minutes vs 580 ± 416 minutes; $P = 0.33$).[11] Lastly, a comparison between ultrasound-guided rectus sheath block and local anesthetic infiltration showed no difference in time to rescue analgesia (49.7 vs 32.4 minutes; $P = 0.11$).[7]

Based on the current evidence, ultrasound-guided blocks prolong block duration relative to the landmark technique, nerve stimulation technique, and local anesthetic wound infiltration. Given the accuracy of ultrasound imaging when conducting blocks, this is not surprising. There were a few studies reporting nonsignificant results; more studies in the future comparing the effect of ultrasound-guided PNBs with other nerve localization techniques on block duration should lend support to the superiority of ultrasound guidance to other means of nerve localization.

Improves block quality (pain): Ultrasound-guided nerve blocks provide excellent pain relief when compared with the landmark technique (Statement of Evidence Ib, Grade of Recommendation A) *and local anesthetic wound infiltration* (Statements of Evidence Ib, Grade of Recommendation A) *but may not be superior to nerve stimulation* (Statements of Evidence Ib, Grade of Recommendation C).

In the recovery room, pain was significantly less in patients who received an ultrasound-guided block compared with the landmark-based technique (modified OPS scores were significantly higher in the landmark-based group at arrival to the PACU [$P < 0.01$] and at 30 minutes [$P < 0.01$]),[6] local anesthetic wound infiltration,[12,13] or no block.[5,11] In dorsal penile nerve blocks, O'Sullivan et al[8] found no difference between ultrasound guidance and landmark technique in initial pain scores during emergence from general anesthesia (0 [0–3.8] vs 0 [0–5.8]; $P = 0.483$). Faraoni et al[6] found no difference in the incidence of severe pain (defined as modified OPS >5) (5% vs 30%; $P = 0.083$). Although neither was significant, these results suggest that pain is managed equally as well with ultrasound-guided blocks, if not better than the traditional gold standard landmark technique, in patients undergoing circumcision.

In a case series of 45 proximal subgluteal and distal sciatic nerve blocks for lower limb surgery, excellent pain relief (Visual Analogue Scale score <4) was achieved with ultrasound guidance.[25] In axillary brachial plexus blocks for forearm and hand surgery, sensory block duration was longer with ultrasound guidance compared with nerve stimulation guidance (29.4% vs 33.3% experienced pain within the first 12 hours postoperatively), but there was no significant difference in the analgesic effect between the block techniques at 2-hour intervals up until 12 hours postoperatively.[4]

Given the increasing popularity of using TAP blocks in children, Palmer et al[17] prospectively audited 27 TAP blocks to determine the extent of dermatomal block. The anterior supra-iliac ultrasound-guided approach reliably produced lower abdominal sensory blockade of 3–4 dermatomes, however, only 25% of children had upper abdominal block extension (median upper and lower dermatomal levels of sensory block to ice of T10 and L1).

Recent evidence demonstrates that ultrasound-guided blocks suppress pain satisfactorily when compared with the landmark method or local anesthetic wound infiltration, although ultrasound-guidance may not be superior to nerve stimulation.

Local anesthetic spread: Local anesthetic spread can be visualized with ultrasound-guidance (Statement of Evidence III, Grade of Recommendation B)

There was limited evidence documenting the ability of ultrasound imaging to visualize local anesthetic spread in PNBs. A case series of ultrasound-guided suprazygomatic maxillary nerve blocks for cleft palate repair in children concluded that ultrasound allows good visualization of local anesthetic spread (spread seen in 94% of cases).[24] Palmer et al[17] prospectively audited the use of ultrasound-guided TAP block and found no significant correlation between dermatomal block spread and dose, volume, or concentration, although this study was limited by a small sample size.

Local anesthetic dose: Limited evidence suggests that there is no correlation between local anesthetic dose and number of dermatomes blocked for TAP blocks (Statement of Evidence III, Grade of Recommendation C).

One observational study investigated the effect of local anesthetic dose in TAP blocks and found no significant correlation between dose, volume, and concentration to the number of dermatomes blocked (Spearman correlation coefficient, 0.31; $P = 0.19$).[17] Usually, 3 to 4 dermatomes were blocked to sensation to ice (median, 3). Because the evidence from these results is limited, they must be interpreted carefully. Because TAP blocks are performed at various locations depending on the study, the number of dermatomes blocked may depend on the site of injection as well as other factors, such as operator experience and local anesthetic. Local anesthetic volume can affect the number of dermatomes blocked, and the limited evidence reported here should not be used as justification for using smaller volumes, particularly for large surgeries.

Visualization of anatomical structures, needle, and catheter: Ultrasound guidance allows for visualization of anatomical structures, needle, and catheter (Statement of Evidence Ib, Grade of Recommendation A).

Ultrasound imaging allows for accurate identification of nerves as well as important anatomical structures[15,19,25,26] and can aid in the placement of the needle/catheter.[21,25] Three studies[21,23,24] reported being able to visualize the needle tip in all patients, and 1 study[23] reported visualization of the catheter tip in 73% of sciatic perineural catheter placements in children listed for congenital talipoequinovarus surgery. Boretsky et al[21] was able to confirm the positioning of thoracic paravertebral perineural block catheters with ultrasound guidance. Ultrasound imaging can even detect differences in anatomical structure that are dependent on age and/or weight: 1 observational study found an age-dependent significant difference in anterior-superior iliac spine (ASIS)-ilioinguinal/iliohypogastric nerve distance,[16] and another was able to derive formulas for predicting distances from the spine-to-needle insertion point and from insertion point to the paravertebral space at the thoracic (T1-T12), lumbar (L1), and cervical (C6) levels based on age and weight in children up to 5 years of age.[18] Ultrasound imaging has allowed the ultrasonographer to reliably visualize peripheral structures and the needle/catheter when placing PNBs in children.

Other Comments

De Jose Maria et al[14] described a "3-hand technique" for ultrasound-guided placement of peripheral nerve catheters in children listed for orthopedic or trauma surgery and found that all catheter placements were 100% effective during surgery and provided analgesia for 3 days or longer without any complications. A third hand was used to hold the ultrasound probe in the long-axis view, permitting the operator to withdraw or rotate the needle and allow for threading of the catheter until resistance is met. In the future, there may be evidence establishing the clinical efficacy and relevance of this 3-hand technique not only for continuous catheter placements but for other regional anesthesia techniques as well.

Neuraxial Anesthesia

Block performance time: Neuraxial needling time is shorter when ultrasound is used (Statement of Evidence Ib, Grade of Recommendation A).

Previously, we did not identify any studies reporting block performance time in neuraxial anesthesia with the use of ultrasound guidance.[1] In the current review, we identified 1 study[29] that compared ultrasound-guided epidural blocks with epidural blocks in the absence of ultrasound scanning and 1 study[31] that compared ultrasound-guided caudal block by sacral hiatus injection with traditional sacral canal injection. In the former study, Tachibana et al[29] found a shorter needling time in the ultrasound group compared with the control group (100 [77–116] seconds vs 165 [130–206] seconds; $P = 0.001$). Although the time to perform the epidural itself was shorter with ultrasound prescanning, the scan to visualize neuraxial structure took a median of 133 (115–154) seconds, a considerable amount of time that, when combined with the epidural block, took longer than performing the epidural without the prescan. In the latter study, Wang et al[31] reported shorter block performance duration with the use of ultrasound guidance (145 ± 23 seconds vs 164 ± 31 seconds; $P < 0.05$) but did not comment on the duration of time for the scan itself. From a feasibility perspective, LOR is still the most commonly used means to confirm needle placement in neuraxial blockade, and the use of ultrasound scanning may not be necessary. However, the clinical relevance of the time differences when ultrasound is or is not used is questionable. Many regional anesthesiologists would likely be willing to accept a few extra minutes' time to ensure proper catheter location and spread of local anesthetic. In fact, the added time at the beginning of the procedure may save time in the long run by enhancing safety and efficiency of the block.

Block success: Ultrasound imaging of neuraxial structure allows the operator to perform blocks more easily but does not necessarily increase block success (Statement of Evidence Ib, Grade of Recommendation B).

As with block performance time, our previous review did not identify any studies reporting neuraxial block success under ultrasound guidance. In the current review, an RCT comparing caudal block by sacral hiatus injection with traditional sacral canal

injection for inguinal hernia repair showed that the success rate on first puncture was higher with ultrasound guidance (92.8% vs 50%; $P < 0.05$), but the overall success rate was similar in both groups (92.8% vs 95.7%; $P > 0.05$).[31] In an RCT comparing thoracic epidural blocks for Nuss procedures with or without an ultrasound prescan, the number of epidural puncture attempts was lower in the prescan group compared with the control group without the prescan (1 [1–2] vs 2 [1–3] attempts; $P = 0.14$).[29] The lack of statistical significance may be caused by a small sample size (n = 10 in each group). The same study evaluated difficulty in performing epidural blocks by having the operator assign a difficulty score from 0 to 5 (1 = very easy; 5 = very difficult). Operators found blocks significantly more difficult in the absence of a prescan (4 [3–4] vs 2 [1–2]; $P < 0.001$). Shin et al[28] compared 2 ultrasound-guided caudal block approaches—one involving the commonly used sacral hiatus and the other involving the S2-S3 interspace. The first epidural puncture attempt success rate was higher when injecting at the S2-S3 interspace compared with the hiatal approach (96.2% vs 77.5%; $P < 0.05$); however, the overall success rate between the 2 was the same (96.3%). As needle placement and block success are dependent on the operator's ability to detect LOR with tactile means, ultrasound scanning of neuraxial structure may not necessarily improve the success rate of neuraxial blocks.

Local anesthetic spread: Ultrasound imaging allows real-time visualization of local anesthetic spread in neuraxial blockade (Statement of Evidence Ib, Grade of Recommendation A), *and caudal spread has an inverse relationship to physical characteristics such as age, weight, and height* (Statement of Evidence III, B).

There were a number of studies that assessed direct visualization of caudal local anesthesia spread using ultrasound during neuraxial blockade.[27,30,35,37,39] Brenner et al[27] used ultrasound to show correlations between injectate volume (0.7, 1.0, or 1.3 mL/kg) and cranial spread during caudal blockade. There were significant positive correlations between 1.3 mL/kg and 0.7 mL/kg ($P = 0.0002$) as well as 1.3 mL/kg and 1.0 mL/kg ($P = 0.03$); however, the observed differences were small and did not allow for a reasonable prediction of a volume–cranial extension relationship. Lundblad et al[35] used ultrasound imaging to show a significant inverse relationship with regard to age ($r_s = -0.5325$; $P = 0.0001$), weight ($r_s = -0.5104$; $P = 0.0002$), and height ($r_s = -0.5326$; $P = 0.0001$) and maximum cranial spread after caudal blockade. Triffterer et al[30] compared cranial spread of 2 injection speeds of local anesthetic (0.5 mL/s vs 0.25 mL/s) under ultrasound guidance in children receiving caudal blockade for subumbilical surgery and found no significant difference in the level of cranial spread ($P = 0.2$) or distance of spread relative to the conus medullaris in the epidural space. In a prospective observational study of children undergoing a surgical procedure or ongoing a chemotherapy regimen, Tsui et al[37] found that color flow Doppler ultrasound could be used to successfully distinguish epidural injection from intrathecal injection. Finally, Ueda et al[39] presented a novel technique involving the use of transesophageal echocardiography (TEE) for guidance and placement of thoracic epidural catheters in 12 infants undergoing cardiac surgery. This method allowed for 3-dimensional visualization of local anesthetic spread.

Recent studies have used the benefits of ultrasound imaging in neuraxial blockade to evaluate the cranial spread of local anesthetic with varying interventions (injectate volume, injectate speed) or parameters (age, weight, height). Furthermore, novel forms of ultrasound imaging such as TEE can be applied to pediatric neuraxial anesthesia because of its relatively medial position in relation to other structures in the body.

Visualization of anatomical structures and catheter: Ultrasound imaging can detect variations in anatomical structure and visualize the catheter during neuraxial blockade (Statement of Evidence III, Grade of Recommendation B) *as well as predict epidural depth* (Statement of Evidence Ib, Grade of Recommendation A).

In an observational study of children scheduled for postoperative caudal or epidural block, ultrasound evaluation of the effect of body position on the end of the dural sac showed significant cephalad shifts in dural sac position in the lateral flexed position (S2-middle when neutral and S2-upper when flexed; $P < 0.001$).[33] In another observational study, ultrasound allowed for visualization of the sacral hiatus, which offers benefits relative to the equiangular triangle landmark technique, because the position of the sacral hiatus can vary based on patient age, weight, and height.[36] One study used ultrasound imaging to examine spinal structures and determine the prevalence of spinal dysraphism in children with urogenital anomalies.[34] Children suspected of spinal cord tethering showed a lower level of conus medullaris and thicker filum terminale when compared with the normal group. Evidence suggests that ultrasound imaging enables sufficient visibility of structures accurately enough to detect anatomical variations dependent on body positioning or age, weight, and height. One study briefly mentioned being able to visualize the catheter and caudal spread of local anesthetic in thoracic-placed epidural catheters using TEE.[39]

Using the longitudinal paramedian view of ultrasound imaging for thoracic epidural blocks, Tachibana et al[29] found a significant correlation between needle depth and ultrasound estimation of the skin-dura distance ($r = 0.98$; $P < 0.001$). Using ultrasound imaging, Shin et al[28] was able to reveal significant differences in the depth of the sacral space at S2-S3 when compared with the sacral hiatus ($P < 0.05$). These results suggest that ultrasound scanning can allow the operator to predict distance from the skin to target neuraxial spaces.

Block quality: Epidural blocks are sufficient at providing analgesia (Statement of Evidence III, Grade of Recommendation B).

Only 1 study commented on the quality of neuraxial blocks in children. Willschke et al[38] retrospectively described the performance of ultrasound-guided thoracic epidural blocks for 20 infants with hypertrophic pylorus stenosis. Ultrasound-guided single-shot epidural blocks provided sufficient analgesia (OPS, <5) in all infants after pyloromyotomy surgery. They were also stable with respect to heart rate and oxygen saturation intraoperatively. A likely explanation for the paucity of studies evaluating analgesia control is that the use of ultrasound imaging in neuraxial anesthesia does not affect neuraxial block quality—detection of the catheter in the epidural space can be detected clearly by tactile means (LOR) before injection of local anesthetic.

Other Comments

Ultrasound imaging has not only been used to assist neuraxial blocks, but its application has been extended to other uses such as measuring acute changes in peripheral arterial flow patterns in limbs after neuraxial block. A prospective observational study evaluating peripheral hemodynamic changes with ultrasonography after caudal block in children receiving general anesthesia detected increases in dorsalis pedis artery peak velocity (24%), flow volume (76%), and the diameter (20%).[32]

Safety and Complications: Pediatric regional anesthesia has a low incidence of adverse events and complications (Statement of Evidence IV, Grade of Recommendation B).

Although we did not identify any studies that focused exclusively on safety and complication rates of ultrasound-guided

pediatric anesthesia, we did identify 2 large-scale prospective studies describing the incidence of complication rates in pediatric regional anesthesia.[40,41]

Polaner et al[41] created a centralized database to collect prospective data on 14,917 blocks performed at 14 participating centers in the United States. Although a subanalysis on the use of ultrasound for regional blocks was not performed, it was mentioned that only 3% of single-injection caudal blocks were performed with ultrasound guidance. In contrast, 82% of single-injection upper extremity PNBs, 70% of single-injection lower extremity blocks, and 61% of other single-injection blocks (eg, intercostal, ilioinguinal/iliohypogastric, rectus sheath, paravertebral, penile, TAP) were placed under ultrasound guidance. The percentage of adverse events (not limited to ultrasound-guided blocks) in each of these single-shot PNB groups was 2%, 1%, and 0.3%, respectively. Ultrasound was used as a localizing technique in 3% of continuous neuraxial blocks, 92% of continuous upper extremity blocks, and 64% of continuous lower extremity blocks. Adverse events in each of these groups were 18%, 23%, and 18%. Catheter problems (including dislodgement, kinking, or malfunction) were responsible for approximately one third of all postoperative adverse events.

Ecoffey et al[40] reported on 1 year of prospective data on the epidemiology and morbidity of pediatric regional anesthesia at 47 participating institutions in France, Belgium, Canada, Italy, Switzerland, and Tunisia. There were a total of 31,132 regional block procedures. Central neuraxial blocks (of these, 80% were caudal blocks, 11% were lumbar epidural blocks, and 3% were spinals and thoracic epidural blocks) were responsible for 34% of all regional anesthesia, and PNBs accounted for 66% (of these, 71% were face blocks, 10% were upper limb blocks, and 19% were lower limb blocks). The overall incidence of complication (not limited to ultrasound-guided blocks) was 0.12%, which was six times higher for central blocks compared with peripheral blocks.

It would seem intuitive that the use of ultrasound imaging for pediatric regional anesthesia would decrease the incidence of complications because of the ability to perform the block under direct guidance, but there are limited studies documenting the safety profile of regional anesthesia in the pediatric population. Although this warrants further investigation, the necessity of large-scale prospective studies, usually across multiple institutions, makes this a difficult undertaking.

CONCLUSIONS

Since our last assessment, there has been an increase in literature evaluating the use of ultrasound imaging in pediatric regional anesthesia. More evidence was found in the area of PNBs relative to neuraxial anesthesia. Compared with our previous review of 1994 to 2009, the evidence identified in the current review (2009–2014) is reassuring because there are more studies in a shorter period and studies have shifted from those with lower Statements of Evidence to higher Statements of Evidence. Furthermore, many important outcomes that lacked strength in evidence or were not previously investigated have now been reported with stronger evidence. The years from 1994 to 2009 contain the transition period when pediatric ultrasound-guided anesthesia became prominent; earlier studies were composed of mostly case series and few controlled trials, but, in recent years, published studies have evolved to mostly RCTs and prospective observational studies. These have allowed for more concrete conclusions regarding our outcomes of interest to be drawn.

Implications for Practice

In the period since our last review, credible evidence for the use of ultrasound guidance in PNBs has increased, especially with ultrasound being applied to new types of peripheral blocks. The evidence for neuraxial anesthesia has not progressed as much relative to peripheral anesthesia—likely because LOR remains the most accurate means of confirming needle/catheter placement in the epidural space. It is also worth mentioning that evidence surrounding the use of ultrasound imaging for TAP blocks for abdominal surgeries and the novel use of TEE for neuraxial anesthesia has emerged. In conclusion, the increase in evidence during the past few years reflects the efficacy and adoption of ultrasound imaging in pediatric regional anesthesia.

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APPENDIX
MEDLINE and EMBASE Search Strategy

1. exp Ultrasonography/
2. ultrasound.mp.
3. 1 or 2
4. exp Anesthesia/
5. exp Analgesia.
6. 4 or 5
7. neuraxial.mp.
8. caudal.mp.
9. epidural.mp.
10. subarachnoid.mp.
11. spinal canal/mp.
12. nerve.mp.
13. block.mp.
14. regional.mp.
15. 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14
16. 3 and 6 and 15
17. limit 16 to yr="2009-Current"
18. limit 17 to (humans and "all children [0–18 years]")

Evidence Base for the Use of Ultrasound for Upper Extremity Blocks
2014 Update

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Abstract: This article reviews and summarizes randomized, controlled studies that have assessed ultrasound (US) guidance for brachial plexus blocks in comparison with other nerve localization methods as well as those that have compared different US-guided brachial plexus block techniques. Both PubMed and EMBASE databases were searched using the MeSH terms *anesthetic technique*, *brachial plexus*, and *ultrasound*. Studies were included if they had randomized allocation comparing US with another conventional nerve localization technique or if they compared 2 different US-guided techniques, such as single versus multiple injections. Each study was classified as a categorical outcome as being supportive, unclear, or negative for the use of US. These were compared with χ^2 analysis with the null hypothesis that US provides no benefit for brachial plexus blocks. Forty-seven studies met the inclusion criteria, and 29 compared US guidance to landmark or peripheral nerve stimulation techniques. Our analysis of the literature supports the use of US over other nerve localization techniques as being beneficial for several block performance outcomes including block performance time, reducing the number of needle passes and the incidence of vascular puncture, shortening sensory block onset time, and improving block success.

(*Reg Anesth Pain Med* 2016;41: 242–250)

WHAT'S NEW

In the last review, grade A recommendations supporting the use of US for brachial plexus block included faster sensory block onset and greater block success. However, grade A recommendations can now be made for the following outcomes: (1) faster block performance, (2) fewer needle passes, (3) reduced incidence of vascular puncture, (4) faster sensory block onset, and (5) greater block success.

The past decade has seen ultrasound (US) guidance become the de facto guidance modality for peripheral nerve blockade (PNB) and, in particular, upper extremity PNB. Anatomical landmarks, paresthesia, or nerve stimulation techniques have varying success rates (60%–95%) and were typically the domain of specialized centers. Real-time ultrasonographic visualization of peripheral nerves, needle placement, and local anesthetic spread has allowed a greater number of anesthesiologists to have confidence to provide the opioid sparing and analgesic benefits of regional anesthesia (RA).

The advantages of US guidance are multiple and typically grouped under the term "block success." The definition of "block success," however, is variable as demonstrated in a recent review.[1] For example, there are few data to suggest that specific acute pain outcomes are improved by US guidance when PNB is successful.[2] The difference, however, may be in block success rates for nonexperts. Initial estimates of the incidence of nerve injury associated with PNB ranged from 0.34 to 2.84 per 100 PNBs when US guidance was not used[3]; however with US guidance becoming more common, estimates are as low as 0.4 per 1000 PNBs.[4] A randomized trial with nerve injury as the primary outcome would require a prohibitively large sample size and is unlikely to be performed highlighting the minimal risk of nerve injury associated with PNB regardless of nerve localization technique.[5] Most of the trials comparing US guidance with other nerve localization modalities focus on technical or procedural-related outcomes and less serious complications such as vascular puncture. These include metrics such as block performance time or proportion of patients achieving surgical anesthesia. In our last article, these outcomes were examined qualitatively because the varying outcomes and techniques used preclude any formal quantitative analysis. The aim of this article was to provide an update of the evidence published in the last 4 years and provide anesthesiologists with data and recommendations regarding the benefits of US guidance for brachial plexus block techniques.

METHODS

Search Strategy

PubMed and EMBASE were searched (between August 2009 and June 2013) using the following MeSH terms: *anesthetic techniques*, *brachial plexus*, and *ultrasound*. Inclusion criteria were randomized trials comparing US guidance to any other established nerve localization technique for brachial plexus block or randomized trials comparing 2 different US-guided techniques. References of eligible articles were manually searched to identify studies not found in the electronic search. Studies were excluded if they only compared different volumes of local anesthetic or if a comparison group was not used (case reports or series). Letters to the editor, abstracts, and non–peer-reviewed studies were also excluded. Previously identified studies from the report in 2010 (literature search to August 2009) were included.

