The ASRA Evidence-Based Medicine Assessment of Ultrasound-Guided Regional Anesthesia and Pain Medicine

Executive Summary

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Objectives: The American Society of Regional Anesthesia and Pain Medicine charged an expert panel to examine the evidence basis for ultrasound guidance as a nerve localization tool in the clinical practices of regional anesthesia and interventional pain medicine.

Methods: The panel searched, examined, and assessed the literature of ultrasound-guided regional anesthesia (UGRA) from the past 20 years. The qualities of studies were graded using the Jadad score. Strength of evidence and recommendations were graded using an accepted rating tool.

Results: The panel made specific literature-based assessments concerning the relative advantages and limitations of UGRA relative to traditional nerve localization methods as they pertained to block characteristics and complications. Assessments and recommendations were made for upper and lower extremity, neuraxial, and truncal blocks and include pediatrics and interventional pain medicine.

Conclusions: Ultrasound guidance improves block characteristics (particularly performance time and surrogate measures of success) that are often block specific and that may impart an efficiency advantage depending on individual practitioner circumstances. Evidence for UGRA impacting patient safety is currently limited to the demonstration of improvements in the frequency of surrogate events for serious complications.

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We are approaching 2 decades since the first descriptions of using ultrasound as a tool for nerve localization, which were first published in this[1,2] and other journals.[3,4] The first decade of ultrasound-guided regional anesthesia (UGRA) largely established its feasibility and described approaches to common peripheral nerve blocks (PNBs). As ultrasound technology improved, investigators began to experiment with deeper blocks and perineural catheter placement, and anesthesiologists started to appreciate the advantages and limitations of this new localization tool. Perhaps most important in this evolution is the beginning of efforts to critically compare UGRA to other forms of nerve localization—the building of an evidence base for potentially improving effectiveness and enhancing patient safety. From these foundations comes a body of literature that enables practitioners to assess the role for UGRA in their practice. Although the rapidity of these formative stages is encouraging, the effort to scientifically assess what is arguably one of the most exciting periods in the history of regional anesthesia is in its adolescence.

This executive summary represents an overview of the assessments and recommendations that are detailed and defended within the individual supporting articles contained within this supplement. Clinicians are encouraged to read these supporting articles for a more robust understanding of the evidence base for UGRA.

METHODS

In April 2008, the Board of Directors of the American Society of Regional Anesthesia and Pain Medicine (ASRA) commissioned a group of UGRA experts to review, critically assess, and present in evidence-based medicine (EBM) format the scientific underpinnings of ultrasound guidance as a tool for nerve localization. Of interest to the panel was published evidence that related to 3 general areas pertinent to UGRA: (1) block-related outcomes such as improvements in onset, duration, or patient satisfaction; (2) process-related outcomes such as reduction in block performance time; and (3) safety-related outcomes. The board's charge was issued in concert with its partnering with the European Society of Regional Anaesthesia and Pain Therapy to develop a suggested learning curriculum for UGRA.[5] Panelists were chosen based on demonstrated expertise in UGRA research, clinical care, and/or education. Primary

TABLE 1. Key to Evidence Statements 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, 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.[17]

participants in the evidence-based medicine program are listed as authors of this article. Panelists were charged with evaluating the evidence for their assigned topic and presenting it on May 2, 2009 at the ASRA spring meeting in Phoenix, Ariz, then creating manuscripts that were internally peer reviewed by fellow panelists before undergoing external peer review in accordance with the standards of this journal.

This project was designed to accomplish several goals. First was to directly compare UGRA to other nerve localization tools with regard to block- and performance-related outcomes (block performance time, onset, success, and duration) and patient safety issues (2 global issues: postoperative neurologic symptoms (PONSs) 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, the project assessed the role of ultrasound guidance in special patient populations, notably pediatrics and interventional pain medicine. Third, related topics such as education, scope of practice, ultrasound physics, ultrasound machine function, and billing were presented at the symposium, some of which are presented in this supplement or related articles.[5–8]

Specific methodologies for the various components of this project are detailed in the accompanying individual articles.[9–16] In brief, putative evidence was gathered using a variety of standard electronic search engines to identify relevant literature from the early 1990s through fall 2009. Specific search engines used, language limitations, and MeSH (medical subject headings) are described in the individual articles. Central to our collective search criteria was the inclusion of only randomized controlled trials (RCTs), systematic reviews, meta-analyses, comparative studies, or case series of at least 10 subjects. Case reports and letters-to-the-editor were used only to document rare complications. Cadaver or imaging studies, or case series of less than 10 subjects, were used to demonstrate feasibility, but not to determine comparative attributes of UGRA.

Evidence-based statements are constructed from a common schema developed by the US Department of Health and Human Services Agency for Health Care Policy and Research[17] for evaluating strength of evidence and grades of recommendation (Table 1). To further evaluate the quality of studies from which these assessments were made, we graded scientific quality using the Jadad score[18] (Table 2). This numerical score (from 0 = weakest to 5 = strongest) is a validated measure of study design and quality of reporting.

RESULTS

As detailed within the supporting articles, our literature search terms identified up to 211 articles. After exclusion of those articles that did not fit inclusion criteria or were related to ultrasound uses other than regional anesthesia, most individual topic assessments were based on less than 25 applicable studies. In this executive summary article, pertinent results are summarized as a prelude to individual subtopics within the discussion.

Because study design and definitions of block characteristics vary widely among studies, we made no attempt to pool results for further statistical analysis. Useful information can be gleaned from case series and studies that compare various block approaches that use ultrasound guidance. However, the most

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 criteria met. The last 2 items indicate poor study quality; a point is subtracted for each criteria met. The Jadad score therefore ranges from 0 to 5.[18]

TABLE 3. Topics Assessed by Studies Comparing UGRA With Another Nerve Localization Technique

	Comparative Technique				Block Characteristics				Complications				
Author, Year	Jadad Score	Peripheral Nerve Simulation	Other Localization Technique	Pediatric	Block Performance Time	Block Onset	Block Success	Block Duration	Hemidiaphragmatic Paresis	Local Anesthetic Toxicity	Neurologic Symptoms	Pneumothorax	Vascular Puncture
Antonakakis et al,[62] in press	5	•			•		•				•		
Barrington et al,[46] 2009	N/A	•								•	•		•
Brull et al,[25] in press	5	•			•		•						
Casati et al,[19] 2007	3	•				•	•				•		
Casati et al,[26] 2007	4	•					•				•		
Chan et al,[20] 2007	5	