The 2 authors independently performed the literature search and assessed all identified full text articles for inclusion. The method of the study including randomization, blinding, and follow-up were scored according to the method described by Jadad and colleagues.[6] Specific study characteristics and outcomes sought included the following: brachial plexus block technique, volume, type and concentration of local anesthetic, type of surgery, performance time or number of needle passes, block onset, block success (requirement for supplemental local or general anesthesia), procedure-related pain, and other adverse effects. Studies were classified supportive for US if any of the previously measured outcomes demonstrated a statistically significant difference between groups in favor of US guidance, unclear if no difference was observed, or negative if the non–US group was superior. For the specific outcome of performance time, the study was

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TABLE 1. Randomized Studies Comparing US Techniques With an Existing End Point (Landmark, Paresthesia, or PNS)

Author	Jadad Score	Block Type	n	Study Type	Nerve Localization Method	Local Anesthetic	Major Findings	Authors' Conclusions
Danelli et al[8]	2	ISB	50	R, SB	US vs PNS for ISB catheter	1% ropivacaine, 20 mL	US faster block performance (5 vs 8 min; $P = 0.01$) and US fewer vascular puncture ($P = 0.041$)	US better
Salem et al[7]	1	ISB	60	R	US/PNS vs PNS	1% prilocaine, 30 mL	No observed differences	No benefit of US/PNS over PNS alone
McNaught et al[11]	5	ISB	40	R, DB, U/D	US vs PNS	0.5% ropivacaine, variable dose	US fewer needle passes (1 vs 3; $P < 0.0001$), US reduced pain ($P = 0.003$), US reduced MEAV (0.9 vs 5.4 mL; $P = 0.034$)	US better
Thomas et al[9]	2	ISB	41	R, SB	US vs PNS	1.5% mepivacaine, 20 mL + 0.75% ropivacaine, 20 mL, epinephrine 5 μg/mL	US faster block performance (4.3 vs 10 min; $P = 0.003$) and faster onset (12 vs 19 min; $P = 0.02$)	US better
Strub et al[10]	2	AXB	141	R	US vs anatomical landmark	2% mepivacaine, 15 mL + 0.5% bupivacaine, 15 mL	US greater block success ($P = 0.0003$) and faster onset (10 vs 30 min; $P < 0.0001$)	US better
Mariano et al[12]	3	ISB	40	R	US vs PNS for ISB catheter	1.5% mepivacaine, 40 mL + epinephrine 5 μg/mL	US faster block performance (8 vs 14 min; $P = 0.02$)	US better
Fredrickson et al[18]	3	ISB	72	R	US vs PNS for ISB catheter	0.5% ropivacaine, 30 mL 0.2% ropivacaine 2 mL/h	US faster block performance (49 vs 97 s; $P < 0.0001$), reduced procedure-related pain ($P = 0.002$), fewer catheter manipulations (7 vs 14; $P = 0.007$), and reduced tramadol consumption ($P = 0.04$)	US better
Mariano et al[16]	2	ICB	40	R	US vs PNS for ICB catheter	1.5% mepivacaine, 40 mL + epinephrine 5 μg/mL	US faster block performance (9 vs 15 min; $P < 0.01$), greater block success (100% vs 70%; $P < 0.01$), fewer vascular puncture (0% vs 30%; $P < 0.01$)	US better
Morros et al[15]	2	AXB	129	R	US/PNS vs PNS	1% mepivacaine, 40 mL	US/PNS longer performance time (350 vs 291 s; $P < 0.05$), fewer vascular puncture (8% vs 28%; $P < 0.01$), improves block quality ($P < 0.05$)	No difference
Conceicao et al[19]	2	AXB	40	R	US vs PNS	0.5% ropivacaine, 40 mL	US reduced vascular puncture (4% vs 32%, $P < 0.05$)	No difference

(Continued next page)

TABLE 1. *(Continued)*

Author	Jadad Score	Block Type	n	Study Type	Nerve Localization Method	Local Anesthetic	Major Findings	Authors' Conclusions
Liu et al[17]	3	ISB	219	R	US vs PNS	1.5% mepivacaine, 45–55 mL + epinephrine	US fewer needle passes (1 vs 3; $P < 0.001$) and faster motor onset ($P = 0.04$)	US better
Brull et al[20]	5	ICB	103	R, DB	US vs dual end point PNS	0.5% bupivacaine, 15 mL + 2% lidocaine, 15 mL	US greater surgical readiness at 20 min (85 vs 65%; $P = 0.04$) and faster block performance (5 vs 10.5 min; $P < 0.001$)	US better
Ponde and Diwan[14]	4	ICB	50	R, DB	US vs PNS	0.5% bupivacaine, 0.5 mL/kg	US greater block success (96% vs 64%; $P = 0.0053$)	US better
Taboada et al[13]	3	ICB	35	R, SB	US vs PNS (radial end point)	1.5% lidocaine, 40 mL	US shorter procedure time (3 vs 6 min; $P < 0.0001$)	US better
Sauter et al[22]	3	ICB	80	R, SB	US cranioposterior to axillary artery with 1 to 3 injections vs single injection PNS	1.5% mepivacaine 0.6 mL/kg + epinephrine 2.5 μg/mL	US fewer needle passes (1 vs 3; $P < 0.001$).	No difference
Dhir and Ganapathy[26]	3	ICB	66	R	Nonstimulating catheter with PNS; stimulating catheter with PNS; US + PNS catheter	1.5% mepivacaine, 40 mL + epinephrine 2.5 μg/mL	US greater primary (96 vs 58%) and secondary (91% vs 83%; $P < 0.001$) block success	US better
Macaire et al[23]	2	Wrist	59	R, SB	US vs PNS for median and ulnar nerve block at wrist	1.5% mepivacaine 4 mL/nerve	PNS faster block onset. Overall no difference for block performance + onset time	No difference
Gurkan et al[25]	3	ICB	80	R, SB	US/PNS vs PNS lateral sagittal ICB	0.5% levobupivacaine 20 mL + 2% lidocaine 20 mL	Faster block performance in PNS compared to US/PNS group (6.4 vs 7.2 min; $P < 0.05$)	PNS better
Kapral et al[24]	2	ISB	160	R, SB	US vs PNS	0.75% ropivacaine, 20 mL	US greater surgical anesthesia (99% vs 91%; $P < 0.01$) and prolonged duration (899 vs 679 min; $P < 0.05$)	US better
Tran de et al[21]	1	ICB AXB	70	R	US ICB vs PNS AXB	0.5% bupivacaine, 17.5 mL + 2% lidocaine, 17.5 mL + epinephrine 2.5 μg/mL	US ISB faster (3.9 vs 8 min; $P < 0.001$) and reduced procedural pain (2.7 vs 42; $P = 0.01$)	US better
Yu et al[27]	3	AXB	80	R	US vs PNS	0.75% ropivacaine + 2% lidocaine, 32 mL	US faster performance (5.2 vs 14.6 min; $P = 0.000$), greater success (100% vs 77.5%; $P = 0.005$) and less vascular puncture (0 vs 40%; $P = 0.000$)	US better

Chan et al[29]	5	AXB	188	R, DB	PNS vs US vs US/PNS	2% lidocaine + 0.5% bupivacaine + epinephrine 5 μg/mL , 42 mL (14 mL/nerve)	US faster block performance (9.3 vs 11.4 min; $P < 0.01$) comparing US vs PNS groups. Greater block success in US (82.8%) and US/PNS (80.7%) groups compared to PNS alone (62.9%; $P = 0.03$)	US better
Casati et al[30]	3	AXB	60	R, SB	Injection of all 4 nerves by US or PNS	0.75% ropivacaine, 20 mL	US fewer needle passes (4 vs 8; $P = 0.002$) and shorter sensory block onset (14 vs 18 min; $P = 0.01$)	US better
Dingemans et al[28]	2	ICB	72	R	US vs US/PNS	1.5% lidocaine + 0.25% bupivacaine, 0.5 mL/kg	US alone faster performance (3.1 vs 5.2 min; $P = 0.006$), US alone greater success (86 vs 57%; $P = 0.007$)	US alone better
Sites et al[31]	3	AXB	56	R, SB	US perivascular vs transarterial	1.5% lidocaine, 30 mL	US greater success (100% vs 71%; $P < 0.01$) and faster performance (7.9 vs 11.1 min; $P < 0.05$)	US better
Soeding et al[32]	1	ISB AXB	40	R	US vs anatomical landmark	0.75% ropivacaine for ISB; 0.6% ropivacaine for AXB, 3 mL/kg	US better sensory block ($P = 0.01$), motor block ($P = 0.002$), and less paresthesia ($P = 0.01$)	US better
Liu et al[33]	2	AXB	90	R, SB	PNS 2 injection vs US 2 injections vs US 1 injection	1.5% lidocaine + epinephrine 5 μg/mL, 0.5 mL/kg	US shorter procedure time (6.7 vs 8.2 min; $P < 0.01$) and fewer complications (0% vs 20%; $P = 0.03$)	US better
Marhofer et al[34]	3	ICB	40	R, SB	US lateral approach vs PNS	0.5% ropivacaine, 0.5 mL/kg	US less procedural pain ($P = 0.03$), faster sensory onset (9 vs 15 min; $P < 0.001$), and prolonged block in US group (384 vs 310 min; $P < 0.001$)	US better
Williams et al[35]	2	SCB	80	R	US/PNS vs PNS (perivascular approach)	0.25% ropivacaine + 1% lidocaine, 0.5 mL/kg (max 40 mL)	US shorter procedure time (5 vs 9.8 min; $P = 0.0001$)	US better

DB indicates double blind; ISB, interscalene block; MEAV, minimal effective analgesic volume; R, randomized; SB, single blind; U/D, up/down dose finding study.

TABLE 2. Studies That Compared One US Technique Against Another for Upper Extremity Block

Author	Jadad Score	Block Type	n	Study Type	Method	Local Anesthetic	Major Findings	Conclusion
Bernucci et al[38]	5	US AXB	50	R, DB	US-guided perivascular vs perineural (3 nerves)	1.5% lidocaine + epinephrine 5 μg/mL, 32 mL	Perineural requires more time (15.7 vs 8.2 min; $P < 0.0001$), requires more needle passes ($P = 0.0001$), more paresthesia ($P = 0.001$), fewer vascular puncture ($P = 0.01$)	Perineural requires more performance time, but shorter onset with no difference in block success
Roy et al[37]	5	US SCB	102	R, DB	Single vs double injection SCB	1.5% mepivacaine, 30 mL	Single injection shorter procedural time (179 vs 275 s; $P < 0.0001$) and fewer needle passes (10 vs 23; $P = 0.02$)	No difference between techniques
Tran de et al[36]	3	US AXB	120	R	Double vs triple vs quadruple injection	1.5% lidocaine + epinephrine 5 μg/mL, 35 mL	Double injection required fewest needle passes ($P < 0.001$)	No difference between techniques
Subramanyam et al[39]	5	US SCB	80	R, SB	Lateral vs medial approach	2% lidocaine, 15 mL + 0.5% bupivacaine + epinephrine 5 μg/mL, 15 mL	No difference between techniques	Equivalent techniques
Bowens et al[44]	1	US/PNS ICB	218	R	Central (posterior cord) vs peripheral (lat/med cord) target	1% mepivacaine/0.25% bupivacaine, 30–40 mL	Central target, longer procedure time (11 vs 9 min; $P = 0.26$), higher block success (96 vs 85%; $P = 0.004$), reduced procedural pain ($P = 0.012$)	Central target more difficult, but "better" block
Frederiksen et al[42]	3	US ICB US AXB	80	R, SB	ICB (single injection) vs AXB (each nerve)	0.75% ropivacaine + epinephrine 5 μg/mL, 0.5 mL/kg	ICB faster (3.8 vs 5.8 min; $P < 0.0001$) and fewer needle passes ($P < 0.001$)	No significant differences between techniques
Fredrickson et al[41]	3	US ICB	100	R, SB	Single vs triple injection	2% lidocaine, 30 mL	Single injection faster (111 vs 158 s; $P = 0.002$), greater success ($P = 0.04$)	Single injection superior to triple injection
Imasogie et al[40]	2	US/PNS AXB	120	R, DB	Double vs quadruple injection	0.5% ropivacaine, 40 mL	Double injection faster (7.86 vs 10.95 min; $P = 0.03$)	Double injection better because faster
De Tran et al[43]	3	US ICB	88	R	Single vs double injection	1.5% lidocaine + 5 μg/mL epinephrine, 35 mL	Double injection less procedural pain (1.1 vs 2.1; $P = 0.021$)	No difference between techniques
Desgagnes et al[49]	5	US ICB	100	R, SB	Single vs triple injection	1.5% mepivacaine, 30 mL	Single injection faster (124 vs 185 s; $P < 0.01$)	Single injection better because faster

Tran de et al[46]	4	US SCB	92	R, SB	Single vs double injection	1.5% lidocaine + epinephrine 5 μg/mL, 35 mL	Single injection faster procedure (11.2 vs 14.6 min; $P = 0.03$) but longer block onset (21.2 vs 17.5 min; $P = 0.021$)	No difference between techniques
Koscielniak-Nielsen et al[47]	3	US ICB vs US SCB	120	R, SB	US SCB vs US ICB	0.75% ropivacaine + 2% mepivacaine, 0.5 mL/kg	ICB greater block success (93% vs 78%; $P = 0.017$) and less diaphragm paresis (0 vs 7; $P < 0.0001$) than SCB	ICB better than SCB
Tran de et al[45]	2	US SCB vs US ICB vs US AXB	120	R, SB	Perivascular spread technique for all blocks	1.5% lidocaine, 35 mL	AXB longer procedure duration (8.5 vs 6–6.2 min; $P < 0.008$) SCB greater incidence of Horner syndrome (37.5% vs 0–5%; $P < 0.001$)	No difference
Fredrickson et al[48]	4	US SCB vs US ICB	60	R, DB	US SCB (corner pocket) vs ICB (triple-point injection)	2% lidocaine, 30 mL (25 mL for <65 kg)	ICB greater surgical anesthesia (93% vs 67%; $P = 0.01$)	ICB better than SCB due to better ulnar coverage
De Jose Maria et al[50]	2	US SCB vs US ICB	80	R	SCB (in plane) vs ICB (out of plane) in children under GA	0.5% ropivacaine, up to 0.5 mL/kg	No difference in block success in SCB vs ICB (95% vs 88%; $P = 0.39$)	No overall difference
Arcand et al[51]	3	US/PNS ICB vs US SCB	80	R	US/PNS group target PNS <0.6 mA	0.5% bupivacaine 0.5% + 2% lidocaine (1:3), 0.5 mL/kg, max 40 mL	Greater supplementation required for ICB (18% vs 0%) ($P = 0.006$) for radial distribution	SCB better than ICB
Kapral et al[52]	1	US SCB vs US AXB	40	R	Lateral paravascular SCB approach	0.5% bupivacaine, 30 mL + radio-opaque dye, 10 mL	Greater anesthesia in SCB group due to missed musculocutaneous nerve in AXB group	SCB better than AXB

DB indicates double-blind; ISB, interscalene block; R, randomized; SB, single blind.

classified as supportive for US only if it was directly stated that US scan time was included in block performance time. If this was not explicitly stated, the study was classified as unclear.

A χ^2 analysis was undertaken for each specific outcome with the null hypothesis that US guidance offered no benefit over other nerve localization techniques. The outcomes were classified as categorical variables (supportive, unclear, or negative) and no attempt was made at meta-analysis because of the widely divergent techniques and definitions of outcomes. The outcomes were defined according to the individual authors' definitions of the outcomes and their subsequent conclusions. In addition, a grade of recommendation was assigned based on the number of studies supporting individual outcomes according to the United States Agency for Health Care Policy and Research.

RESULTS

Forty-seven studies met the inclusion criteria and are detailed in Tables 1 and 2. Twenty-nine studies compared US against another nerve localization method,[7–35] of which 10 were published since the first iteration of this article.[7–12,15,16,18,19] Seventeen studies compared 2 (or more) different US-guided approaches,[36–52] with 11 new articles published since August 2009.[36–44,46,49] The median Jadad score for included articles was 3. Five studies had a score of 1, 15 studies a score of 2, 17 studies a score of 3, 3 studies a score of 4, and 7 studies a score of 5.

Studies Comparing US with Another Nerve Localization Technique

Most of the studies (22 of 29) concluded that US guidance was beneficial for upper extremity brachial plexus block (Table 1). These conclusions were based on several different outcomes and demonstrated superiority for US guidance including shorter block performance time,[8,9,12,13,16,18,20,21,27–29,31,33,35] fewer needle passes,[11,17,22,27,30] reduced incidence of vascular puncture,[8,15,16,19] increased proportion of patients with "block success" as defined by surgical anesthesia,[10,14–16,18,20,21,24,26–29,31,32,34] reduced procedural pain,[18,21,34] and more rapid sensory/motor onset.[9,10,17,23,30,34] Five studies concluded that there were no differences between nerve localization techniques.[7,15,19,22,23] Although these studies concluded that US offered no overall benefit compared with peripheral nerve stimulation (PNS), several demonstrated reduced vascular puncture,[15,19] fewer needle passes,[22] and improved block "quality."[15] A single study examining infraclavicular block (ICB) concluded PNS was superior to US guidance with respect to block performance time.[25]

A χ^2 analysis suggests that US guidance offers benefits over other nerve localization techniques for faster block performance time ($P = 0.015$), fewer needle passes ($P = 0.018$), less vascular puncture ($P = 0.001$), shorter sensory block onset ($P = 0.008$), and greater block success ($P = 0.001$).

Studies Comparing Different US-Guided Brachial Plexus Blocks

In the previous iteration of this paper, 6 studies compared US-guided supraclavicular block (SCB) versus ICB, or axillary block (AXB) and concluded that each specific technique had benefits and drawbacks with no technique that was clearly superior.[53] An additional 11 studies comparing different US-guided techniques have been published in the intervening period (Table 2). These studies have again compared SCB, ICB, and AXB but rather than comparing different blocks have compared single versus multiple injection techniques of the same specific US-guided block. All demonstrated that procedural time was shorter with injection techniques involving fewer targets (ie, single vs double or double vs quadruple).

DISCUSSION

Since the original literature review published in 2010, an additional 14 studies have been published comparing US guidance with other nerve localization techniques for brachial plexus blocks. Among the 29 studies included, 22 demonstrated significant benefit for the use of US guidance in at least one of the surrogates for block performance or quality. These included faster performance time, fewer needle passes, fewer vascular punctures, faster sensory onset, and greater success. On the basis of the number of studies supporting each outcome, the recommendation that US guidance is superior to other nerve localization methods can be made for the 5 outcomes discussed previously. Previously, supportive recommendations were made only for faster sensory onset and block success.[53]

TABLE 3. Recommendations for Individual Outcomes Comparing US Against Other Nerve Location Methods for Upper Extremity Block (Randomized Studies Only)

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

Grades of recommendation: A, good evidence (level I studies with consistent finding) for or against recommending intervention; B, fair evidence (level II or III studies with consistent findings) for or against recommending intervention; C, poor quality evidence (level IV or V studies) for or against recommending intervention; I, insufficient or conflicting evidence not allowing a recommendation for or against intervention.

*Four studies that were unclear[13,27,28,35] demonstrated faster block performance time with US but did not define whether prescan time was included.

†Two of the negative studies compared PNS vs PNS and US.[15,23] Macaire et al demonstrated faster performance time for each nerve but no difference was found when total block time was evaluated (including scan time).

‡Study by Macaire et al[23] where faster onset time in the PNS group was associated with intraneural injection.

For the specific outcome of block performance time, 14 studies were clearly supportive,[8,9,11,12,16–18,20–22,29–31,33] 6 were unclear,[7,10,13,27,28,35] and 3 studies were negative.[15,23,25] Of the 6 unclear studies, 4 actually concluded that US guidance was faster,[13,27,28,35] but the decision was made to downgrade the results from supportive to unclear because it was not clear if authors had included scanning time in block performance time. Among the 3 negative studies, all used combined US and PNS guidance compared with PNS alone. Longer block performance time associated with combined US/PNS guidance was previously postulated to be a result of operator distraction and/or false-negative responses that occur with PNS in an attempt to seek both end points and seems to be a continuing theme.[29] Conversely, studies using only US guidance were overwhelmingly favorable for US guidance.

Regarding studies comparing different US guidance techniques, it is clear that fewer injections reduce block performance time and number of needle passes. This is unsurprising. However, authors' specific interpretation of the shorter procedural time associated with fewer injections varied with 7 concluding that US guidance was superior and thus recommended,[40,41,47–49,51,52] whereas the remaining 10 concluded that these differences did not merit a recommendation of superiority.[36–39,42–46,50]

Several themes are apparently based on the current literature review. The concept of statistical versus clinical superiority and the subjectivity of that designation are highlighted. Individual clinicians must decide whether the degree of time saving offered by US guidance or varying injection techniques is worthwhile in their particular clinical setting. Conversely, reduced vascular puncture is an outcome that most clinicians will agree is beneficial regardless of magnitude.

There are limitations of this review and of the included studies inherent to their method. First, the effects of the operators' level of expertise may have been variable. This is especially so for those studies where blocks were performed by both residents and consultant staff and this may have introduced bias particularly with block performance time. At the present time, no high-quality randomized studies exist that examine the learning of US by novices alone and this area needs further investigation. Second, additional bias may have been introduced by the fact that the same individuals performed both types of blocks, US guidance and the comparator. Investigators may unintentionally have been biased toward a particular outcome and this may have affected the overall results. In the early stages of RA research, an argument could be made for expertise-based randomization,[54] but this is not feasible with modern regional anesthetic practice as the use of US guidance now predominates practice. Third, data regarding complications with US guidance are sparse and significantly limit any conclusions that can be drawn. Adverse outcomes need to be examined by good quality studies across many more patients than have currently been examined in the relatively small randomized studies discussed here.

Ultrasound guidance is only one component of successful and safely performed brachial plexus block. Vigilance is even more important as US guidance allows even closer needle to nerve proximity and a false sense of security from being able to visualize neural structures may paradoxically result in more injury as practitioners aim to be more precise in local anesthetic deposition. Preexisting basic rules of safe RA practice remain very important and proper training, anatomical knowledge, and meticulous technique including slow injection of local anesthetic with regular syringe aspiration and maintenance of verbal contact with the patient.

Ultrasound-guided brachial plexus block techniques demonstrate several advantages (Table 3) when compared with preexisting nerve location methods. Importantly, there is no evidence to suggest that US may be inferior to other techniques.

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Lumbar Neuraxial Ultrasound for Spinal and Epidural Anesthesia
A Systematic Review and Meta-Analysis

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Background: This systematic review examines the evidence for preprocedural neuraxial ultrasound as an adjunct to lumbar spinal and epidural anesthesia in adults.

Methods: We searched MEDLINE, EMBASE, and Cochrane Central Register of Controlled Trials databases from inception to June 30, 2014, for randomized controlled trials (RCTs) and cohort studies that reported data answering one or more of the following 3 questions: (1) Does ultrasound accurately identify a given lumbar intervertebral space? (2) Does ultrasound accurately predict the needle insertion depth required to reach the epidural or intrathecal space? (3) Does ultrasound improve the efficacy and safety of spinal or lumbar epidural anesthesia?

Results: Thirty-one clinical trials and 1 meta-analysis were included in this review. Data from 8 studies indicate that neuraxial ultrasound can identify a given lumbar intervertebral space more accurately than by landmark palpation alone. Thirteen studies reported an excellent correlation between ultrasound-measured depth and needle insertion depth to the epidural or intrathecal space. The mean difference between the 2 measurements was within 3 mm in most studies. Thirteen RCTs, 5 cohort studies, and 1 meta-analysis reported data on efficacy and safety outcomes. Results consistently showed that ultrasound resulted in increased success and ease of performance. Ultrasound seemed to reduce the risk of traumatic procedures but there was otherwise insufficient evidence to conclude if it significantly improves safety.

Conclusions: There is significant evidence supporting the role of neuraxial ultrasound in improving the precision and efficacy of neuraxial anesthetic techniques.

What's New: We know that neuraxial ultrasound is a useful complement to clinical examination when performing lumbar central neuraxial blocks. It provides anatomical information including the depth of the epidural space, the identity of a given intervertebral level, and the location of the midline and interspinous/interlaminar spaces. This information can be used to successfully guide subsequent needle insertion.

Since 2010, new data from RCTs and 1 meta-analysis suggest that neuraxial ultrasound increases the success and reduces the technical difficulty of lumbar central neuraxial blocks. Findings from the meta-analysis suggest that neuraxial ultrasound reduces the risk of traumatic procedures, and thus may possibly contribute to the safety of lumbar central neuraxial blocks.

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Spinal anesthesia and lumbar epidural anesthesia are commonly performed anesthetic and/or analgesic techniques with a long track record of efficacy and safety. However, neuraxial blocks can occasionally be challenging to perform, particularly if the spinal anatomy is altered or obscured by factors such as obesity, spinal deformities, or previous spine surgery.[1] Technical difficulty can result in procedural failure, suboptimal epidural analgesia, and increased needle trauma. It may also increase the risk of both minor complications such as postdural puncture headache and backache and major complications including epidural hematoma and spinal cord injury.[2–4]

Neuraxial ultrasound is a recent development in the field of regional anesthesia. A "pre-procedural" ultrasound examination of the spine accurately delineates the underlying relevant anatomy, thus aiding in successful insertion of a spinal or epidural needle; this has also been termed "ultrasound-*assisted*" neuraxial blockade. Although real-time ultrasound-*guided* spinal and epidural techniques have been described, they are distinctly different from the ultrasound-*assisted* approach. They remain experimental at this time and will not be discussed in this review.

The objective of this review was to examine the evidence supporting the use of preprocedural neuraxial ultrasound to facilitate spinal or lumbar epidural anesthesia and, based on this, to set forth recommendations for practice. We addressed 3 distinct clinical questions:

1) Does neuraxial ultrasound accurately identify a given lumbar intervertebral space?
2) Does neuraxial ultrasound accurately predict the needle insertion depth required to reach the epidural or intrathecal space?
3) Does neuraxial ultrasound improve the efficacy and safety of spinal or epidural anesthesia?

METHODS

For this review, we included all randomized controlled trials (RCTs) and cohort studies involving neuraxial ultrasound and spinal or lumbar epidural anesthesia/analgesia in adult patients. We also included studies involving diagnostic lumbar puncture, given that the needle insertion technique is identical to that of spinal anesthesia. We excluded studies of real-time ultrasound-guided neuraxial blocks as well as those related to interventional pain procedures on the spine. Studies that did not report outcomes related to the 3 primary questions were excluded. We performed a literature search of the MEDLINE, EMBASE, and Cochrane Central Register of Controlled Trials databases from the time of inception until June 30, 2014. The following search terms were used: ultrasound, ultrasonography, epidural, peridural, subarachnoid space, epidural analgesia, epidural anesthesia, spinal anesthesia, and conduction anesthesia. No language restrictions were applied. The abstracts of all references identified by the search were independently reviewed by 2 authors. Full text copies of potentially relevant studies were obtained and again underwent independent review

by 2 authors. Data from studies that met the inclusion criteria were entered into a standardized data extraction form. All disagreements were resolved by discussion and mutual consensus among the 3 authors of this review. We performed a risk of bias assessment for each study. The QUADAS-2 tool[5] was used for studies of diagnostic accuracy of neuraxial ultrasound in identifying lumbar intervertebral spaces. We used the Jadad score[6] and the Cochrane Collaboration's risk of bias assessment tool for RCTs[7] looking at the effect of neuraxial ultrasound on clinical outcomes.[7] We performed meta-analysis using RevMan 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2014). The treatment effect was expressed as risk ratio for dichotomous outcomes and as mean difference (MD) for continuous data outcomes, respectively, along with 95% confidence intervals (CIs). Statistical heterogeneity was assessed using both the χ^2 test and I^2. The studies that reported on the correlation of the ultrasound-determined depth of the epidural or intrathecal space versus needle insertion depth underwent meta-analysis using R software (version 2.15.3). Fisher *z*-transformation was applied to the Pearson product moment correlation coefficients before meta-analysis. The final results of pooled *z* scores were back-transformed to the pooled correlation coefficients.

Summary recommendations follow the format suggested by the US Department of Health and Human Services Agency for Health Care Policy and Research.[8] We followed the reporting recommendations of the PRISMA statement.[9]

RESULTS

Seven hundred six citations were identified in the initial search of which 57 were selected as potentially relevant and underwent full-text review (Fig. 1). Of these, we excluded 25 studies for the following reasons: 9 were narrative reviews or descriptive articles, 6 were in the pediatric population, 6 involved interventions on the thoracic or cervical spine, and 4 were case reports. One meta-analysis was identified and included in this review.[10]

Does Neuraxial Ultrasound Accurately Identify a Given Lumbar Interspace?

Eight studies[11–18] involving a total of 624 patients addressed this question (Table 1). All 8 studies used a "counting-up" approach in which the ultrasound probe was placed in a longitudinal orientation over the sacrum (identified as a continuous hyperechoic line) and then moved cephalad to identify successive spinous processes or laminae and the corresponding interspinous or interlaminar spaces.[19] A low-frequency curved-array probe was used in all studies except one.[16] These 7 studies were generally of good quality according to the QUADAS-risk of bias assessment tool for diagnostic studies, with only 2 studies receiving a "high" rating in one domain each. Five studies examined the agreement between ultrasound and palpation of surface landmarks in identifying a given intervertebral space.[13–15,17,18] None of these studies, however, verified accuracy against a more

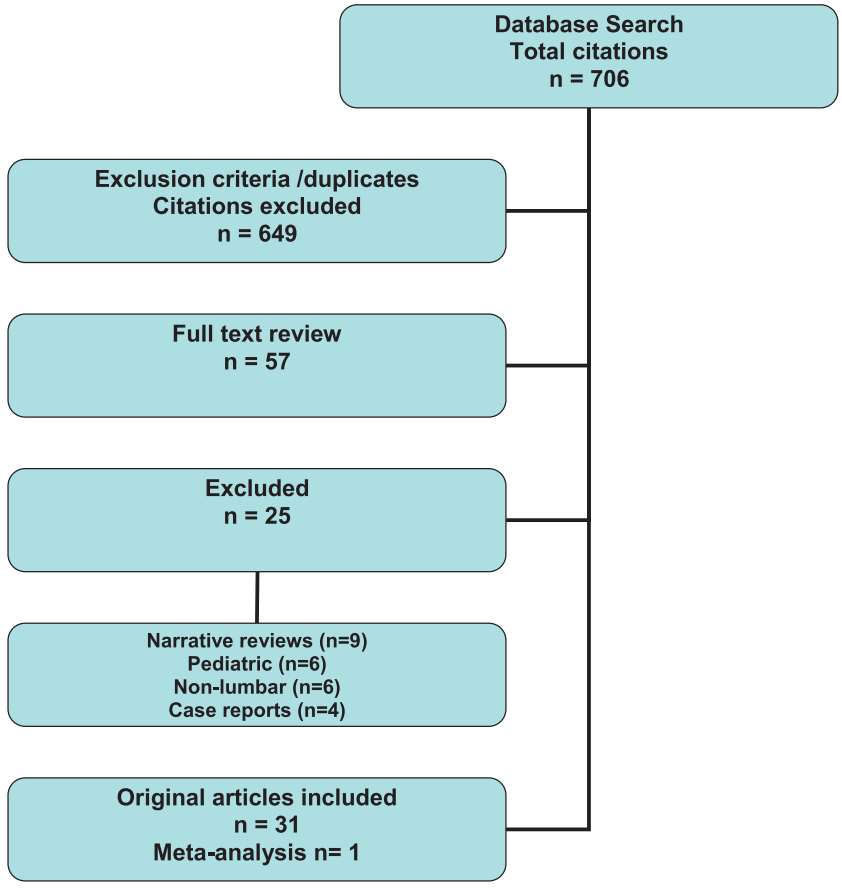

FIGURE 1. Flow chart of database search and study selection.

TABLE 1. Studies Reporting Accuracy of Intervertebral Space Identification

Author	Year	Country of Origin	n	Separate Reference Standard	Primary Outcome	Main Findings
Furness	2002	United Kingdom	50	X-ray	Accuracy L3-4	Ultrasound 71% accurate Palpation 30% accurate
Duniec	2013	Poland	122	Palpation	Agreement	64% agreement 18% higher by palpation by 1 level 0.8% higher by palpation by 2 levels 16.4% lower by palpation by 1 level 0.8% lower by palpation by 2 levels
Halpern	2010	Canada	74	CT scan	CUSUM analysis for 90% accuracy	90% accuracy after 22 and 36 scans
Lee	2011	United States	51	Palpation	Agreement	14% agreement 23% higher by palpation by 1 level 25% higher by palpation by >1 level
Locks	2010	Brazil	90	Palpation	Agreement at L3-4	50% agreement
Schlotterbeck	2008	United Kingdom	99	Palpation	Agreement	36% agreement 50% higher by palpation 14% lower by palpation
Watson	2001	United Kingdom	17	MRI	US accuracy at L3-4	76.5% accuracy (13/17) 23.5% off by 1 level
Whitty	2008	Canada	121	Palpation	Agreement	55% agreement 32% higher by palpation

established gold-standard imaging modality (the reference standard). Schlotterbeck et al[15] and Whitty et al[17] both studied a retrospective cohort of patients who had received labor epidural analgesia and in whom the documented level of epidural insertion was correlated with ultrasonographic identification of the intervertebral level corresponding to the visible skin puncture site. They excluded patients with multiple puncture marks or who had inadequate documentation of epidural insertion site. For these reasons, they received a "high" risk of bias rating in the "flow and timing" domain of the QUADAS-2 tool. In all 5 studies, the agreement between ultrasound and palpation-determined interspaces was generally poor with rates ranging from 14% to 64%. In cases of disagreement, palpation-determined landmarks were usually higher than ultrasound-determined landmarks (52%–78% of cases) and often erred by more than one interspace.

The remaining 3 studies used x-ray, magnetic resonance imaging (MRI), or computed tomographic (CT) scan as a separate reference standard to verify intervertebral level.[11,12,16] Using plain x-ray of the lumbar spine as a reference standard, Furness et al[11] demonstrated that ultrasound correctly identified individual interspaces (from L2-3 to L4-5) 71% of the time, whereas palpation was only correct 29% of the time. Furthermore, the margin of error never exceeded one level with ultrasound, but was up to 2 spaces higher or lower in 27% of palpation assessments. These findings are consistent with those reported by Watson et al[16] who, using MRI as their reference standard, found that ultrasound accurately identified the L3-4 interspace in 76% of cases with a margin of error that did not exceed one level. Finally, in a learning curve study that used CT as a reference standard, Halpern et al[12] reported an overall identification accuracy rate for ultrasound of 68%. However, analysis of the learning curve showed that the 2 anesthesiologists in the study with no previous experience with neuraxial ultrasound achieved accuracy rates of 90% or greater after 22 and 36 procedures, respectively.

Recommendation

There are consistent data (evidence level IIa) to suggest that neuraxial ultrasound identifies lumbar intervertebral levels, with greater accuracy than palpation of surface anatomical landmarks (grade B recommendation).

Does Neuraxial Ultrasound Accurately Predict the Needle Insertion Depth Required to Reach the Epidural or Intrathecal Space?

Thirteen studies involving a total of 875 patients examined the correlation between ultrasound-measured depth and actual needle insertion depth required to reach the epidural or intrathecal space (Table 2).[20–32] Nine studies were performed in obstetric patients,[20,21,23,24,27–29,31,32] 3 in non–obstetric surgical patients (urology, vascular, and orthopedics),[22,26,30] and 1 in patients requiring a diagnostic lumbar puncture in the emergency department.[25] The quality of the studies was generally good, with the most common deficiency being unclear patient selection criteria. Two studies[30,32] received a "high" risk of bias rating in the reference standard domain because of lack

TABLE 2. Studies Reporting Accuracy of Ultrasound Measurement of Epidural Space Depth

					Bland-Altman Analysis				
Author	Year	Country of Origin	Sample Size (n)	Pearson CC (*r*)	Mean, mm	SD, mm	LOA (95% CI), mm	Patients	Structure Evaluated
Arzola	2007	Canada	61	0.88	0.1	3.5	−6.6 to 6.9	Obstetrics	LF-D complex
Balki	2009	Canada	48	0.84	3.0		−7.0 to 13.0	Obstetrics	LF-D complex
Chin	2009	Canada	50	0.82	2.1		−8.5 to 12.7	Orthopedics	LF-D complex and PVB
Cork	1980	United States	36	0.98				Obstetrics	Lamina
Currie	1984	United Kingdom	75	0.96				Obstetrics	Lamina
Ferre	2009	United States	39	0.80				ER patients for LPs	LF-D complex
Gnaho	2012	France	31	0.98	2.2	1.8	−1.4 to 5.8	Orthopedics	LF-D complex
Grau AAS	2001	Germany	36	0.93	7.9			Obstetrics	LF-D complex
Grau RAPM	2001	Germany	80	0.96	2.0	2.3	−3 to 7	Obstetrics	LF-D complex
Grau	2002	Germany	150	0.91	1.7		−6.0 to 8.0	Obstetrics	LF-D complex
Helayel	2010	Brazil	60	0.66	0.04	0.1	−2.3 to 2.2	Orthopedics, urology, vascular	LF-D complex
Tran	2009	Canada	20	0.89	−4.8		−14.8 to 5.2	Obstetrics	LF-D complex
Vallejo	2010	United States	189	0.91				Obstetrics	LF-D complex

of blinding (ie, the anesthesiologist performing the epidural procedure was aware of the ultrasound-measured depth to the epidural space) (Table 3). The Pearson correlation coefficient reported by the individual studies ranged from 0.66 to 0.98.[23,26,30] The pooled Pearson product moment correlation coefficient was 0.91 (95% CI, 0.87–0.94), using a random-effects model to account for heterogeneity, suggesting the ultrasound-measured depth of the epidural space was highly correlated with the depth of the epidural space measured during the epidural needle insertion (Fig. 2). Four studies measured depth to the epidural space using a longitudinal parasagittal oblique ultrasound view[23–25,31]; 3 of these studies also used a linear-array probe.[23–25] All other studies used a low-frequency curved-array probe and measured depth to the epidural/intrathecal space in the transverse midline ultrasound view. A midline approach was used for needle insertion in all studies. The ultrasound landmark used for measuring depth to the epidural space in most studies was the ventral aspect of the hyperechoic ligamentum flavum-dura mater complex (Table 2). The older studies by Cork et al and Currie measured depth to the ventral surface of the laminae; this choice, however, reflects the technological limitations of ultrasound visualization at the time. Despite these minor variations in method, there was excellent correlation between ultrasound-measured depth and actual needle insertion depth in all studies. It should be noted, however, that a strong linear correlation does not necessarily imply accuracy. To evaluate the accuracy of the ultrasound measurement, 8 of the more recent studies also performed a Bland-Altman analysis to study the extent to which the 2 depth measurements differed.[20–23,28–31] The ultrasound-determined depth of the

TABLE 3. Risk of Bias Assessment of Studies Reporting the Accuracy of Epidural Space Depth

			Risk of Bias				Applicability Concerns		
Author	Year	Country of Origin	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Arzola	2007	Canada	Low	Low	Low	Low	Low	Low	Low
Balki	2009	Canada	Low	Low	Low	Low	Low	Low	Low
Chin	2009	Canada	Low	Low	High	Low	Low	Low	Low
Cork	1980	United States	Unclear	Low	Low	Low	Low	Low	Low
Currie	1984	United Kingdom	Unclear	Low	Low	Low	Low	Unclear	Low
Ferre	2009	United States	Low	Low	Low	Low	Low	Low	Low
Gnaho	2012	France	Unclear	Low	Low	Low	Low	Low	Low
Grau AAS	2001	Germany	Low	Low	Unclear	Low	Low	Low	Low
Grau RAPM	2001	Germany	Unclear	Low	Low	Low	Low	Low	Low
Grau	2002	Germany	Unclear	Low	Low	Low	Low	Low	Low
Helayel	2010	Brazil	Unclear	Low	High	Low	Low	Low	Low
Tran	2009	Canada	Unclear	Low	Low	Low	Low	Low	Low
Vallejo	2010	United States	Low	Low	High	Low	Low	Low	Low

Risk of bias assessment as per the Cochrane Collaboration's tool.[7]

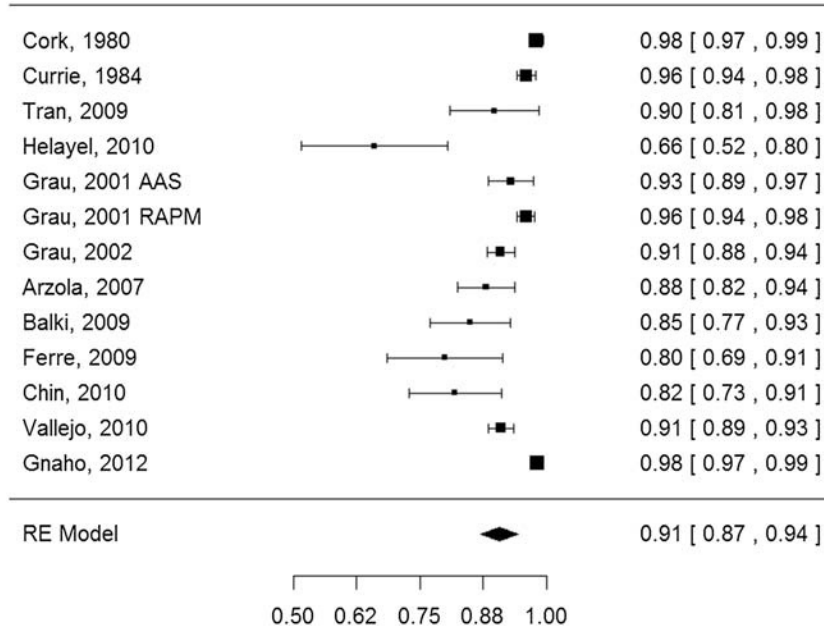

FIGURE 2. Meta-analysis of studies reporting the correlation of ultrasound-measured versus needle depth of the epidural or intrathecal space.

epidural or intrathecal space was found to be accurate within 1 to 13 mm of actual needle insertion depth, with 7 of the 8 studies reporting an MD of less than or equal to 3 mm. The tendency in most studies was for ultrasound to underestimate needle insertion depth; this has been attributed to tissue compression by the probe during the scan.

Recommendation

Data from 13 prospective comparative studies (evidence level Ia) consistently show that preprocedure neuraxial ultrasound can be used to accurately predict the needle insertion depth required to reach the epidural or intrathecal space (grade A recommendation).

Does Neuraxial Ultrasound Improve the Efficacy or Safety of Neuraxial Techniques?

Fourteen RCTs involving 1768 patients[27–29,32–42] (Table 4) and 5 prospective cohort studies involving 227 patients[20–22,25,26] examined efficacy and safety outcomes. Eight RCTs[27–29,32,34,36,38,42] and 2 cohort studies[20,21] evaluated epidural analgesia in obstetric patients, whereas 3 RCTs[33,37,39] and 2 cohort studies[22,26] evaluated spinal anesthesia in orthopedic procedures. The remaining 3 RCTs[35,40,41] and 1 cohort study[25] each evaluated diagnostic lumbar punctures by emergency physicians. Three RCTs[27,33,36] and 1 cohort study[21] enrolled only patients in whom technical difficulty was expected due to obesity,[21,27,33,36] documented lumbar scoliosis,[33] or previous lumbar spine surgery.[33] The risk of bias assessment showed the RCTs to be of reasonable quality, with the commonest deficiency being lack of blinding of the patient and study personnel (Figs. 3 and 4), a limitation that is often difficult to overcome in procedural studies of this nature.

Thirteen RCTS that reported the risk of technical failure were meta-analyzed (Fig. 5). The combined risk ratio of technical failure was 0.51 (95% CI, 0.32–0.80) when ultrasound guidance was used compared to palpation. In addition, meta-analysis from 8 RCTs suggests that ultrasound guidance results in a lower number of needle passes required for success (Fig. 6).

Safety outcomes were consistently reported as secondary outcome measures; thus, none of the individual studies were designed or sufficiently powered to study these outcomes. Four studies reported a nonsignificant trend toward a lower incidence of headache and backache favoring ultrasound.[27,29,34,42] There was no difference in the reported rate of unintended dural punctures, which was universally low (<1%).[29,32] Only 1 study reported a lower incidence of "puncture site hemorrhage" of 7% with ultrasound versus 20% in the control group.[36] No major complications such as epidural hematoma, epidural abscess, or intracord injections were reported in any of the RCTs.

A recent meta-analysis also addressed the question of whether neuraxial ultrasound can reduce the technical failure of lumbar puncture or epidural catheterization.[10] The studies included were heterogeneous (both preprocedure as well as real-time ultrasound guidance, and both adult and pediatric patients were included). Nevertheless, the findings were consistent with those of our meta-analysis reported in the present review. Pooled data from 12 RCTs showed a 79% reduction in the risk of failed lumbar puncture or epidural catheterization (relative risk, 0.21; 95% CI, 0.1–0.43, $P < 0.001$) with neuraxial ultrasound. They also found a significant reduction in the number of needle redirections required for success (MD, −1.00; 95% CI, −1.24 to −0.75, $P < 001$). Pooled data from 5 RCTs showed a 73% reduction in the risk of a traumatic procedure (relative risk, 0.27; 95% CI, 0.11–0.67, $P = 0.05$), which was defined as visible blood on aspiration or a fluid red blood cell count above a predetermined threshold. The authors further calculated the number needed to treat to prevent one procedural failure and one traumatic procedure as 16 and 17, respectively.

Recommendation

Data from 14 RCTs and 2 meta-analysis (this article and 1 previously published) (level of evidence Ia) support the conclusion that neuraxial ultrasound increases the efficacy of lumbar epidural or spinal anesthesia by decreasing the risk of technical failure and the number of needle punctures required, both in patients with normal surface landmarks and those at

TABLE 4. RCTs Reporting Efficacy and/or Safety Outcomes of Ultrasound-Assisted Neuraxial Techniques

Author	Year	Country	Technique	Study Design	Sample Size	Patient Population	Primary Outcome	Secondary Outcomes	Jadad Score
Abdelhamid	2013	Egypt	Spinal	RCT	90	Adult unspecified	First attempt success	Procedure time, patient satisfaction	2
Ansari	2014	UAE	Spinal	RCT	150	OB	Procedure time	No. needle insertions/passes, headache, backache, patient satisfaction	3
Chin	2011	Canada	Spinal	RCT	120	Orthopedic difficult spine	First attempt success	No. needle insertions/passes, failure rate, procedure time	5
Grau AAS	2001	Germany	Epidural	RCT	72	OB	No. punctures, no. levels	Failure rate, headache, backache	2
Grau RAPM	2001	Germany	CSE	RCT	80	OB difficult spine	No. punctures, procedure time		1
Grau	2002	Germany	Epidural	RCT	300	OB	Agreement US-CP	Unintended dural punctures, complete analgesia	2
Grau	2004	Germany	CSE	RCT	30	OB	No. punctures	Procedure time, duration of blockade	2
Lim	2014	Singapore	Spinal	RCT	170	Non-OB	First attempt success	No. needle redirections, procedure time, paresthesia, traumatic taps, patient satisfaction	3
Mofidi	2013	Iran	LP	RCT	80	ER	Procedure time	No. needle insertions, traumatic taps, pain score	2
Nomura	2007	United States	LP	RCT	46	ER	Success of LP	No. attempts	4
Peterson	2014	United States	LP	RCT	100	ER	Success of LP	No. needle insertions, traumatic taps, procedure time, pain score, patient satisfaction	2
Sahin	2014	Turkey	Spinal	RCT	100	OB	First attempt success	No. needle insertions/passes/levels attempted, failure rate, procedure time, paresthesia, headache, backache	4
Vallejo	2010	United States	Epidural	RCT	370	OB	Incidence of epidural catheter replacement	No. attempts, unintended dural puncture	3
Wang	2012	China	CSE	RCT	60	OB obese patients	First attempt success	Procedure time, complications, puncture site hemorrhage	2

risk of difficult insertion due to obesity, scoliosis, or previous spine surgery (grade A recommendation).

DISCUSSION

Although the feasibility of neuraxial ultrasound imaging was first reported several decades ago,[23,24] it was not until the early 2000s that the role of neuraxial ultrasound as we understand it today became established following pioneering work by Grau et al and significant advances in ultrasound technology resulting in greater resolution.[27–29,34] Since a previous review,[43] more data have become available for non–obstetric patients[22,25,26,33,37,39–41] and for patients presumed at risk for difficult insertion due to obesity, scoliosis, or previous surgery.[33] These special patient populations are clinically important because they are at increased risk for technical difficulty. The present review identified 31 studies that addressed at least 1 of 3 driving clinically relevant questions.

Studies evaluating the "diagnostic" performance of ultrasound as an extension of the physical examination consistently show that it enhances the accuracy of landmark identification compared with palpation of surface landmarks alone, and that it accurately measures the depth of the epidural space. A growing body of evidence suggests that the additional anatomical information provided by neuraxial ultrasound results in increased efficacy as evidenced by a reduction in the risk of failure and a lower number of needle passes required for success.

Epidural hematoma and spinal cord injury due to unintended intracord injection are rare but serious complications of neuraxial anesthesia.[4] Multiple insertion attempts and "traumatic insertion" increase the risk of epidural hematoma[4,44] and an inaccurate assessment of the location of intervertebral spaces can lead to unintended intracord injection resulting in spinal cord injury and permanent neurologic sequelae.[45,46] Given the very low baseline incidence of these catastrophic complications (usually less than 1 in 100,000 cases), it is not feasible to design prospective studies to conclusively prove that image guidance improves safety. However, the evidence strongly suggests that preprocedure neuraxial ultrasound prevents the occurrence of several well-recognized mechanisms of injury.

By increasing the accuracy of needle placement and decreasing the number of needle passes, ultrasound may result in less traumatic procedures, likely contributing to the prevention of epidural hematoma.[23–25,29,32] Similarly, by improving the accuracy of intervertebral space identification, a preprocedure spinal ultrasound could help prevent injuries to the conus medullaris that are consistently associated with a higher-than-intended needle insertion point resulting from imprecise surface

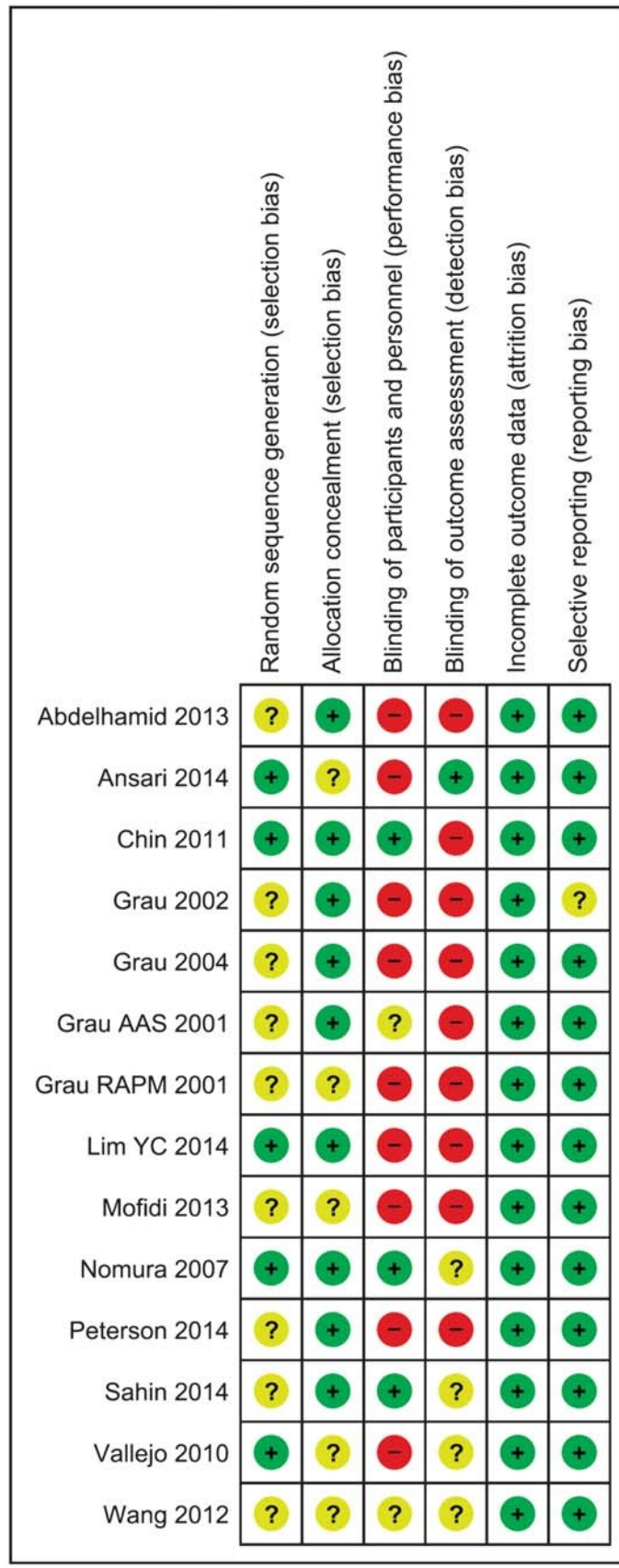

FIGURE 3. Risk of bias of individual RCTs reporting efficacy and safety outcomes following the Cochrane Risk of Bias assessment tool for RCTs.

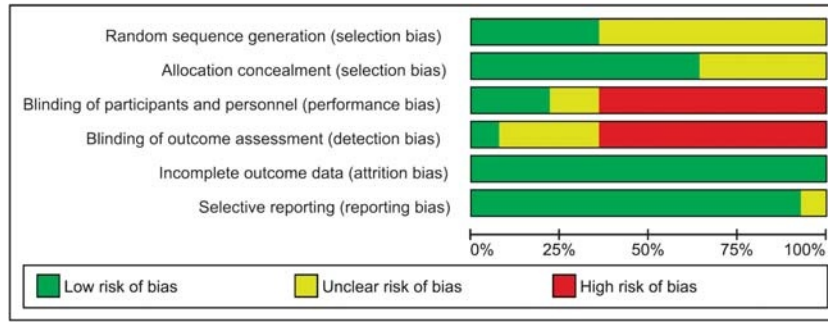

FIGURE 4. Summative risk of bias of RCTs reporting efficacy and safety outcomes following the Cochrane Risk of Bias assessment tool for RCTs.

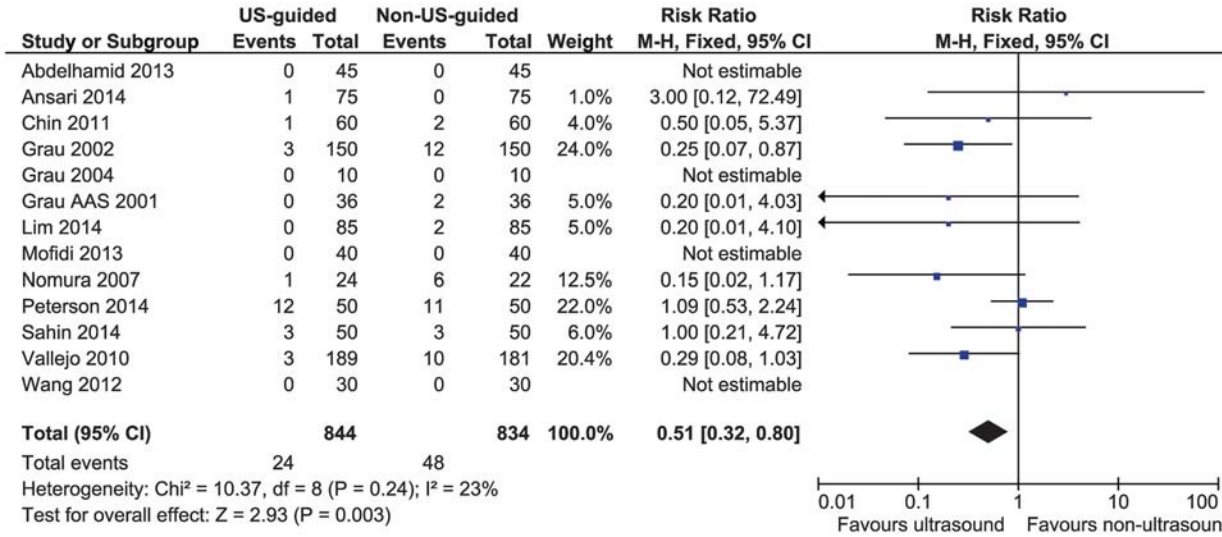

FIGURE 5. Meta-analysis of RCTs (using RevMan 5.3, the Cochrane Collaboration) reporting the risk of technical failure of neuraxial procedures with and without ultrasound imaging.

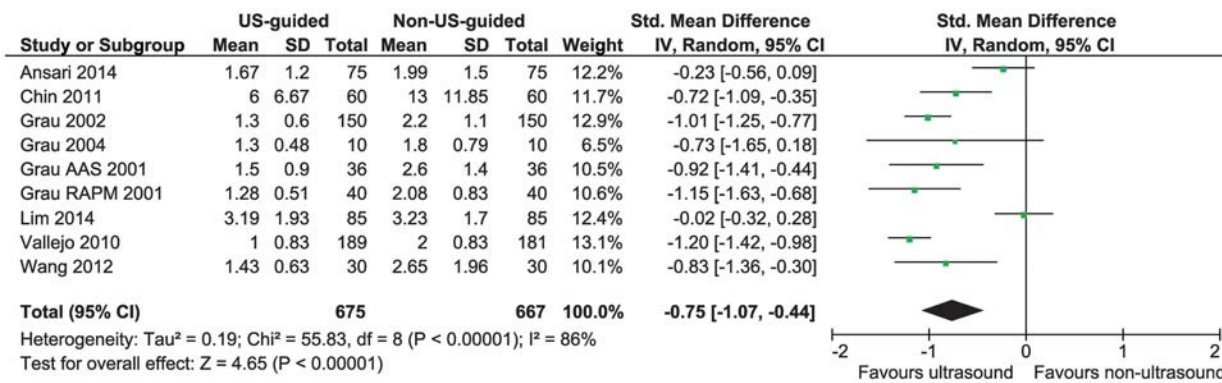

FIGURE 6. Meta-analysis of RCTs (using RevMan 5.3, the Cochrane Collaboration) reporting the number of needle passes required for neuraxial procedure success with and without ultrasound imaging.

TABLE 5. Summary Statements, Grades of Recommendations, and Supporting Level of Evidence

Outcome	Grade of Recommendation	Level of Evidence
Increased accuracy of identification of lumbar interspaces	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

Following the format suggested by the US Department of Health and Human Services Agency for Health Care Policy and Research.[8]

landmarks.[11,12,16,17] Therefore, level III evidence supports a grade B recommendation that neuraxial ultrasound may help improve the safety of neuraxial anesthesia (Table 5).

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Evidence Basis for Ultrasound Guidance for Lower-Extremity Peripheral Nerve Block
Update 2016

Francis V. Salinas, MD

Abstract: This article reviews and summarizes randomized controlled studies that have investigated ultrasound guidance (USG) for lower-extremity peripheral nerve blocks in comparison with other peripheral nerve localization techniques and those that compared different ultrasound-guided techniques investigating optimal perineural local anesthetic distribution patterns.

Thirty-four studies met the inclusion criteria (minimum Jadad score 3), and 10 additional studies directly compared USG with peripheral nerve stimulation, and 5 additional studies directly compared USG with landmark-based field blocks. Fourteen studies compared different local anesthetic distribution parameters.

Analysis of the literature supports the use of USG for decreased block performance time, decreased block onset time, increased rate of complete sensory block, and increased analgesic efficacy. Ultrasound was never inferior to peripheral nerve stimulation. The research focus has evolved during the last 5 years into investigating optimal ultrasound-guided techniques.

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This review aims to critically analyze and update the evidence for ultrasound guidance (USG) as compared with alternative methods of peripheral nerve localization for lower-extremity peripheral nerve blocks (PNBs). Traditionally, the alternative techniques for lower-extremity peripheral nerve localization have included peripheral nerve stimulation (PNS), loss of resistance, and landmark-based field blocks. In the initial evidence-based review of USG for lower-extremity PNBs published in 2010,[1] no studies were designed to assess *"block success"* when defined as surgical anesthesia. However, the 11 randomized controlled trials (RCTs) analyzed provided level Ib evidence for a grade A recommendation (Table 1) that USG provided outcome benefits. These benefits included a decrease in block onset time (BOT), a decrease in block performance time (BPT), an increased success of sensory block, and a decrease in local anesthetic requirements.[1]

In the last 5 years, USG has become the predominant technique for peripheral nerve localization.[2,3] The research focus has evolved from comparative studies on USG versus traditional peripheral nerve localization techniques to predominantly comparative studies investigating different ultrasound-guided injection techniques and, in particular, studies investigating optimal local anesthetic perineural distribution patterns.[4] Thus, this review will also critically analyze and summarize the evidence-based outcomes comparing different local anesthetic perineural distribution techniques. Lastly, RCTs directly comparing the outcomes of USG (as the sole peripheral nerve localization technique) compared with a combined USG and PNS (USG + PNS) technique will also be reviewed.

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METHODS

The National Library of Medicine's MEDLINE database was searched for the period from November 2009 to June 2015. Search strategies included the terms "ultrasound" and "peripheral nerve block." Two-stage searches were also performed using additional key words to capture studies not additionally identified including the terms "ultrasound" with "lumbar plexus," "3-in-1," "fascia iliaca," "femoral nerve," "adductor canal," "saphenous nerve," "lateral femoral cutaneous nerve," "obturator nerve," "sacral plexus," "sciatic nerve," "popliteal block," and "ankle block."

The author assessed whether articles met the following predefined inclusion criteria: RCTs directly comparing USG (as the primary technique with or without concurrent PNS) with PNS, loss of resistance, or landmark-based field block techniques for single-injection and continuous lower-extremity PNBs in adult (older than 18 years) patients. A single large retrospective case series was included because it was the best available clinical (nonvolunteer) evidence for the use of USG when performing ankle blocks. The RCT inclusion criteria for this updated review required a minimal Jadad score[5] of 3, with an appropriate sample size calculation based on the primary outcome of interest. Two RCTs[6,7] in the initial review had Jadad scores less than 3. Randomized controlled trials directly comparing USG + PNS with USG alone were also included to define the advantages and disadvantages of each technique. Randomized controlled trials directly comparing different ultrasound-guided techniques (such as short-axis in-plane [SAX-IP] vs long-axis in-plane [LAX-IP]) for peripheral nerve localization and differences in local anesthetic perineural distribution patterns (such as circumferential vs not; and extraparaneural vs subparaneural for popliteal sciatic nerve blocks) were also included to define the outcome benefits for these more recently described ultrasound-guided techniques. Studies investigating the minimum local anesthetic volume or concentration requirements were not included. References from eligible articles were manually searched to identify studies not found in the electronic search. Only English language articles were included in the evidence-based review. Studies on the evidence for USG for lower-extremity pediatric PNBs and evidence for safety are addressed in separate evidence-based reviews (Fig. 1).

For the purpose of this review, the primary outcomes of interest included BOT, BPT, total anesthesia-related time (ART = BOT + BPT), postoperative analgesic efficacy (reported pain scores, rescue systemic analgesic requirements, and local anesthetic consumption) of continuous peripheral perineural infusions, analgesic efficacy in hip fractures (pain associated with positioning for spinal anesthesia), and "block success." *Block success* was defined differently across various studies; definitions included the rate of complete sensory anesthesia (to either pinprick or cold sensory testing) and/or rate of complete motor block,

TABLE 1. Statements of Evidence and Grades of Recommendation

Statement 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 Recommendation	
A	Requires at least 1 prospective, randomized, controlled trial as part of the body of literature of overall good quality and consistency addressing the specific recommendations (evidence levels Ia and Ib)
B	Requires the availability of well-conducted clinical studies but no prospective randomized clinical trial 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: US Department of Health and Human Services, Agency for Healthcare Policy and Research.

varying degrees (depth) of sensory or motor block within a predefined time frame, surgical anesthetic block, and calculated volume of local anesthetic in direct contact with the target nerve.

Block performance time included time to perform single-injection block techniques or time to successfully place a continuous peripheral perineural catheter. Secondary outcomes were also

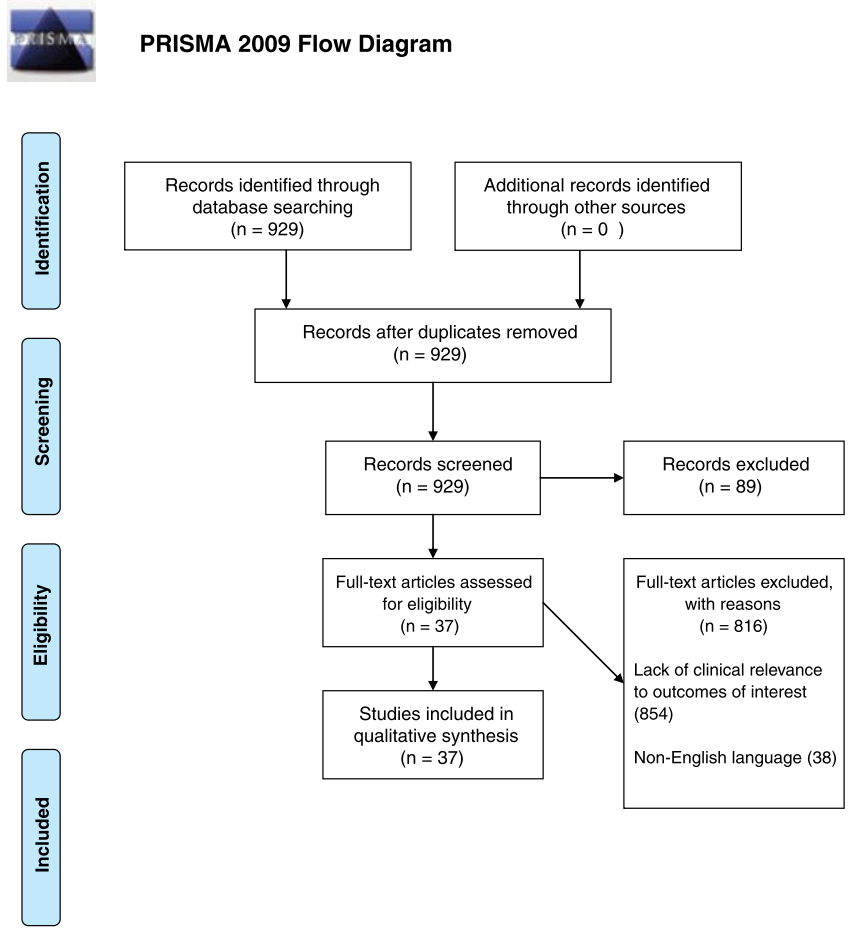

FIGURE 1. PRISMA 2009 flow diagram.

defined differently across various studies and included the number of needle passes (redirections), procedure-related pain, procedure-related complications (primarily vascular puncture), *postoperative block efficacy* (defined as postoperative pain scores and/or opioid requirements, or continuous peripheral perineural local anesthetic requirements), and *block failures* (inability to successfully localize the target nerve within a predefined duration of time).

RESULTS

Femoral Nerve and Fascia Iliaca Block (3-in-1 Block)

In the initial evidence-based review based on 4 RCTs (240 patients),[6–9] there was level Ib evidence to make a grade A recommendation that USG (compared with either PNS or loss of resistance) significantly decreased BOT, decreased local anesthetic volume requirements, and increased the rate of sensory block success for femoral nerve block (FNB).[1] Although these 4 RCTs lacked sufficient power to provide additional rigorous recommendations, there was a trend toward improved quality of sensory block, increased block success rate, and more rapid onset of sensory block in the distribution of the femoral nerve as secondary outcomes. Since the initial review, there have been 11 additional high-quality RCTs (Jadad scores ≥3) investigating the utility of USG for FNB (Tables 2 and 3) in 1061 patients and 16 volunteers.[10–15,17–21]

USG (With or Without Concurrent PNS) Versus PNS Alone

A single RCT directly compared USG with PNS (Table 2) for placement of continuous femoral nerve catheters in patients undergoing total knee arthroplasty (TKA). In this study, femoral catheters placed with an ultrasound-guided SAX-IP technique required a significantly shorter BPT (5.0 vs 8.5 minutes, $P = 0.012$; primary outcome) compared with a PNS stimulating catheter technique. However, there was no difference in the secondary outcomes of either average or worst reported pain during the first postoperative day.[10] Two RCTs investigated the utility of combined USG + PNS compared with PNS alone with the primary outcomes being BPT[11] and postoperative analgesic efficacy.[12] In the RCT investigating BPT, the use of USG to guide initial femoral perineural needle tip placement followed by a concurrent PNS technique (through the stimulating needle initially as well as when advancing the stimulating catheter beyond the needle tip) significantly decreased BPT (9.0 vs 13.5 minutes, $P = 0.024$). There was also an advantage with the combined USG + PNS technique in the secondary outcome of decreased number of needle passes compared with a PNS-only technique. However, there were no significant differences in either resting or dynamic pain scores for the first 48 hours after TKA between the 2 techniques.[11] In the RCT powered to demonstrate a difference in postoperative analgesic efficacy as the primary outcome, the use of USG to guide initial femoral perineural needle tip placement, followed by concurrent PNS (via the stimulating needle) using a nonstimulating catheter technique (followed by *"blind"* advancement of the catheter beyond the needle tip), the addition of USG significantly decreased 48-hour perineural local anesthetic requirements after TKA (299 vs 333 mL, $P = 0.003$) and provided benefits in secondary outcomes that included 48-hour postoperative rescue opioid requirements (19.8 vs 40 mg, $P = 0.0079$), resting and dynamic analgesia, as well as BPT (6.3 vs 9.3 minutes, $P = 0.0007$).[12]

In summary, there is level Ib evidence for a grade A recommendation that USG (with or without concurrent PNS) significantly decreased BPT for placement of continuous femoral catheters. In a single RCT, USG decreased 48-hr local anesthetic requirements compared with PNS alone as the primary technique for femoral catheter placement.

USG With the Addition of PNS Versus USG Alone

Three RCTs investigated whether the addition of PNS to USG compared with USG alone (Table 2) would improve the primary outcomes of block quality[13] or postoperative analgesic efficacy (reported pain scores or rescue analgesic requirements) after TKA.[14,15] The addition of concurrent PNS to USG did not increase sensory or motor block quality 40 minutes after a preoperative single-injection FNB of 30 mL bupivacaine 0.5% but did increase BPT and number of needle passes compared with using USG alone.[13] The 2 RCTs investigating the addition of concurrent PNS (with a nonstimulating femoral catheter[14] or stimulating femoral catheter technique[15]) to USG compared with USG alone did not demonstrate any significant benefit in postoperative analgesic efficacy after TKA. However, the addition of PNS to USG compared with USG alone significantly increased BPT in these 2 studies[14,15] and was found to increase the cost of femoral nerve catheter placement in 1 study.[15] Thus, the addition of PNS to an ultrasound-guided technique compared with USG-alone technique confers no significant outcome benefit in terms of postoperative analgesic efficacy but consistently increases BPT and number of needle passes and, in a single study, increased the economic cost of continuous femoral nerve catheter placement.

In summary, based on these 3 RCTs, there is level Ib evidence for a grade A recommendation that all 3 techniques (SAX-IP, short-axis out-of-plane [SAX-OOP], and LAX-IP) for continuous femoral catheter placement provide equivalent analgesic efficacy, that a SAX-IP technique decreases BPT compared with a LAX-IP, and that there is no outcome benefit (in terms of increased depth of sensorimotor block or postoperative analgesic efficacy) using concurrent electrophysiological-based confirmation when USG is initially used as the primary nerve localization technique to place the needle tip in close proximity to the femoral nerve.

Different Ultrasound-Guided Femoral Catheter Placement Techniques

Continuous femoral nerve catheters may be placed and advanced either parallel to the longitudinal course of the femoral nerve (using either a LAX-IP technique or a SAX-OOP technique) or perpendicular to the longitudinal course of the femoral nerve (using a SAX-IP technique).[16] Three different RCTs compared these various ultrasound-guided techniques for femoral nerve catheter placement (Table 3) with primary outcomes of BPT,[17] BOT from the initial local anesthetic bolus dose,[18] or postoperative analgesic efficacy.[19] The LAX-IP technique consistently increased BPT[17,18] but did provide a slightly faster onset of complete sensory anesthesia compared with a SAX-IP technique.[18] More importantly, all 3 techniques provided similar postoperative analgesic efficacy.

In summary, there is level Ib evidence for a grade A recommendation that all 3 techniques (SAX-IP, SAX-OOP, and LAX-IP) for continuous femoral catheter placement provide equivalent analgesic efficacy, and that a SAX-IP technique decreases BPT compared with a LAX-IP technique.

Different Ultrasound-Guided Femoral Perineural Local Anesthetic Distribution Patterns

Two RCTs investigated whether ultrasound-guided facilitation of targeted local anesthetic distribution around the femoral nerve (Table 3) influenced sensory or motor block quality or

TABLE 2. RCTs Comparing Ultrasound-Guided Techniques With Existing Nerve Localization Techniques

Author	Jadad Score	Block Type	Primary Outcome	N	Comparative Techniques	Local Anesthetic	Major Findings	Authors' Conclusion
Mariano et al[10]	3	Femoral catheter	BPT	40	USG vs PNS (stimulating catheter)	Mepivacaine 1.5%, 40 mL (initial bolus) Ropivacaine 0.2% at 8 mL/h with 4 mL Q 30 min for inadequate analgesia (perineural infusion)	USG decreased BPT (5.0 vs 8.5 min, $P = 0.012$)	USG better than PNS
Li et al[11]	3	Femoral catheter	BPT	120	USG + PNS vs PNS	Lidocaine 1%, 20 mL (initial bolus) Ropivacaine 0.2% at 5 mL/h (perineural infusion)	USG decreased BPT (9.0 vs 13.5 min, $P = 0.024$)	USG + PNS better than PNS alone
Aveline et al[12]	4	Femoral catheter	48-h local anesthetic requirement	92	USG + PNS vs PNS	Lidocaine 0.5%, 20 mL (initial bolus) Levobupivacaine 0.125% at 5 mL/h with 5 mL Q 1 h for inadequate analgesia	USG + PNS decreased 48-h local anesthetic consumption (299 vs 333 mL, $P = 0.0003$) USG + PNS decreased BPT, postoperative opioid requirements, and postoperative pain*	USG + PNS better than PNS alone
Sites et al[13]	4	Femoral	Block success	107	USG + PNS vs PNS	Bupivacaine 0.5%, 30 mL	No difference (quality of sensorimotor block at 40 min)	No difference between USG + PNS and PNS alone
Fredrickson and Danesh-Clough[14]	3	Femoral catheter	Postoperative analgesia	45	USG + PNS vs USG	Ropivacaine 0.5%, 30 mL (initial bolus) Ropivacaine 0.2–0.3% at 2 mL/h with 5 mL Q 1 h for inadequate analgesia	No difference in postoperative analgesic efficacy	No difference between USG + PNS and USG alone
Farag et al[15]	3	Femoral catheter	Postoperative analgesia	453	**1.** USG alone **2.** USG + PNS (nonstimulating catheter) **3.** USG + PNS (stimulating catheter)	Ropivacaine 0.1%, 20 mL (initial bolus) Ropivacaine 0.1% at 8 mL/h	No difference in postoperative analgesic efficacy	No difference between USG + PNS and USG alone
Manassero et al[23]	4	Obturator	BOT	50	USG + PNS vs USG	Lidocaine 2%, 10 mL	No difference in BOT (of complete adductor motor block) USG + PNS increased BPT (188 vs 148 s, $P = 0.01$)*	No difference between USG + PNS and USG alone
Kent et al[31]	4	Saphenous	Block success	20	USG (at AC and SS compartment) vs below the knee landmark-based field block	Lidocaine 1.5%, 10 mL	USG increased block success (80%–100% vs 30%, $P < 0.0001$)	USG better

Lam et al[44]	5	Popliteal sciatic	BPT	24	USG vs PNS	Mepivacaine 1.5%, 20 mL	Decreased BPT with USG (266 vs 571 s, P < 0.00) Fewer needle passes and block-related pain with USG*	USG better
Sala-Blanch[45]	3	Popliteal sciatic	Block success	48	USG vs PNS	Mepivacaine 1.5%, 20 mL	Increased rate of sensory (80% vs 4%, $P < 0.001$) and motor (60% vs 8%, $P < 0.001$) success at 15 minutes. No difference in surgical anesthesia (100%) at 30 min*	USG better
Cataldo et al[46]	5	Popliteal sciatic	Block success	64	USG vs PNS	Ropivacaine 0.75%, 10 mL + Lidocaine 2%, 10 mL	No difference (94%) in block success (rate of complete sensory block between techniques)	No difference
Maalouf et al[47]	5	Popliteal sciatic catheter	48-h opioid requirement	50	USG vs PNS	Bupivacaine 0.5%, 30 mL (initial bolus) Ropivacaine 0.2% at 4 mL/h; increased to max of 12 ml/h for inadequate analgesia	No difference in 48-h cumulative opioid requirement No difference in postoperative pain scores* USG decreased 48-h local anesthetic requirement by 75% (50 vs 197 mL)*	No difference
Bendtsen et al[48]	3	Popliteal sciatic catheter	Block success	100	USG vs PNS	Ropivacaine 0.75%, 30 mL (initial bolus) Bupivacaine 0.25% at 8 mL/h; increased as needed for inadequate analgesia	Block success (persistent presence of postoperative sensory block) increased with USG (94% vs 79%, $P = 0.03$) Decreased postoperative opioid requirements by 47% (18 vs 34 mg)* No difference in postoperative pain scores*	USG better
Redborg et al[62]	4	Ankle (sural)	Block Success	18	USG vs landmark-based field block	2-Chloroprocaine 3%, 5 mL	Block success (rate of complete sensory block at 10 min) increased with USG (78% vs 28%) Increased BPT with USG (172 vs 70 s)*	USG better
Redborg et al[63]	4	Ankle (posterior tibial)	Block Success	18	USG vs landmark-based field block	2-Chloroprocaine 3%, 5 mL	Block success (rate complete sensory block at 30 min) increased with USG (72% vs 22%, $P < 0.01$)	USG better
Antonakakis et al[64]	4	Ankle (deep peroneal)	Block Success	18	USG vs landmark-based field block	2-Chloroprocaine 3%, 5 mL	No difference in rate complete sensory block Increased BPT with USG (143 vs 81 s, $P < 0.001$)*	No difference
Fredrickson et al[66]	4	Ankle	Postoperative analgesia	72	USG vs landmark-based field block	Ropivacaine 0.5% USG (16 mL) Landmark based field block (30 mL)	Improved postoperative analgesia with higher volume landmark-based technique (NRS pain 0 vs 1, $P = 0.01$)	Higher volume marginally increased postoperative analgesia

*Secondary outcomes.

BOT indicates block onset time; BPT, block performance time; NRS, Numerical Rating Scale; PNS, peripheral nerve stimulation; USG, ultrasound guidance.

TABLE 3. Randomized Controlled Studies Comparing Different Ultrasound-Guided Techniques

Author	Jadad Score	Block Type	Primary Outcome	N	Comparative Techniques	Local Anesthetic	Major Findings	Authors' Conclusion
Wang et al[17]	5	Femoral nerve catheter	BPT	50	SAX-IP vs LAX-IP	Ropivacaine 0.5%, 20 mL (initial bolus)	SAX-IP technique decreased BPT (12 vs 22 min, $P < 0.01$)	SAX-IP better than LAX-IP for femoral catheter placement
						Ropivacaine 0.2% at 5 mL/h	No difference in postoperative analgesic efficacy*	No difference in postoperative analgesic efficacy
Mariano et al[18]	4	Femoral nerve catheter	BOT	50	SAX-IP vs LAX-IP	Mepivacaine 2%, 30 mL (initial bolus)	LAX-IP decreased BOT (6.0 vs 9.0 min, $P = 0.044$).	LAX-IP better for BOT, but increase in BPT
						Ropivacaine 0.2% at 6 mL/h with 5 mL Q 30 min as needed for inadequate analgesia	SAX-IP decreased BPT (5.0 vs 9.0 min, $P < 0.001$)*	No difference in postoperative analgesic efficacy
							No difference in BPT postoperative analgesic efficacy*	
Fredrickson and Danesh-Clough[19]	4	Femoral nerve catheter	Worst pain first 24 h	81	SAX-IP vs SAX-OOP	Ropivacaine 0.5%, 20 mL (initial bolus)	No difference in analgesic efficacy	No difference
						Ropivacaine 0.2% at 2 mL/h with 5 mL Q 1 h as needed for inadequate analgesia		
Ilfeld et al[20]	5	Femoral nerve catheter	Quadriceps motor strength	16	Femoral catheter placement above vs below femoral nerve	Ropivacaine 0.1% at 4 mL/h for 6 h (perineural infusion)	No difference in quantitative reduction in quadriceps motor strength between femoral catheters placed above or below femoral nerve	No difference
Szűcs et al[21]	4	Femoral	Analgesic efficacy	52	LAD: Group A: above femoral nerve Group B: below femoral nerve Group C: circumferential LAD around femoral nerve.	Lidocaine 2%, 15 mL	No significant difference in analgesic efficacy for spinal block positioning in hip fracture patients	No difference
Brull et al[49]	5	Popliteal sciatic	Block success	64	Circumferential (multi-injection) LAD vs noncircumferential (single-injection) LAD	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	Circumferential LAD around increases rate of complete sensory block (94% vs 69%, $P = 0.01$)	Circumferential LAD better
Buys et al[50]	5	Popliteal sciatic	BOT	76	Circumferential LAD at sciatic nerve vs circumferential LAD at both TN and CPN	Mepivacaine 1.5%, 30 mL + clonidine 100 μg	Separate circumferential LAD around TN and CPN increases BOT (19.2 vs 261 min, $P = 0.006$)	Circumferential LAD around both TN and CPN better than just around sciatic nerve

Prasad et al[51]	5	Popliteal sciatic	BOT	48	Circumferential LAD at sciatic nerve vs circumferential LAD at both TN and CPN	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	Separate circumferential LAD around TN and CPN increases BOT (21 vs 31 min, $P = 0.005$)	Circumferential LAD around both TN and CPN better than just around sciatic nerve
Germain et al[52]	5	Popliteal sciatic	Block success	102	Circumferential LAD around both TN and CPN better than just around sciatic nerve	Ropivacaine 0.75%, 25 mL	Separate circumferential LAD around TN and CPN increases rate of complete sensory block and surgical anesthesia (96% vs 51%, $P < 0.0001$)	Circumferential LAD around both TN and CPN better than just around sciatic nerve
Tran et al[53]	5	Popliteal sciatic	BOT	48	Subparaneural LAD vs circumferential extraparaneural LAD	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	Subparaneural LAD decreases BOT (10.7 vs 16.4 min, $P = 0.028$) Subparaneural LAD increases rate of complete sensory block, decreases BPT and ART, and decreases number of needle passes*	Subparaneural LAD better
Perlas et al[54]	5	Popliteal sciatic	BOT	84	Subparaneural LAD vs circumferential extraparaneural LAD	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	Subparaneural LAD decreases BOT (14 vs 21 min, $P = 0.006$) Subparaneural LAD increases rate of complete sensory-motor block, increases longitudinal spread along sciatic nerve*	Subparaneural LAD better
Choquet et al[55]	5	Popliteal sciatic	BOT	48	Subparaneural LAD vs circumferential extraparaneural LAD	Mepivacaine 1%, 30 mL	Subparaneural LAD decreases BOT (11 vs 19 min, $P = 0.001$). Subparaneural LAD increases rate of block success, increases sensory block duration*	Subparaneural LAD better
Missair et al[56]	5	Popliteal sciatic	Calculated volume of local anesthetic contact	60	Subparaneural LAD vs circumferential extraparaneural LAD	Ropivacaine 0.5%, 30 mL	Subparaneural LAD increases volume of local anesthetic contact with sciatic nerve (5.57 vs 1.48 mL, $P < 0.001$) Subparaneural LAD increases rate of complete sensory block*	Subparaneural LAD better
Tran et al[57]	5	Popliteal sciatic	ART	68	Subparaneural LAD proximal vs at SNBF	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	No difference in ART No difference in BPT, BOT, or block success*	Subparaneural LAD proximal to and at SNBF equal
Tiyaprasertkul et al[58]	5	Popliteal sciatic	ART	100	Subparaneural LAD at SNBF: single-injection vs triple-injection	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	No difference in ART No difference in BPT, BOT, or block success*	Subparaneural LAD with single-injection equal to triple-injection technique

Continued next page

TABLE 3. *(Continued)*

Author	Jadad Score	Block Type	Primary Outcome	N	Comparative Techniques	Local Anesthetic	Major Findings	Authors' Conclusion
Abdallah et al[59]	4	Subgluteal sciatic	BPT	24	Single-injection interfascial technique vs multiple-injection circumferential LAD	Bupivacaine 0.5%, 15 mL + Lidocaine 2%, 15 mL	No difference in BPT	No difference
Yamamoto et al[60]	5	Subgluteal sciatic	Block success	86	Single-injection interfascial technique vs multiple-injection circumferential LAD	Mepivacaine 1.5%, 20 mL	Multiple-injection circumferential LAD increased rate of complete sensory block (41.2% vs 16.2%, $P = 0.018$)	Multiple-injection circumferential LAD better
Ota[61]	3	Proximal sciatic nerve block	Block success	94	USG + PNS: posterior subgluteal approach vs anterior approach	Mepivacaine 1.5%, 20 mL	No difference in block success rate	No difference

*Secondary outcomes.

ART indicates anesthesia-related time; BOT, block onset time; BPT, block performance time; CPN, common peroneal nerve; LAD, local anesthetic distribution; LAX-IP, long-axis in-plane; PNS, peripheral nerve stimulation; SAX-IP, short-axis in-plane; SAX-OOP, short-axis out-of-plane; TN, tibial nerve; USG, ultrasound guidance.

analgesic outcome. In a volunteer study, ultrasound-guided femoral catheters were positioned either above or below the femoral nerve using a SAX-IP technique, followed by a continuous infusion of ropivacaine 0.1% at 4 mL/h during a 6-hour period.[20] This volunteer study demonstrated a significant (70%–80%) decrease in quadriceps motor strength at 6 hours (as measured by maximum voluntary isometric contraction compared with baseline) in both groups but found no significant between-group difference based on catheter tip location above or below the femoral nerve. In contrast, placement of the catheter above the femoral nerve significantly increased sensory block depth as measured by tolerance to transcutaneous electrical stimulation as a secondary outcome. No studies in patients undergoing major knee surgery have been conducted to validate the findings in this well-controlled, but nonetheless, volunteer study design. A single RCT compared the analgesic efficacy of an ultrasound-guided single-injection FNB with 15 mL lidocaine 2% based on local anesthetic distribution above, below, or circumferentially around the femoral nerve.[21] *Analgesic efficacy* (defined as pain associated with positioning hip fracture patients for placement of spinal anesthesia 30 minutes after FNB) was similar among the 3 local anesthetic distribution patterns. Although BPT was also similar among the 3 techniques, the circumferential group required significantly more needle passes (2 vs 1) compared with the other 2 groups. No RCT to date has investigated the effects of circumferential local anesthetic distribution around the femoral nerve for BOT, rate of complete sensory/motor block, or success of surgical anesthesia.

In summary, there is level Ib evidence for a grade A recommendation that there appears to be no difference in analgesic efficacy and degree of quadriceps motor block with local anesthetic distribution above or below the femoral nerve. However, there is a notable absence of evidence on the effects of different femoral perineural local anesthetic distribution patterns when a surgical block may be required.

Obturator Nerve Block

No RCT has directly compared USG with PNS for obturator nerve block (Table 2). Ultrasound-guided obturator nerve block may be often performed by identification of the fascial planes between the pectineus muscle and the adductor longus and adductor brevis muscles (typically where the anterior division of the obturator nerve is located) and between the adductor brevis and adductor magnus muscles (typically where the posterior division of the obturator nerve is located).[22] A single RCT investigated whether concurrent PNS added to an ultrasound-guided interfascial injection technique compared with an ultrasound-guided interfascial technique alone would improve BOT for complete adductor motor block in patients with established occurrence of electrocautery-induced adductor spasm associated with transurethral bladder surgery.[23] The end point for the USG interfascial group was local anesthetic distribution within the 2 separate fascial planes, whereas the USG + PNS group required separate confirmatory evoked motor responses (at a current output of 0.4 mA) of both the anterior division and the posterior division of the obturator nerve before local anesthetic injection. The addition of PNS in conjunction with USG did not increase either BOT or rate of complete adductor motor block but significantly increased BPT (188 vs 148 seconds, $P = 0.01$) and number of needle passes (4.2 vs 1.1, $P = 0.01$).

In summary, there are no RCTs directly comparing USG with PNS for any of the previously stated primary outcomes. Based on a single RCT, there is limited Ib evidence for a grade A recommendation that addition of concurrent PNS to an ultrasound-guided interfascial plane technique offers no benefit for BOT or rate of

complete adductor motor block. However, the addition of concurrent PNS did increase both BPT and number of needle passes.

Saphenous Nerve Block

USG Compared With Landmark-Based Field Block

Saphenous nerve block may be performed via several approaches along the anatomical course of the saphenous nerve (Table 2) from the femoral triangle, within the adductor canal (AC), just distal to the AC within the subsartorial (SS) compartment located between the sartorius and vastus medialis and, lastly, below the knee depending on the surgical indications.[24,25] In addition, saphenous nerve block has been performed with landmark-based techniques below the knee,[26] with PNS,[27,28] and more recently with USG either within the AC[29] or within the SS compartment distal to the AC.[30] A single volunteer RCT compared the *block success rate* (defined as complete sensory loss with pinprick sensation in the saphenous nerve distribution below the knee) between 2 ultrasound-guided approaches (within the AC and within the SS) and with a below-the-knee landmark-based field block technique (3–4 cm distal to the tibial condyle) after injection with 10 mL lidocaine 1.5%.[31] Ultrasound guidance significantly increased block success rate (100% with the AC approach and 80% with the SS approach, respectively) compared with the 30% block success rate with the below-the-knee landmark-based field block technique.

Ultrasound-Guided Saphenous Nerve Block at the AC Compared With Ultrasound-Guided Saphenous Nerve Block in the SS Compartment (Distal to the AC)

Two prospective RCTs compared low-volume (5 mL 1.5 % lidocaine[32] and 8 mL 2% lidocaine,[33] respectively) ultrasound-guided saphenous nerve blocks at either the AC or within the SS compartment and found no significant difference in *block success rate* (complete loss of pinprick sensation) within 15 minutes[32] or saphenous nerve visibility between the 2 approaches.[33] In contrast, a double-blind RCT comparing an AC approach to a distal transsartorial approach with 10 mL of ropivacaine 0.5% demonstrated that the more proximal AC approach significantly increased (100% vs 86%, $P = 0.003$) *block success* (defined as complete loss of pinprick sensation within 30 minutes). The conflicting outcome data between 2 of the studies[32,34] that investigated block success may be explained by the differences in study design (different local anesthetic and local anesthetic volumes, different predetermined time to assess successful block, as well as testing one or both branches [infrapatellar and sartorial] of the saphenous nerve).

In summary, based on a single RCT, there is limited level Ib evidence for a grade A recommendation that USG increases saphenous nerve block success (both within and distal to the AC) compared with a landmark-based technique. The limited evidence for which approach (AC vs distal SS) is superior for ultrasound-guided saphenous nerve block is conflicting. Thus, no definitive recommendations can be made, and further RCTs investigating which ultrasound-guided saphenous nerve block approach is superior are needed.

Sciatic Nerve Block

In the initial review based on 5 RCTs (214 patients),[35–39] there was level Ib evidence to make a grade A recommendation that USG increased sensory block success, decreased local anesthetic volume requirements, and decreased BPT compared with PNS.[1] Although these 5 RCTs lacked sufficient power to provide additional rigorous recommendations, there was a trend toward decreased sensory and motor BOT, decreased procedure-related discomfort and vascular punctures, and lower block failure as secondary outcomes. None of the studies investigated surgical block success as a primary outcome.

The sciatic nerve may be blocked at different anatomical locations, most commonly distally in the popliteal fossa and more proximally in the subgluteal space (compartment). The subgluteal compartment is defined by the greater trochanter laterally, ischial tuberosity medially, in a tissue plane deep to the gluteus maximus muscle and superficial to the quadratus femoris muscle. At the anatomical level of the popliteal fossa, the sciatic nerve (as well as the tibial nerve [TN] and common peroneal nerve [CPN] branches) is surrounded by a paraneural sheath or paraneurium.[40] Anatomical studies[41] and high-definition ultrasound imaging[42] have demonstrated that there are actually 2 extraneural connective tissue sheaths closely enveloping the sciatic nerve that extends from the subgluteal space to the popliteal fossa. The inner paraneural sheath (or paraneurium) creates a fat-filled subparaneural compartment immediately superficial to the epineurium, whereas the outer epimyseal sheath of the surrounding muscles forms a fat and vessel-rich intermuscular extraparaneural compartment between the epimysium and the paraneurium.[42,43] It has been proposed that the subparaneural compartment functions as a conduit not only for circumferential local anesthetic spread but also for extensive spread proximally and distally (from the injection site) along the length of the sciatic nerve, subsequently resulting in a larger surface area for local anesthetic absorption.[43]

Since the initial systematic review, there have been 18 additional high-quality RCTs (Jadad scores ≥3) investigating the utility of USG for sciatic nerve block in 1186 patients. Five RCTs directly compared USG with PNS (Table 2) for popliteal sciatic nerve block; 3 for single-injection techniques[44–46] and 2 for continuous popliteal sciatic nerve catheter placement.[47,48] Ten studies (Table 3) compared clinically relevant block-related outcomes based on different local anesthetic distribution patterns within these defined fascial compartments[49–58]: (1) circumferential local anesthetic distribution proximal versus distal with the sciatic nerve bifurcation (SNBF) and (2) subparaneural versus extraparaneural local anesthetic distribution proximal or distal with the SNBF. In addition, there were 2 RCTs that compared single-injection interfascial plane injection with targeted circumferential local anesthetic injection around the sciatic nerve at the anatomical level of the subgluteal space[59,60] and a single RCT that compared an ultrasound-guided subgluteal approach with an ultrasound-guided anterior approach.[61]

USG Compared With PNS for Popliteal Sciatic Nerve Block

In the 3 RCTs that directly compared USG with PNS (Table 2), the primary outcomes were BPT[44] and rates of complete sensory block at 15 minutes[45] and at 30 minutes.[46] These 3 studies demonstrated that USG consistently decreased BPT and increased the rate of complete sensory block within the predefined time frames. In addition, USG also demonstrated significant benefits in secondary outcomes of decreased number of needle passes[44,46] and decreased block-related discomfort,[44] as well as higher rates of complete motor block.[45,46] In contrast, there was no difference between USG compared with PNS in terms of surgical block success or sensory block duration.[44,45]

One study comparing an ultrasound-guided SAX-IP technique with a PNS technique for placement of continuous popliteal sciatic catheters found no significant difference in the primary outcome of 48-hour cumulative postoperative opioid consumption[47] and no significant differences in the secondary outcomes

of postoperative resting or dynamic analgesia. However, the use of USG decreased postoperative 48-hour local anesthetic perineural requirements by 75% (50 vs 197 mL). A second study comparing an ultrasound-guided SAX-OOP technique with a PNS technique demonstrated a significantly higher rate of postoperative sensory block (primary outcome) and decreased number of needle passes with USG.[48] Although there was no difference in postoperative visual analog scale pain scores, USG significantly decreased postoperative opioid requirements by 50% compared with PNS.

In summary, there is level Ib evidence for a grade A recommendation that USG decreases BPT and increases the rate of complete sensory block compared with PNS for single-injection popliteal sciatic nerve block. In terms of postoperative analgesic efficacy of continuous popliteal sciatic catheters, there is level Ib evidence to provide a grade A recommendation that USG appears to offer no clinically relevant advantage for either resting or dynamic analgesia but may decrease postoperative opioid and perineural infusion requirements.

Influence of USG Popliteal Sciatic Circumferential Local Anesthetic Distribution Patterns

Circumferential local anesthetic distribution (Table 3) around the sciatic nerve in the popliteal fossa typically requires multiple needle redirections and injections, potentially increasing the required number of needle passes and block-related discomfort, as well as BPT. Circumferential local anesthetic distribution may be accomplished either proximal to the SNBF (Pre-SNBF), at or just distal to the SNBF (SNBF), or distal to bifurcation of the sciatic nerve targeting the physically separate TN and CPN branches (Post-SNBF).

A single RCT of Pre-SNBF ultrasound-guided sciatic nerve block compared the techniques of multi-injection targeted circumferential local anesthetic injection around the sciatic nerve versus a single-injection (at the posterior surface of the sciatic nerve) technique and demonstrated that the rate of sensory block success (at 30 minutes) was significantly higher (94% vs 69%, $P = 0.01$) with circumferential local anesthetic distribution without significantly increasing BPT.[49] Three RCTs directly comparing Pre-SNBF with Post-SNBF circumferential local anesthetic distribution consistently demonstrated significantly faster (30% faster) sensory and motor BOT,[50,51] a higher rate of complete sensory block in both the TN and CPN distribution, as well as a higher rate of surgical block success (surgical anesthesia) at 30 minutes when circumferential local anesthetic distribution is targeted specifically at the Post-SNBF around both the TN and the CPN.[52]

In summary, there is level Ib evidence for a grade A recommendation that targeted circumferential local anesthetic distribution of the sciatic nerve increases the rate of sensory block success compared with noncircumferential local anesthetic distribution. Furthermore, there is level Ib evidence for a grade A recommendation that circumferential local anesthetic distribution specifically targeting the separate Post-SNBF TN and CPN branches significantly increases BOT and block success rate compared with targeting circumferential local anesthetic distribution around the more proximal Pre-SNBF common sciatic nerve.

Influence of USG Popliteal Sciatic Circumferential Local Anesthetic Distribution Compared With USG Popliteal Sciatic Subparaneural Local Anesthetic Distribution

Four RCTs with similar study designs compared 2 ultrasound-guided popliteal sciatic nerve block techniques (single-injection subparaneural at the SNBF vs multiple-injection extraparaneural Post-SNBF) investigating complete sensory BOT[53–55] or calculated the volume of local anesthetic in direct contact with the sciatic nerve[56] as the primary outcomes of interest (Table 3). These studies consistently demonstrated a significant decrease (33% to 42%) in BOT for compete sensory block and increased local anesthetic volume directly contacting the sciatic nerve with the subparaneural injection technique, highlighting the ability of the paraneural sheath to "trap" local anesthetic within the subparaneural compartment.[43] Additional secondary outcome benefits of the subparaneural SNBF injection technique included decreased BPT and ART, decreased number of needle passes, and increased block success rate (complete sensory block and/or surgical anesthesia), further confirming its outcome benefits compared with the extraparaneural Post-SNBF technique.

Given the superior outcome benefits demonstrated with the use of the ultrasound-guided subparaneural technique, a single RCT compared a single injection of local anesthetic within the subparaneural compartment either at Pre-SNBF or SNBF locations.[57] This study did not demonstrate any differences in ART, BOT, BPT, or block success rates when a subparaneural injection technique was performed at either anatomical location along the popliteal sciatic nerve. Given the high success rate of a single-injection subparaneural technique, a more recently published RCT compared a single-injection (at the SNBF) with a triple-injection technique within the subparaneural compartment (at the SNBF, as well as medial to the TN, and lateral to the CPN).[58] This RCT demonstrated equivalent outcomes of block success and ART, but expectedly, fewer needle passes with the single-injection subparaneural SNBF technique.

In summary, there is level Ib evidence for a grade A recommendation that the ultrasound-guided subparaneural injection technique significantly increases BOT and block success rate compared with an extraparaneural injection technique regardless of whether it is performed before or at the SNBF. Furthermore, the equivalence of the single-versus triple-injection technique supports the efficiency and simplicity of performing a single subparaneural injection, especially where the SNBF is easily identified with USG.

Influence of Ultrasound-Guided Subgluteal Sciatic Local Anesthetic Distribution

The influence of local anesthetic distribution for ultrasound-guided subgluteal sciatic nerve block (Table 3) has been studied in 2 RCTs, where the primary outcomes of interest were BPT[59] and block success.[60] One of the studies compared local anesthetic injection (15 mL bupivacaine 0.5% + 15 mL lidocaine 2%) with either a single-injection interfascial (subgluteal compartment between the gluteus maximus muscle and quadratus femoris muscle) technique versus a targeted circumferential multi-injection interfascial technique and demonstrated a significant decrease in BPT (4.4 vs 9.0 minutes, $P < 0.0001$), decreased number of needle passes, but no difference (64% vs 77%) in the secondary outcome of block success (complete sensorimotor block) at 30 minutes or postoperative analgesic efficacy when using the single-injection interfascial technique.[59] In contrast, a more recent study found that an ultrasound-guided multi-injection interfascial technique (using 20 mL mepivacaine 1.5%) significantly improved *block success*, defined as complete sensory block (41.2% vs 16.3%, $P = 0.018$) at 30 minutes, with only a slight increase in BPT (318 vs 276 seconds, $P = 0.037$) compared with a single-injection interfascial technique.[60] Although these 2 studies concur that a single-injection interfascial technique decreases BPT and (expectedly) number of needle passes, the differences in reported block success are likely caused by a number of differences in study design. First, the study that showed equivalent block success had a sample size of only 27 patients based on the primary outcome of BPT but

lacked the statistical power (would have needed 416 patients to show a 20% difference in block success) to demonstrate a clinically relevant difference in block success.[59] Second, the RCT that demonstrated improved block success with the multi-injection technique required only complete sensory anesthesia to define a successful block.[60] In contrast, the trial that demonstrated no difference required both a complete sensory and complete motor block to define a successful block.[59] Third, the higher overall block success rates in the study by Abdallah et al[59] may have been influenced by the higher local anesthetic given (300 mg lidocaine + 75 mg bupivacaine) compared with the lower local anesthetic dose (300 mg mepivacaine) given in the study by Yamamoto et al.[60]

A single RCT compared the block success rate between an ultrasound-guided subgluteal (posterior) approach with an ultrasound-guided anterior approach and found no significant differences in block success (primary outcome) or BPT.[61] Notably, an anterior sciatic nerve block approach is considered an advanced ultrasound-guided block because of the typically deep target location (with the average sciatic nerve depth of 5.9 vs 3.4 cm in the subgluteal group). The lack of difference in this study may have been influenced by the relatively small size (average body mass index, 22.7 in both) of the patients in both groups and may not be applicable in larger patient populations.

In summary, there is limited level Ib evidence for a grade A recommendation that a multi-injection technique specifically targeted to achieve circumferential local anesthetic distribution around the sciatic nerve within the subgluteal compartment increases BPT but increases the rate of complete sensory block compared with a single-injection technique.

Ankle Blocks

A series of volunteer studies with similar study designs (each with 18 volunteers) compared USG with traditional landmark-based field block for ankle block (Table 2) at the sural nerve,[62] tibial nerve,[63] or the deep peroneal nerve.[64] All 3 studies used 5 mL of 3% 2-chloroprocaine for each peripheral nerve with the *block success* defined as complete sensory block at defined time intervals after block placement. All 3 studies demonstrated a significantly faster onset of complete sensory block at all times points, whereas 2 of the studies demonstrated a significantly higher rate of complete sensory block with USG at the posterior tibial nerve (72% vs 22%, $P < 0.01$)[63] and sural nerve (78% vs 28%) within a predefined time interval.[62] However, in 2 of the 3 studies,[62,64] the use of USG doubled the BPT. Although there have been no prospective RCTs comparing USG with landmark-based field techniques for surgical anesthesia in the clinical setting, a large retrospective review of 655 patients during a 6-year period examined the block success rate of surgical anesthesia when USG was used to block the posterior tibial nerve and deep peroneal nerve as part of an ankle block.[65] In this retrospective study, ultrasound-guided block significantly increased the overall success of ankle block (84% vs 66%, $P < 0.001$) compared with landmark-based technique and was highly predictive of successful surgical anesthesia (adjusted odds ratio, 2.35; 9% confidence interval, 1.48–3.74, $P < 0.001$). The local anesthetic volumes used in this retrospective cases series was approximately 30 mL in both groups. An RCT compared a low-volume ultrasound-guided ankle block (16 mL) with a higher-volume landmark-based ankle block (30 mL) with 0.5% ropivacaine placed shortly after induction of general anesthesia.[66] This study demonstrated that the reduced local anesthetic volume associated with the use of USG marginally compromised postoperative resting analgesia (median numerical rating scale of pain = 1 vs 0, $P = 0.01$) during the first 24 hours compared with higher local anesthetic volume associated with the landmark-based technique, with no other clinically relevant outcome differences.

In summary, there is level Ib evidence for a grade A recommendation that USG increases the rate of complete sensory block. However, USG increased BPT within the setting of these volunteer studies. A single study comparing ultrasound-guided ankle block (using 50% less volume) with a landmark-based technique demonstrated no clinically relevant difference in postoperative analgesia. There is level III evidence for a grade B recommendation that USG may increase overall block success rate and possibly surgical anesthesia.

DISCUSSION

Since the initial review was published in 2009, there have been 34 additional high-quality RCTs (in 2439 patients and 64 volunteers) investigating the outcome benefits of USG for lower-extremity PNBs. Of those 34 additional studies, only 10 additional RCTs compared directly USG (4 combined with PNS) with PNS alone, and 5 RCTs directly compared USG with a landmark-based technique. In contrast, 14 RCTs investigated the influence of local anesthetic distribution around the femoral nerve (2 studies), the proximal sciatic nerve (2 studies), and the popliteal sciatic nerve (10 studies), highlighting the change in research focus to comparative studies of different ultrasound-guided techniques.[4,67] In addition, 3 RCTs investigated the influence of different ultrasound-guided techniques for continuous femoral nerve catheter placement.

In the clinical studies that directly compared USG with PNS, USG significantly decreased BPT,[10,11,46] decreased cumulative 48-hour local anesthetic requirements,[12] and increased the rate of complete sensory and motor block.[45,48] Ultrasound guidance was equivalent to PNS in only 1 RCT in terms of surgical block success for single-injection popliteal sciatic nerve block,[46] and this was a secondary outcome. In a single RCT, USG provided no significant analgesic benefit in cumulative 48-hour opioid consumption as the primary outcome but did provide significant local anesthetic sparing (75% less) during the 48-hour sciatic perineural infusion as a secondary outcome.[47] More importantly, USG was never inferior compared with PNS for any of the primary outcomes of interest.

In those RCTs where USG is used to guide needle tip localization before using concurrent PNS (as the primary nerve localization modality to further "fine-tune" needle tip–to–nerve proximity by adjusting the minimum current output) compared with PNS as the sole nerve localization technique, the combined technique provided superior outcome benefits. The benefit of USG before using PNS as the primary technique is most likely caused by more efficient needle tip placement offered by USG. In contrast, when USG is used as the primary modality to guide needle tip to nerve proximity, the addition of PNS to further "fine-tune" needle tip–to–nerve proximity provided no significant benefit in terms of block quality,[13] postoperative analgesic efficacy,[14,15] or motor BOT.[23] However, the combined technique consistently increased BPT and increased the number of needle passes and procedure-related discomfort as secondary outcomes when compared with the USG-only technique.[13–15,23] Thus, it seems that there is minimal clinical benefit to adding PNS to USG as an indicator of adequate needle-nerve proximity when USG is the primary nerve localization modality. Previous studies have documented the lack of correlation between needle tip–to–nerve distances and minimum current output requirements, highlighting the lack of sensitivity of current output to detect needle-to-nerve contact.[68,69] However, PNS may still play a complementary role as a qualitative adjunctive tool ("yes or no") to confirm

peripheral nerve location (or identity) when ultrasound visualization of target structures is less than optimal (because of obesity or deep location of target nerves) or when there is unexpected anatomical variability.[70,71]

There have been significantly more RCTs published in the last 5 years investigating the use of USG to optimize local anesthetic perineural distribution to further improve outcome benefits. For continuous FNB, there seems to be little difference in the degree of quadriceps motor block when the catheter tip is placed either above or below the femoral nerve, but there seems to be a slightly higher degree of sensory block with the catheter placed above the nerve. These findings in a volunteer study have not been validated in a clinical study of continuous femoral analgesia after TKA.

There has been increased interest in the last 5 years investigating the role of USG in achieving specific and targeted local anesthetic perineural distribution patterns at the anatomical level of the popliteal sciatic nerve. Three initial RCTs consistently demonstrated the benefits of more rapid BOT by specifically targeting circumferential local anesthetic distribution distal to where the sciatic nerve bifurcates into the TN and CPN.[50–52] The proposed mechanism for the more rapid BOT is that the local anesthetic is able to diffuse more rapidly and completely (from the outer mantle to the inner core) through the smaller-diameter TN and CPN compared with the larger common sciatic nerve located several centimeters cephalad to the SNBF.[72,73] Subsequent RCTs have consistently demonstrated that USG local anesthetic deposition within the subparaneural compartment decreases BOT, BPT, and ART compared with circumferential local anesthetic deposition in the more superficial extraparaneural compartment,[53–56] Although these randomized clinical studies highlight the outcome benefits of the subparaneural injection technique,[41,43] the potential risk of nerve injury associated with intentional injection deep to the paraneural sheath has not been defined in adequately powered RCTs or large case series.

There are limitations of this updated review and of the included studies. First, RCTs are often performed in academic medical centers with substantial expertise in both USG and PNS (or landmark-based field blocks). Thus, with high success rates inherent with traditional PNB techniques in these circumstances, it may be difficult to demonstrate significant improvements with USG. Conversely, the high success rate of USG reported in these RCTs (especially when comparing an established ultrasound-guided technique with a newer ultrasound-guided technique, such as the recently described subparaneural technique) might not be generalizable to daily practices that lack experience of expertise with USG. Second, additional bias may arise from the fact that the same individuals performed (or supervised) the comparative techniques (USG vs PNS or different USG techniques vs each other). Investigators may have been biased toward a particular technique, and this may have affected the overall outcomes. Third, a meta-analysis was not performed because of the substantial heterogeneity in the study designs, including multiple different primary outcomes and even different definitions of one of the primary outcomes (block success). In addition, the majority of the additional studies since the initial review focused now on which ultrasound-guided technique is superior, rather than which peripheral nerve localization technique is superior. Lastly, recently published large-scale case series have demonstrated that, although USG decreased (but has not eliminated) the incidence of local anesthetic systemic toxicity[74] compared with PNS, USG has not decreased the incidence of peripheral nerve injury.[75,76] However, outcome data regarding complications comparing different ultrasound-guided techniques are limited and need to be investigated by quality prospective observational studies in large databases, in addition to the limited number of small RCTs published to date.[77]

TABLE 4. Summary Statements, Grades of Recommendation, and Supporting Level of Evidence Comparing USG With an Alternative Peripheral Nerve Localization for Lower-Extremity PNBs

Primary Outcome	Grade of Recommendation	Level of Evidence
Decreased BPT (vs PNS)	A: Supportive of USG	Ib
Decreased BOT	A: Supportive of USG	Ib
Decreased local anesthetic requirements	A: Supportive of USG	Ib
Addition of concurrent PNS to USG	A: Not supportive of addition of concurrent PNS	Ib
Increased block success (rate of complete sensory block)	A: Supportive of USG	Ib
Improved postoperative analgesic efficacy for femoral perineural catheters	A: Not supportive of USG	Ib

BOT indicates block onset time; BPT, block performance time; PNS, peripheral nerve stimulation; USG, ultrasound guidance.

In summary, USG has clearly become the dominant peripheral nerve localization technique. Since the initial grade A recommendation based on level Ib evidence provided by 11 RCTs that USG decreased BOT, BPT, local anesthetic requirements, only 6 additional RCTs directly comparing USG with a PNS technique[10,44–48] and 5 additional RCTs (3 of them volunteer studies) directly comparing USG with landmark-based field block techniques[31,62–64,66] have been conducted. These 11 additional RCTs further reinforce the initial recommendations of decreased BOT and increased rate of complete sensory block and additionally supports decreased BPT but does not support improved analgesic outcomes in both continuous femoral and continuous sciatic catheters compared with a PNS technique (Table 4). The variety of primary outcomes of interest and the heterogeneity of study methodologies makes meta-analysis difficult. Importantly, there is no evidence to suggest that USG is inferior to PNS.

As importantly, the widespread adoption of USG has significantly increased the use of regional anesthesia, especially for lower-extremity PNBs. The research focus has appropriately evolved into investigating the optimal techniques for ultrasound-guided PNBs. Ultrasound guidance has expanded the applications of regional anesthesia and its well-known benefits of superior postoperative analgesia, decreased postoperative nausea and vomiting, and, currently with use of USG, increased efficiency in terms of decreased BPT, decreased BOT, and, when defined as rate of complete sensory block, increased block success.

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Update on Ultrasound for Truncal Blocks
A Review of the Evidence

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Abstract: We summarized the evidence for ultrasound (US) guidance for truncal blocks in 2010 by performing a systematic literature review and rating the strength of evidence for each block using a system developed by the United States Agency for Health Care Policy and Research. Since then, numerous studies of US guidance for truncal blocks have been published. In addition, 3 novel US-guided blocks have been described since our last review. To provide updated recommendations, we performed another systematic search of the literature to identify studies pertaining to US guidance for the following blocks: paravertebral, intercostal, transversus abdominis plane, rectus sheath, ilioinguinal/iliohypogastric, as well as the Pecs, quadratus lumborum, and transversalis fascia blocks. We rated the methodologic quality of each of the identified studies and then graded the strength of evidence supporting the use of US for each block based on the number and quality of available studies for that block.

What's New: Since our last review, numerous studies have been published, especially for the paravertebral and transversus abdominis plane blocks, and 3 novel US-guided blocks (Pecs, quadratus lumborum, and transversalis fascia blocks) have been described. Although some of these studies support the use of US for performing these blocks, others do not. Additional studies have used US to improve our understanding of the anatomy pertinent to these blocks and evaluated the effect on patient outcomes and risk of complications.

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The purpose of this review is to identify recent studies that evaluate the use of ultrasound (US) for performance of truncal blocks and to grade the strength of evidence recommending the use of US for each block based on amount and quality of evidence available. This update is part of an ongoing effort by the ASRA (American Society of Regional Anesthesia and Pain Medicine) to systematically review the evidence supporting the use of US for regional anesthesia. Updated reviews for other types of blocks will be published separately,[1] and an executive summary will accompany these reviews to provide an overview of this project.[2]

Peripheral nerve blocks of the trunk have been used extensively to provide anesthesia and/or analgesia for surgical procedures and painful conditions of the thorax or abdomen. The most commonly performed truncal blocks are the paravertebral, Pecs, intercostal, transversus abdominis plane (TAP), rectus sheath, and ilioinguinal/iliohypogastric (II/IH) blocks. Most of these blocks were initially described using landmark-based techniques[3,4] and have been used for decades with varying degrees of success. Because success rates using traditional approaches are highly operator dependent[5] and associated with potential serious complications,[6–9] these blocks were often underutilized despite potential benefits to patient outcomes.[10,11] Ultrasound guidance has renewed interest in these blocks by allowing anesthesiologists to reliably place local anesthetic (LA) in the desired location and avoid inadvertent needle trauma to surrounding structures.

We repeated our systematic search of the medical literature, with particular attention to recently published studies, to provide the most up-to-date recommendations that incorporate the numerous studies performed since our original summary on this increasingly popular subject.[12] Because we previously described the indications, traditional techniques, and potential complications for most of these blocks,[12] we have not included similar background information as part of this update. We also discuss 3 novel types of US-guided truncal blocks (the Pecs, quadratus lumborum [QL], and transversalis fascia blocks) that have been described since our previous article.

METHODS

We searched the MEDLINE, Cochrane Central Register of Controlled Trials, Ovid, and Google Scholar databases for studies published between August 2009 and March 2015 using the following search terms: "ultrasound" *with* "paravertebral," "Pecs," "pectoralis," "serratus," "intercostal," "transversus abdominis plane," "TAP," "rectus sheath," "quadratus lumborum," "transversalis fascia," "ilioinguinal," and "iliohypogastric." Only studies involving humans and available in English were included for review. Randomized controlled trials (RCTs), nonrandomized studies, and large case series were included. We also included relevant volunteer and cadaver anatomic, imaging, and pharmacokinetic studies because these have added substantially to our understanding of the blocks and inform current clinical practice. In addition, we searched the references of included studies for additional studies. We scored eligible studies for methodologic quality based on a system described by Jadad et al,[13] which is attached as Appendix 1. Based on the number and quality of studies for each block, we then graded the strength of evidence for use of US to perform each block using a system developed by the United States Department of Health and Human Services, Agency for Health Care Policy and Research.[14] This grading system is attached as Appendix 2.

As we reviewed recent literature, we felt that the various new studies regarding US-guided truncal blocks could be categorized into 3 groups: studies on the anatomy or technical performance of the blocks, studies on clinical outcomes in patients receiving the blocks, and studies related to complications of the blocks. As a result, we have structured our discussion by grouping studies into these 3 groups. We have summarized the studies included in this review in Table 1. Whenever possible, we emphasize studies that directly compare blocks performed using US with those performed using traditional techniques. However, we include other studies that may help inform clinicians whether or not to use US for these blocks as well as how to safely and effectively perform these blocks with US guidance. We excluded studies that involved these blocks but did not specifically examine the use of US.

We rated the quality of the individual studies using a widely used validated scoring system.[13] Our grades for strength of recommendation are based on a validated standardized system

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TABLE 1. Summary of Studies Included in This Review

First Author (Year Published)	Study Design	Comments	N	Success Rate/Outcomes	Complications	Jadad Score	Level of Evidence/ Recommendation
Paravertebral: Grade B anatomy/technique							
Albokrinov, AA (2014)	Cadaver anatomic	Unilateral transverse IP USG TPVBs done at T12 level in 20 unembalmed infant cadavers. Divided into 5 groups, depending on volume of dye injected (0.1, 0.2, 0.3, 0.4, or 0.5 mL/kg)	20	Dye stained T11-L1 nerve roots in all specimens. Craniocaudad spread, spread anterior to vertebral body, contralateral spread all correlated with volume injected	N/A	N/A	IIb
Kaur, B (2013)	Prospective observational	Unilateral USG TPVBs using either longitudinal IP approach or longitudinal OOP approach (w guidance system). Blocks w 5 mL 0.5% ropi per level, 3 levels per patient	10 (24 blocks in 8 patients, 5 patients each technique, 1 withdrawal guidance group)	80%. 2 patients did not have blocks completed	No major complications reported. One failed block in GPS group had 35 min procedure time	N/A	III
Marhofer, P (2013)	Volunteer anatomic/imaging	Volunteers had bilateral (1 side per day, randomly assigned) USG transverse OOP TPVBs T6 w 20 mL 1% mepi. MRI (radiologist blinded to side injected) to measure LA spread, pinprick testing done (blinded?)	10 volunteers (20 blocks)	MRI LA spread 4 vertebral levels. Sensory changes mean 10 levels. Sensory levels unpredictable, poorly correlated w MRI	No major complications reported. 2 volunteers treated for low HR or BP	2	IIb
Guay, J (2011)	Cadaver anatomic	US-assisted technique, USG transverse, IP intercostal techniques in embalmed cadavers. Spread of dye/ nerve involvement assessed by dissection	3 cadavers (61 blocks: 55 US-assisted, 6 real-time USG)	3 mL/level to cover nerve roots from C8 to T6. Calculated volume of 41 mL to cover all levels. USG intercostal technique not possible above T4 because of scapulae	N/A. US-assisted blocks w needle advanced 2 cm past contact w transverse process had intrapleural latex 8 of 17 injections	N/A	III
Luyet C (2011)	Cadaver anatomic/imaging	Blocks placed using LOR or transverse OOP USG in embalmed cadavers. Position of needle/catheter tips, spread of dye injected through catheters assessed by CT	10 cadavers (62 blocks: 26 LOR, 36 USG)	Needle tip correctly located 94% USG, 50% LOR. Catheter tip correct 14% USG, 12% LOR	N/A. One catheter tip in pleural space for USG group, 6 catheters w epidural spread (7.7 levels), 4 w pleural spread (6.3 levels)	N/A	III
Cowie B (2010)	Cadaver anatomic	USG transverse, IP TPVBs/catheters in unembalmed cadavers. Blocks were single-injection (20 mL T6-T7) or double injection (10 mL each T3-T4, T7-T8). Catheters placed after injection of dye. Spread of dye and catheter placement assessed by dissection	10 cadavers (30 blocks: 30 injections, 20 catheters)	95% of cadavers w dye in TPVS, 100% w intercostal spread. Single, dual-injection techniques w similar PV spread, (3–4 levels), epidural spread (40%). Dual injection w greater intercostal spread (6 levels vs 4.5)	N/A. Epidural spread limited to 1 level all cases. 60% of catheters in TPVS, 20% prevertebral, 1 epidural, 15% of catheter tips could not be located	N/A	III
Marhofer, P (2010)	Technical/prospective case series	Unilateral USG transverse, OOP TPVBs at T3, T6. Patients had surgery with propofol/LMA anesthesia	20	No patient required opioids intraop or postop	No major complications reported. Mean MAP decreased by 25% postblock. One patient treated for low HR, 12 of 20 treated for low BP	N/A	III
O'Riain, S (2010)	Cadaver anatomic/ technical/ prospective case series	Longitudinal, IP USG technique tested in cadaver then performed in patients. Blocks w 0.3 mL/kg 0.25% bupi bolus, 24-h infusion 5 mL/h started postop	10 (9 blocks completed)	66% sensory change preop, 100% postop. 2 patients given morphine intraop, 2 postop	No major complications reported. No discussion of 1 patient w failed block	N/A	III

Paraskeuopoulos, T (2010)	Cadaver anatomic	USG TPVBs performed using either transverse or longitudinal intercostal in embalmed cadavers. 1 mL dye injected, spread assessed by dissection	11 cadavers (33 blocks: 19 transverse, 14 longitudinal)	Dye in TPVS 89.5% transverse, 92.8% longitudinal. No intrapleural dye either technique	N/A	N/A	III
Renes, S (2010)	Prospective case series	Unilateral USG, IP transverse TPVBs. Blocks w 15 mL 0.75% ropi. Sensory changes assessed by blinded assessor. Catheter location confirmed postop by contrast injection, CXR. Infusion 0.2% ropi 10–14 mL/h	36	100%. 5 patients undergoing breast surgery had surgical blocks. Mean 6 dermatomes blocked after initial injection. All dye from catheters in TPVS on CXR	No major complications reported. One catheter w epidural contrast spread (patient had no contralateral sensory changes, HR/BP stable)	N/A	III
Ben-Ari, A (2009)	Technical/prospective case series	After US scanning a cadaver and a live model, bilateral USG TPVB catheters placed using a transverse, IP intercostal approach. Bolus 10 mL 0.5% ropivacaine preop, 10 mL 1.5% lidocaine postop, infusion 0.2% ropi 10 mL/h	12	96% (confirmed by pinprick after initial bolus of LA). Mean dilaudid 1.9 mg first 24 h. Mean VAS 5.5 day 1	No major complications reported. One patient had failed block 1 side	N/A	III
Pecs: Grade A anatomy/technique							
Blanco, R (2013)	Technical, volunteer anatomic/imaging	Description of "serratus plane" block technique. Bilateral blocks performed with 0.4 mL/kg 0.125% levobupi, 1 mmol/kg gadolinium. Sensory examinations, MRI scans performed in all patients	8 (2 blocks, 1 each side in 4 volunteers). Injection superficial to serratus muscle on 1 side, deep contralateral	100%. All patients had paresthesia T2-T9. Injection superficial to serratus muscle had longer sensory (752 vs 386 min) and motor block (778 vs 502 min) than deep injection	None reported	N/A	IIb
Blanco, R (2012)	Technical	Description of technique for "Pecs II" block, Plain radiographs, MRI scans with contrast done in 1 patient	"Over 100 patients"	Not reported	None reported	N/A	III
Blanco, R (2011)	Technical	Description of technique for "Pecs I" block. Blocks performed with 0.4 mL/kg 0.25% levobupi	"Approximately 50"	Not reported	None reported	N/A	III
Outcomes							
Wahba, SS (2014)	RCT	Patients undergoing modified radical mastectomy under GA randomized to receive either landmark-based TPVB at T4 (15–20 mL 0.25% levobupi) or Pecs I (10 mL 0.25% levobupi) and II (20 mL 0.25% bupi) blocks	60 (30 patients in each group)	Success rates not reported. Patients in Pecs blocks group had lower intraop fentanyl requirement, lower Numerical Rating Scale score at rest and with movement, morphine consumption first 24 h after surgery	None reported	3	Ib
Intercostal: Grade C outcomes							
Shankar, H (2010)	Retrospective case series	Review of internal data. Steroid injections for neuralgia. USG blocks compared with blocks placed using fluoroscopic guidance	39 (12 USG, 27 w fluoro)	Similar reductions in VAS for patients in both groups	None. 2 cases if intravascular injection in fluoro group	N/A	III
TAP: Grade A anatomy/technique							
Moeschler, S (2013)	Cadaver anatomic/ imaging	USG mid-axillary TAP blocks w varying volumes contrast (5, 10, 15, or 20 mL) in unembalmed cadavers, spread assessed by CT	2 cadavers (4 blocks)	Needle tip L3/L4 disk level all injections, 1 level covered w 5 mL, 2 w 10, 15, 20 mL	N/A. Intraperitoneal spread w 15 mL injection	N/A	III

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TABLE 1. *(Continued)*

First Author (Year Published)	Study Design	Comments	N	Success Rate/Outcomes	Complications	Jadad Score	Level of Evidence/ Recommendation
Murouchi, T (2013)	Cadaver anatomic	USG 2-injection (subcostal, mid axillary) TAP blocks w 10 mL dye per injection in embalmed cadavers, involved nerves assessed by dissection	7 blocks (1 per hemi-abdominal wall)	T8-T11 nerves dyed 100%, T7 14%, T12 71%, L1 43% of specimens	N/A	N/A	III
Børglum, J (2012)	Prospective, double-blinded volunteer anatomic/ imaging/ pharmacokinetic study	Volunteers had bilateral USG TAP blocks, 1 side w 30 mL mid-axillary, the other w 2 injections (15 mL subcostal, 15 mL mid-axillary). Sensory distribution assessed, plasma LA levels measured, spread of LA measured with MRI sequentially for 6 h. Sensory examinations by blinded anesthesiologist, neurologist. MRI by blinded radiologist	8 volunteers (16 blocks)	MRI spread mean 7 dermatomes w 2-injections, 3 w 1 injection. Area of spread increasing all time points, all techniques. No spread to upper TAP plexus w mid-axillary injection. No single injection subcostal group	None. No toxic levels of ropivacaine measured during study period	5	Ib
Børglum, J (2011)	Prospective case series	PACU patients had bilateral 2-injection TAP blocks. 15 mL 0.25% bupi per site	25	Mean VAS decreased from 8.2 to 2.2 in 10 min. 84% no opioids 6 h after blocks, 64% mobilized by 6 h postblock	None	N/A	III
Carney, J (2011)	Volunteer anatomic/ imaging	Volunteers divided into 4 groups had TAP blocks using different approaches: landmark LTOP or USG subcostal, mid-axillary, or posterior. Blocks done with 0.125% levobupi, 0.3 mL/kg one side and 0.6 mL/kg on the other. Sensory examination and MRI scans done 1, 2, and 4 h after block	26 (2 blocks per volunteer, 13 volunteers) 8 LTOP, 8 subcostal, 4 mid-axillary, 6 posterior	1 of 8 LTOP block failure. All other blocks successful. LTOP, posterior approaches most similar with spread T4-L2. No spread of LA into TAP. Subcostal LA spread in TAP to T9-T10. Mid-axillary approach had spread in TAP, between internal/ external oblique muscles	None	N/A	IIb
Lee, T (2010)	Prospective observational	Posterior or subcostal USG TAP blocks. Sensory distribution, morphine consumption, pain at rest and w coughing, block duration compared.	50 patients (81 blocks)	98%. Subcostal block 4 dermatomes (highest T8), posterior 3 (highest T10). Morphine consumption, pain at rest and w coughing, block onset (30 min), duration (24 h) similar between groups	None	N/A	III
Barrington, M (2009)	Cadaver anatomic	USG TAP blocks in unembalmed cadavers using subcostal single (20 mL dye) or multiple (4 w 5 mL each) injection techniques. Spread of dye, nerve involvement assessed by dissection	7 cadavers (14 blocks: 7 single, 7 multiple)	Single-injection mostly T10, 11. Multiple-injection technique w larger area of spread. No difference in number of nerves involved	N/A	N/A	III
Tran, T (2009)	Cadaver anatomic	US-guided mid-axillary TAP blocks performed in unembalmed cadavers. Spread of dye, nerve involvement assessed by dissection.	8 cadavers (16 blocks)	T11/12 nerves involved 100%, L1 93%, T10 50%, T9 0%	N/A	N/A	III
Outcomes							
Abdallah, F (2013)	Meta-analysis	Review/analysis of RCTs examining effectiveness of USG lateral vs anatomic LTOP TAP blocks (each vs placebo). No studies directly comparing techniques	12 studies involving 641 patients (7 studies USG, 5 LTOP)	LTOP TAP blocks reduced morphine consumption, VAS first 48 h. No differences USG groups and controls	N/A	N/A	Ia

Abdallah, F (2012)	Meta-analysis	Review/analysis of RCTs examining effectiveness of TAP blocks for pain control following Caesarean section. TAP block compared to compared to patients with/without intrathecal morphine (ITM)	5 studies involving 312 patients (3 studies placebo vs. USG, 2 vs. LTOP)	TAP block reduced morphine consumption, VAS, nausea first 24 hr in patients without ITM. No differences in patients with ITM. No comparison USG vs. LTOP	N/A	N/A	Ia
Johns, N (2012)	Meta-analysis	Review/analysis of RCTs examining effectiveness of TAP block for abdominal surgery	Nine studies involving 413 patients (7 studies involved USG TAP)	Patients in TAP groups had less morphine consumption, nausea, first 24 h. Non-significant reduction in VAS for TAP groups	N/A	N/A	Ia
Complications							
McDermott, G (2012)	Observational case series	Landmark-based TAP blocks, needle position, distribution of LA assessed by US	36	24% of injections had spread of LA in correct plane	None reported despite 13 intraperitoneal injections	N/A	IIb
Aissou, M (2011)	Observational case series	Landmark-based unilateral TAP blocks. Needle position, distribution of LA assessed by US during block	52	14 of 52 blocks placed in correct plane	Of remaining 38, None reported despite 2 intra-peritoneal injections. 25 blocks failed	N/A	IIb
Petersen, M (2011)	Randomized, double-blinded crossover volunteer physiologic	Volunteers randomly assigned to receive dual-injection USG TAP blocks (15 mL per injection) with 0.25% bupi or saline. 3 wk later, volunteers received block w other solution	11	No differences between groups in FEV1, FVC, maximum expiratory pressure or no. abdominal quadrants anesthetized	None but possibly high rate of failed blocks because of inconsistent anesthesia in blocked areas	5	Ib
Quadratus lumborum: Grade B outcomes							
Charkrabouty, A (2015)	Case report	Unilateral continuous block placed in a 7-y-old patient undergoing radical nephrectomy	1	Not reported, though the patient had minimal pain postoperatively	None reported	N/A	III
Kadam, VR (2015)	Case report	Bilateral continuous catheters placed in an 89-y-old man undergoing hemicolectomy with midline incision. 20 mL 0.5% ropi injected per side, 0.2% ropi infusions at 5 mL/h	2 (1 block per side)	Patient had dynamic pain scores 1–2 (0–10 scale) 48 h postop, received minimal rescue analgesics	None reported	N/A	III
Carvhalo, R (2014)	Case report	Unilateral block in a 61-y-old patient with chronic neuropathic abdominal pain. Block done with 25 mL 0.2% ropi, 20 mg methylprednisolone	1	Patient had immediate pain relief, effect sustained for 6 mo after injection	None reported	N/A	III
Kadam, VR (2013)	Case report	Unilateral block performed for a 66-y-old man undergoing duodenal tumor excision with a subcostal incision. 25 mL 0.5% ropi injected, fentanyl PCA given for postop analgesia	1	Patient had 0/10 pain score first 15 h then required fentanyl PCA. Had 7–9/10 VAS scores second postop day	None reported	N/A	III
Rectus sheath: Grade A outcomes							
Gurnaney, HG (2011)	RCT	Patients randomly assigned to receive either bilateral USG RSB (preincision) or LA infiltration by surgeon (end of surgery). Volume of LA predetermined based on weight (same both groups)	54 (26 each group, one dropout each group)	Not formally assessed (blocks performed under GA). Lower intraop opioid requirements in RS group, no difference postop	None	5	Ib

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TABLE 1. *(Continued)*

First Author (Year Published)	Study Design	Comments	N	Success Rate/Outcomes	Complications	Jadad Score	Level of Evidence/ Recommendation
Wada, M (2012)	RCT	Patients having bilateral USG RSB randomly assigned to receive 10 mL (per side) of 1 of 3 concentrations of LA (0.25%, 0.5%, 0.75% ropi), plasma levels of LA measured serially for 3 h after block	39 (13 each group)	Not formally assessed, plasma levels peaked at 30–60 min postblock	None reported. Highest plasma ropi level 2.88 μg/mL 45 min postblock w 0.75% ropi	4	Ib
Transversalis fascia: Grade B anatomy/technique							
Hebbard, P (2009)	Technical	Description of transversalis fascia plane block	17	One patient "early in the experience" required reblock	None reported	N/a	III
Outcomes							
Chin, K (2012)	Retrospective review, case series	Patients requiring anterior iliac crest bone graft harvest for forearm fracture surgery under GA/brachial plexus block	27 patients (12 patients had transversalis fascia block performed)	Patients who received transversalis fascia blocks had lower intra, postop analgesic requirements, had lower resting pain scores in PACU	None reported	N/A	III
II/IH: Grade A anatomy/technique							
Schmutz, M (2013)	Blinded volunteer anatomic/ imaging study	Evaluation of selectivity of USG II and IH nerve blocks performed w 0.9 mL 1% mepi. Sensory changes mapped by blinded assessor	16 volunteers (50 blocks)	Sensory areas blocked overlapped >60%, spread of LA from 1 nerve to the other 12%	None	N/A	IIb
Outcomes							
Nan, Y (2012)	RCT	Patients randomly assigned to receive either unilateral USG (0.2 mg/mL) or landmark-guided II/IH (0.3 mg/mL) blocks w 0.25% levobupi. Intraop HR, BP, fentanyl, sevo concentration recorded. Postop FLACC score used to assess pain postop	100 (50 patients per group)	Lower HR on incision, intraop sevo, postop pain scores, higher parental satisfaction in USG group despite lower volume of LA	One patient in traditional group had vascular puncture. No serious complications reported.	5	Ib
Ford, S (2009)	Prospective observational/ educational	After completing e-learning tutorials, novice operators performed, labeled US scans (in patients under GA), Images/labels scored by a blinded assessor. No blocks performed.	132 (5 scans not recorded)	Novice operators could reliably identify muscle planes after 14–15 scans, not nerves even after 18 scans	N/A	N/A	IIb
Complications							
Randhawa, K (2010)	Prospective observational	Experienced operator placing unilateral II/IH blocks using landmark technique, needle position assessed by US	21	12/21 needle tip in correct plane. Block success not formally assessed	None reported despite 9 blocks performed deep to transversus abdominis	N/A	III

CT, computed tomography; USG, ultrasound-guided/ultrasound guidance; VAS, visual analog scale.

developed by the United States Department of Health and Human Services[14] and are independent of the quality scores. These are discussed below for each block and are summarized in Table 2. Because the grades we gave in this study did not always match those we gave in our previous review, we include our previous grades and then combine both grades to come up with an overall grade for each block.

DISCUSSION

Paravertebral Block

Anatomy/Technique

The recent studies pertaining to US guidance for thoracic paravertebral block (TPVB) have focused primarily on anatomy and technique. Several clinical, imaging, and anatomic studies in volunteers and cadavers have improved our understanding of different US-guided techniques. Several new techniques have been evaluated in prospective clinical case series as proofs of concept.

Many anatomic and imaging studies of cadaveric specimens used US to perform TPVB and evaluate the spread of injectate from a block needle or catheter. Paraskeuopoulos et al[15] compared a technique using axial (transverse) transducer orientation with one using a parasagittal (longitudinal) one in a cadaver model. Both performed an in-plane (IP) needling technique, and both techniques resulted in a high likelihood of dye spread in the thoracic paravertebral space (TPVS). No injection resulted in intrapleural dye spread in either group. Cowie et al[16] studied a similar transverse IP technique in 10 cadavers and compared single- versus dual-injection techniques. They found that both approaches had similar dye spread in the TPVS (3 vs 4 levels, P = NS), whereas there was greater intercostal spread (4.5 vs 6 levels) for the dual-injection technique. Although both groups had a similar incidence of epidural spread (40% or 4 specimens each group), this was confined to a single level irrespective of approach. In addition, they placed catheters after dye injection and found 60% (12 of 20) of the catheters' tips in the TPVS. Twenty percent (4 of 20) were prevertebral, one was in the epidural space, and 15% (3 catheters) could not be located although they were not in the TPVS. Luyet et al[17] used a similar technique (transverse IP) to place needles and catheters in the TPVS (36 US-guided blocks) of cadavers, and they compared this with a traditional loss-of-resistance (LOR) technique (26 LOR blocks). They found that the US technique resulted in a much higher rate of correct needle placement (defined as immediately lateral to the intervertebral foramen, 94% (34 of 36) US group versus 50% LOR (10 of 20). Despite the high rate of proper needle placement in the US group, the rate of correct placement of the catheter tip was similarly low to that of the LOR group (14% or 5 of 36 vs 12% or 3 of 26), with 6 catheters in the US group having extensive spread of dye injected through the catheter into the epidural space (mean, 7 levels). In addition, 4 catheters in the US group had extensive pleural spread (mean, 6.3 levels). Guay and Grabs[18] studied a US-assisted technique in cadavers, measuring the depth to the transverse process, and then using a traditional technique, walking the needle either 1.5 or 2 cm past the transverse process. They found a high rate of intrapleural injection (8 of 17) in the 2-cm group. Albokrinov and Fesenko[19] studied the spread of dye injected into the lower TPVS (T10) of infant cadavers. They used a US-guided transverse IP approach and found dye in the TPVS in all specimens and calculated an optimal volume of 0.2 to 0.3 mL/kg of injectate to optimally cover nerve roots T10 to L1.

Studies in volunteers have used US guidance to further clarify the behavior of LA within the TPVS. Marhofer et al[20] evaluated the clinical effect of US-guided TPVBs and spread of LA in the TPVS using magnetic resonance imaging (MRI). Volunteers had 20 mL of 1% mepivacaine injected at T6 using a transverse out-of-plane (OOP) technique. Sensory changes were mapped by pinprick testing, and MRI scans were done after injection. They found a poor correlation between the extent of LA spread on MRI and the number of dermatomes affected. Magnetic resonance imaging scans showed LA spread covering a mean of 4 vertebral levels, whereas the mean number of dermatomes involved was 10. There was no consistent relationship between the cranial/caudal extent of LA spread on MRI and the dermatomes with sensory changes. Although there were no reported complications, a large percentage of patients (8 of 20 or 40%) had spread of LA outside the TPVS, and 5 of these patients (25%) had epidural spread. Two volunteers required treatment for bradycardia and/or hypotension. One of these patients had LA in the epidural space on MRI. The other 4 patients with epidural spread of LA did not require any treatment for hemodynamic changes.

Case series describing different techniques have provided proof of concept for several new US-guided approaches to the TPVS. To avoid the neuraxis, Ben-Ari et al[21] adapted a blind subcostal approach and developed a US-guided lateral transverse IP intercostal technique by scanning a cadaver and a live model. They then performed this technique in 12 patients undergoing elective abdominal surgery. Bilateral blocks were performed at T7 to T10, and catheters were placed at T9/T10. Ninety-six percent (23 of 24) of blocks produced sensory changes after initial injection, and 11 of 12 patients had "satisfactory" analgesia after surgery (mean Numerical Rating Scale score, 5.5/10, postoperative day 1). Kaur et al[22] performed unilateral TPVBs for 10 patients undergoing percutaneous nephrolithotomy. Blocks were performed using either a US-guided transverse IP technique or a transverse OOP technique with a commercial US image guidance system. Eight blocks were completed. One was abandoned because of patient factors; the second, because of technical problems with the image guidance system. All completed blocks were successful. No complications were reported in any of these case series. Abdallah and Brull[23] recently described a simple modification to a longitudinal IP technique to allow needle entry into the TPVS by moving the target to the side of the US image (as opposed to the center) to prevent a "double fulcrum" effect caused by the relative positions of the US transducer and transverse process.

TABLE 2. Evidence-Based Recommendations for Truncal Blocks

Block	Grade Recommendation	Level of Evidence
Thoracic paravertebral	B	IIb-III
Pecs	A	Ib-III
Intercostal	C	III
TAP	A	Ia-IIb
Quadratus lumborum	B	IIb
Rectus sheath	A	Ib
Tranversalis fascia	B	III
Ilioinguinal/iliohypogastric	A	Ib-IIb

Outcomes

Although no studies have specifically evaluated the effect of US guidance for TPVBs on clinical outcomes, several case series[24–27] demonstrate that several US-guided techniques can

improve early outcomes compared with placebo after a variety of surgical procedures and may provide equivalent pain relief and better hemodynamic stability compared with thoracic epidural analgesia.[28] In addition, recent studies on the potential longer-term effect on clinical outcomes of US-guided TPVBs[29] suggest that US-guided TPVBs may have similar beneficial effects to those placed using traditional techniques,[11] although the effect of the use of US on long-term outcomes has not been specifically investigated.

Although the success rates reported in the above case series are very good, no head-to-head comparisons between any of the US techniques described have been published. In addition, no clinical study has directly compared success rates for any of these techniques and a traditional technique. The cadaver studies by Cowie et al[16] and Luyet et al[17] suggest that US guidance may increase the success rates for single-injection blocks but not for catheter placement. However, these studies used a very strict definition for correct catheter placement, so it is possible that many of the catheters deemed misplaced (epidural, prevertebral, adjacent to the vertebral body, intercostal) could have been effective in a clinical setting. Based on the findings of their anatomic studies, Luyet et al[30] have developed a catheter with a self-coiling tip to help the catheter tip remain close to the needle tip and intended target location. Clinical trials evaluating the effectiveness of this design have not yet been published.

Complications

Although it is tempting to assume that blocks placed with US may have a lower risk of complications because of real-time visualization of the needle tip and spread of LA, there are no data to support such a claim at this time. There has been a report of pleural puncture and intrathoracic catheter placement for a block performed with US,[31] so mechanical complications are certainly still possible even if US is used. These may be especially common for continuous catheter-based techniques, as suggested by the cadaver studies mentioned earlier.[16,17]

There is even a possibility that US techniques could increase the risk of epidural or intrathecal spread of LA because of the proximity of the needle tip to the intervertebral foramen.[16,17] In a case series by Marhofer et al,[25] several patients (12 of 20) had intraoperative hypotension. This is similar to a later MRI study by the same group (2 of 10 subjects hypotensive, no sedation given).[20] These effects were likely related to the blocks (epidural spread or elevated plasma levels of LA), although plasma levels of LA were not measured in these studies. To date, no study has compared directly the different US-guided approaches regarding the relative risk of LA spread to the epidural or pleural spaces, elevated plasma levels of LA, or other complications. No clinical study has been published comparing any of these US-guided techniques and traditional techniques with regard to the risk of complications.

Grade

Despite the large number of studies evaluating the use of US guidance for TPVBs, there is still little information on the effect of US guidance on either block success or complication rates compared with traditional techniques. Only 1 cadaver study suggests that US-guided techniques may allow more consistent placement of needles but not catheters within the TPVS. Ultrasound-guided techniques may also be associated with an increased likelihood of epidural spread of LA, the desirability of which is debatable. In addition, success or complication rates of the various US-guided techniques have not been compared directly. Based on 2 level IIb and 9 level III studies, we give the evidence supporting the use of US to perform TPVB a grade of B. We previously gave a grade of B and, because there are still no level Ia or Ib studies supporting the use of US to perform TPVB, we give an overall grade of B.

Based on these studies, it seems that the use of US is more likely than traditional techniques to allow consistent positioning of a needle's tip but not a catheter within the TPVS. Several US-guided techniques have been described that may be safe and/or effective, although it is possible that current end points used for some of these could be associated with an increased risk of epidural LA spread, the clinical significance of which is unclear. At this time, we cannot comment on which US-guided technique is ideal or which may be best suited for a particular situation. More studies are needed to clearly understand the effect of US on success rates and complications of single-injection and continuous techniques, as well as any effect of US on short- or long-term patient outcomes. It is likely that interest in the use of US for TPVB placement will remain an active area of research until the indications, techniques, and end points for US-guided TPVB are more clearly defined.

Pecs Blocks

First described by Blanco[32] in 2011, the Pecs block is a novel US-guided interfascial plane block intended to provide anesthesia and/or analgesia of the upper anterior chest wall while avoiding some of the more serious complications associated with neuraxial techniques or TPVBs.

Anatomy/Technique

The initial report described a technique placing LA in the plane between the pectoralis major and minor muscles, adjacent to the pectoral branch of the thoracoacromial artery ("Pecs" or "Pecs 1" block).[32] This technique was later adapted to provide better coverage for more extensive procedures, especially involving the axilla.[33] For these, a second injection of anesthetic is performed more laterally in the plane between the pectoralis minor and serratus anterior muscles at the level of the third and fourth ribs ("Pecs 2" block). Blanco et al[33] also reported evaluating the spread of dye using plain radiographs and MRI in 1 patient. They went on to develop another variation, which they called the "serratus plane" block.[34] This block involves an injection superficial to the serratus anterior muscle producing intercostal spread of LA. They described the distribution of LA spread in 4 volunteers using MRI and correlated these findings with detailed sensory examination.

Outcomes

In his initial description, Dr Blanco[32] reported having performed the Pecs 1 block with "good" results in "over 50 patients" as well later having placed "over 100" continuous catheters with "good" results,[33] although objective patient outcomes were not provided. Although this block was initially used for patients undergoing breast surgery, it has also been described for patients undergoing other superficial procedures such as pacemaker insertion[35] and upper-limb fistula surgery.[36]

Wahba and Kamal[37] compared US-guided combined Pecs 1 and 2 blocks to TPVB at T4 in patients undergoing modified radical mastectomy. They found that the patients in the Pecs block group had lower intraoperative opioid requirements and better postoperative pain control. They found that the Pecs blocks provided better coverage of the axilla and that patients in the Pecs block group had less nausea. The Pecs blocks were performed using US guidance, and the TPVBs were performed using a traditional LOR technique. This seems to support the use of US for

Pecs blocks but does not allow for comparisons to be made with other US-guided TPVB techniques.

Complications

To date, no report of complications after US-guided Pecs blocks has been reported. The study by Wahba and Kamal[37] did not report any complications in either study group, although 1 patient in the TPVB group had mild intraoperative hypotension.

Grade

This new block has only been described using US to guide needle placement and deposition of LA in the correct intramuscular plane(s). Several small studies suggest other clinical uses for this novel block, and further investigation is warranted. Based on 1 level Ib study, 1 level IIb study, and 2 level III studies supporting the use of US for Pecs blocks, we give the evidence a grade of A.

Intercostal Block

Anatomy/Technique

No new studies have specifically focused on the anatomy or sonoanatomy of the intercostal block. Studies on the intercostal approach to the paravertebral block are discussed above in the TPVB section.

Outcomes

Ultrasound guidance has been compared with traditional "blind" landmark-based techniques as well as those using fluoroscopic guidance. Shankar and Eastwood[38] retrospectively compared US-guided intercostal injection of corticosteroids with fluoroscopically guided injections to treat patients with neuralgias. They found that both techniques were associated with similar decreases in pain scores, but that 2 blocks placed under fluoroscopic guidance were complicated by intravascular injections. It is unclear how this would apply to blocks performed with LA only for patients with acute pain or for surgical anesthesia, however.

Complications

No new study has specifically focused on the effect of US guidance on complications related to intercostal blocks, but the above study[38] suggests that the use of US may decrease the likelihood (or detection of) intravascular injection.

Grade

Based on evidence from 1 level III study, not clearly supporting the use of US to perform intercostal blocks, we give the evidence a grade of C. We previously gave a grade of D, so the overall grade is C (C is the least strong recommendation possible using the current system). More rigorous studies are needed to determine the effect of US on success rates, complications, or clinically relevant patient outcomes.

TAP Block

Since our last review, several investigators have found that the techniques initially described for US-guided transverse abdominis plane (TAP) block (commonly referred to as the "anterior," "lateral," or "mid-axillary" approach) did not provide adequate analgesia for procedures involving incisions above the level of the umbilicus.[39] For this reason, 2 new approaches to the TAP have been developed using US guidance. The "oblique subcostal" approach was first described by Hebbard[40] in 2008 and the "posterior" approach (also called the "quadratus lumborum" block, see section below), which was first described by Blanco in 2007.[41,42]

Anatomy/Technique

Many recent studies have used US to help define the relevant anatomy of the TAP block. Additional studies have used US to improve the understanding of the spread of LA within the TAP as well as the sensory distribution for several different techniques. These studies have changed many practitioners' block technique because those initially described (performed along the mid-axillary line at the level of the umbilicus) may not be well suited for many procedures, especially those involving incisions above the umbilicus.

Tran et al[43] studied the spread of dye within the TAP in a cadaver model. They injected 20 mL of dye using a mid-axillary IP approach (at the level of the umbilicus) and found that the T11, T12, and L1 nerves were consistently stained with dye, whereas the T10 nerve was only covered in 50% (8 of 16) of the specimens. No specimen had dye reaching the T9 nerve, supporting observations that this approach may be most appropriate for lower-abdominal procedures.[44,45] A follow-up study comparing subcostal single- or multiple-injection techniques[46] found that both techniques involved a similar number of nerves, with T10 and T11 most consistently involved. However, they also found that the multiple-injection technique resulted in a larger area of dye spread. Moeschler et al[47] also studied the spread of dye within the TAP of cadavers. They injected increasing volumes of contrast (transverse IP technique, mid-axillary line at level of umbilicus) and evaluated spread using cross-sectional axial computed tomographic imaging. They found that the needle was placed at the level of the L3/L4 disk in all specimens, and that 5 mL of contrast covered only 1 vertebral level, whereas 10, 15, or 20 mL covered two. Murouchi et al[48] studied a 2-injection technique (transverse IP, mid-axillary, and subcostal injections, 10-mL dye each) in 7 cadavers. They found that the T8 to T11 nerves were dyed in 100% (7 of 7) of blocks, whereas the involvement of other nerves was variable (T7 in 14% or 1 of 7, T12 in 71% or 5 of 7, and L1 in 43% or 3 of 7 of specimens).

Carney et al[42] compared the sensory distribution and spread of LA for different US-guided approaches in 13 volunteers. Four volunteers had bilateral blocks placed using a "blind" LOR technique in the lumbar triangle of Petit (LTOP). Four had bilateral subcostal blocks placed using US guidance, 2 had bilateral US-guided blocks performed at the level of the midaxillary line, and 3 had "posterior" US-guided blocks. These posterior blocks were performed using a technique intended to mimic the landmark-based approach, and the intended site of LA injection was "at the intersection of the QL and the lateral abdominal muscles, superficial to the transversalis fascia" rather than within the TAP. The extent of spread of LA was assessed by MRI scans performed at 1, 2, and 4 hours after injection read by a radiologist blinded to block technique. The sensory extent of the blocks was also assessed, but the methods for this were not described. They found that the landmark-based approach produced a pattern of LA spread within the paravertebral spaces as low as L2 and as high as T4. There was also enhancement of the interforaminal epidural spaces, anterior to the vertebral bodies in a noncontinuous manner within the pleural cavity. The subcostal approach resulted in the spread of LA lateral to the rectus muscle, and the most cranial spread of LA was at the ninth or 10th intercostal space in all subjects. The mid-axillary approach produced spread from the anterior axillary line to the lateral border of the TAP and faint paravertebral spread from T12 to L2. Local anesthetic injected using the posterior approach did not enter the TAP but pooled

between the QL, psoas muscles, and the transversalis fascia and extended from T5 to T10. The sensory distribution of all the approaches was very patchy and did not cover the entire anterior abdominal wall. They concluded that the posterior approach most closely replicated the pattern of LA spread produced by the "blind" LOR approach in the LTOP, and that some of the analgesic effects of the TAP block may be mediated more proximally (TPVS or epidural) or by systemic effects of medications via vascular or lymphatic spread.

Several observational case series have helped clarify the sensory distribution of different techniques for performing US-guided TAP blocks. Lee et al[45] compared subcostal to mid-axillary approaches in a prospective observational study. Despite finding that the subcostal approach covered more dermatome levels (4 vs 3 for posterior) and higher dermatomes (T8 vs T10), 98% of patients in both groups (49 of 50) had successful blocks, and pain scores and morphine consumption were also similar. Børglum et al[49] reported a series of patients who were given bilateral 2-injection TAP blocks in the postanesthesia care unit (PACU). They found that the mean visual analog scale pain score decreased from 8.2 to 2.2 within 10 minutes of block performance. In addition, 86% (22 of 25) of these patients did not require opioids for more than 6 hours, and 64% (16 of 25) were mobilized within 6 hours after PACU discharge.

They further studied this technique[44] by evaluating the spread of LA, clinical effects, and plasma levels of LA after two-injection TAP blocks. Bilateral US-guided TAP blocks were performed on volunteers. One side was performed using a single 30-mL injection of 0.375% ropivacaine (in the TAP at the mid-axillary line or "lower TAP") and the other with 1 injection of 15 mL between the rectus abdominis (RAM) and transversus abdominis muscles (TAM) or "upper TAP" and another injection in the TAP at the mid-axillary line. Anatomic spread of LA was assessed serially for 6 hours with MRI. Clinical effect was evaluated by an anesthesiologist (cold sensation) and neurologist (pinprick) blinded to block side. They found that there was more extensive MRI spread for the 2-injection technique (mean, 7 vs 3 dermatomes). Their clinical evaluations correlated well with the MRI evaluation as 7 dermatomes were affected after 2-injection blocks and 3 after single injection. Although no single-injection subcostal blocks were done to evaluate the possibility of spread of LA from the upper to lower TAP, there was no evidence of intercommunication between LA in the upper and lower TAP, leading the authors to conclude that a 2-injection technique is necessary to block the entire anterolateral abdominal wall. Although the mean dose of ropivacaine per volunteer was 2.8 mg/kg in this study, no volunteer had a potentially toxic plasma LA level at any time during the study as the concentrations consistently peaked approximately 35 minutes postblock and decreased steadily thereafter.

Outcomes

Many studies have evaluated the effect of US TAP blocks on patient outcomes. To date, US-guided TAP blocks have been used for a wide range of surgeries including laparoscopic or open intra-abdominal procedures, implantation of devices into the abdominal wall,[50] and iliac crest bone graft harvest.[51] These studies do not specifically examine the effect of US on outcomes, so an in-depth discussion of these studies is beyond the scope of this review.

Complications

Studies on complications may help clinicians perform TAP blocks more safely. Two studies have used US to evaluate needle placement during traditional "blind" TAP blocks. Aissou et al[52] used US to determine the location of LA injection during LTOP TAP blocks in 52 patients under general anesthesia (GA). Of these, only 14 of 52 injections were in the TAP and 2 intraperitoneal injections occurred. No serious complications resulted, although 25 of the 38 blocks with injections outside the TAP failed. McDermott et al[53] used a similar design to study needle placement during 36 "blind" TAP blocks. They found that only 26% of injections were in the correct plane, and they observed 13 intraperitoneal injections. Fortunately, no patient in this study had any serious complications. Although US guidance may increase safety by decreasing the likelihood of peritoneal puncture, liver injury has been reported after US-guided TAP block,[54] so caution is necessary even if US is used.

Grade

Ultrasound guidance for the TAP block has been extensively studied since our last review. These studies have given us a much better understanding of the spread of LA within the TAP for various techniques and the sensory distribution of the various approaches. Although it is still not clear which approach is best suited for specific surgical procedures, the above studies suggest that an oblique subcostal technique may provide better analgesia for procedures above the umbilicus, and injections in the upper rectus sheath may be helpful for very high incisions (above T8/T9). Because 2 level IIb studies show that the use of US could increase block success rates and decrease the risk of intraperitoneal injection, we give use of US to perform TAP a grade of A. We previously gave a grade of B so we give an overall grade of A according to the Agency for Health Care Policy and Research guidelines.

Additional studies correlating the various US-guided techniques (oblique subcostal, "upper TAP," posterior) are needed to clarify the utility of the US-guided TAP block in surgeries involving incisions above the umbilicus. Further research is also needed to determine which approaches of US-guided TAP blocks are most appropriate for specific procedures and/or patient factors.

QL Block

The QL block was first described as a US-guided "posterior" approach to the TAP block by Blanco[41] in 2007 that approximated the single-injection LTOP TAP technique. The block was further developed in 2011 by Carney et al[42] to provide more reliable coverage above the umbilicus than previously described approaches to the TAP. Supraumbilical coverage had been reported for the LTOP TAP block in a single injection[55] unlike the oblique subcostal approach, which required multiple injections.[40]

Anatomy/Technique

The study by Carney et al[42] that described the technique, sensory distribution, and spread of LA injected using this approach is discussed above in the TAP block section. To date, no other anatomic studies such as cadaveric dissections or alternative approaches have been published.

Outcomes

Several case reports have been published describing the use of the QL block. Kadam and Field[56] reported using a unilateral block for postoperative analgesia in a man undergoing duodenal tumor excision. Kadam[57] later reported performing bilateral continuous catheters in 1 patient undergoing laparotomy. Visoiu and Yang[58] and Chakraborty et al[59] reported using unilateral continuous catheters for a pediatric patient undergoing radical nephrectomy,[59] and Carvalho et al[60] reported performing bilateral

single-injection blocks with LA and corticosteroid to provide long-lasting pain relief in a man with chronic abdominal neuropathic pain.

Complications

To date, no reports of complications from US-guided QL blocks have been published. Because of the possibility of damage to intraperitoneal structures using traditional techniques,[61,62] and because intra-abdominal injuries have been reported for other approaches to the TAP block even if US is used,[54] it is certain that complications will occur even if US is used for the QL block. The extent to which US can reduce the risk of mechanical or other complications remains unknown.

Grade

Based on 1 level IIb and 5 level III studies supporting the use of US to perform the QL block, we give the evidence a grade of B. Larger case series as well as studies comparing this block with the posterior LTOP TAP block will help clarify the role of US in improving success rates and decreasing the risk of complications for the QL block.

Rectus Sheath Block

Anatomy/Technique

Since our last review, no studies have been published on the anatomy, sonoanatomy, or technical aspects of the US-guided rectus sheath block.

Outcomes

Since our last review, no studies have specifically evaluated the effect of US guidance on outcomes for patients receiving rectus sheath blocks.

Complications

No studies have been performed to evaluate the effect of US guidance on the risk of complications for patients receiving rectus sheath blocks since our last review.

Grade

Based on the minimal amount of available data, we give the evidence supporting the use of US for rectus sheath blocks a grade of C. However, we previously gave the evidence supporting the use of US to perform rectus sheath blocks a grade of A based largely on a well-conducted RCT (level Ib) comparing US-guided blocks with those performed using traditional techniques (Dolan RAPM 2009). For this reason, we give the evidence an overall grade of A.

Transversalis Fascia

First described by Hebbard[63] in 2010, this block (initially called the transversalis fascia block) was developed to block the lateral cutaneous branches of the T12 and L1 nerves because these are commonly missed by the various approaches to the TAP block. The intended location of LA deposition is deep to the transversus abdominis muscle between the anterior surface of the QL muscle (posterior) and perinephric fat (anterior).

Anatomy/Technique

In his initial description, Dr Hebbard[63] described the relevant anatomy and sonoanatomy for block performance as well as the desired pattern of LA spread. To date, this has not been further investigated with cadaveric dissections or imaging studies in cadavers, volunteers, or patients.

Outcomes

In his initial description, Hebbard[63] reported having used the block in 17 patients, including 5 undergoing iliac crest bone harvest (other procedures included appendectomy, inguinal hernia repair, and cecostomy). Sixteen of 17 had a "detectable block to ice" and "excellent analgesia" after surgery. One patient early in this series required a repeat block, but no other complications were reported. Chin et al[64] reported a retrospective observational series of 27 patients undergoing upper-extremity fracture repair with iliac crest bone harvest under general anesthesia and brachial plexus block. Twelve patients who had transversalis fascia blocks placed preoperatively had lower perioperative analgesic doses and lower resting pain scores in the PACU. No complications were reported.

Complications

No complications have been reported in any of the published studies.

Grade

Based on 2 level III studies, we give the evidence supporting the use of US to perform the transversalis plane blocks a grade of B. To clarify the role of US in block performance, this block could also be compared with the "blind" LTOP TAP block because this block is very similar to the QL block and may in fact be the same block by a different name.

Ilioinguinal/Iliohypogastric

Anatomy/Technique

Schmutz et al[65] evaluated the specific sensory distribution covered by the II and IH nerves by selectively blocking each nerve. Blocks of individual nerves were performed in volunteers with 0.9 mL 1% mepivacaine. A blinded assessor then mapped the area of sensory change. There was significant overlap of the involved territories (60% or 30 of 50) despite the very low volume of LA used to perform the block and the relatively infrequent (12% or 11 of 50) spread of LA from 1 nerve to the other under US visualization. Ford et al[66] studied the learning curves of novice practitioners to image the relevant anatomy to perform II/IH blocks. Study subjects completed e-learning modules on the basics of US physics, machine controls, and the sonoanatomy of the inguinal region and then scanned patients under GA. Videos and still images were labeled by those performing the scans then reviewed by an experienced sonographer. The study subjects could consistently image and correctly identify the muscular planes after 14 to 15 scans, but they could not reliably identify the nerves even after scanning 18 patients.

Outcomes

Nan et al[67] performed an RCT comparing US-guided with landmark-based II/IH blocks in children undergoing unilateral inguinal surgery under GA. Blocks were performed before skin incision in both groups. They found that US guidance was associated with less hemodynamic response to skin incision, a lower intraoperative sevoflurane requirement, lower pain scores, a decreased need for rescue analgesics in the PACU, and increased parental satisfaction. The US guidance group also had superior outcomes despite a lower dose of LA to perform the blocks (0.2 vs 0.3 mL/kg in the traditional technique group). One patient in the traditional technique group had a vascular puncture during

block placement, but no serious complications occurred in either group.

Complications

Randhawa et al[68] investigated II/IH blocks using a study design similar to those by Aissou et al[52] and McDermott et al[53] for the TAP block. An anesthesiologist experienced in pediatric regional anesthesia performed traditional "blind" II/IH blocks in 21 patients under GA. The location of the needle tip and the site of LA injection were assessed by US. Only 12 of 21 blocks placed LA in the correct planes. Nine injections were deep to the transversus abdominis (intraperitoneal), although no serious complications were reported.

Grade

Although there are not many new studies on US guidance for II/IH blocks, the few that have been done strongly support the use of US to perform these blocks, and there is no new literature to suggest that the use of US is associated with worse outcomes or more complications than traditional techniques. Based on 1 level Ib and 1 level IIb supporting the use of US, we give the evidence supporting the use of US to perform II/IH blocks a grade of A. We previously gave a grade of A, so our overall grade is also A.

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APPENDIX 1: 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 one 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 one point if the study was described as double blind but the method of blinding was inappropriate (e.g., 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.[13]

APPENDIX 2: Statements of Evidence and Grades of Recommendations

Statements of Evidence	
Ia	Evidence obtained from meta-analysis of randomized controlled trials
Ib	Evidence obtained from at least 1 randomized controlled trial
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, randomized, controlled trial 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)*

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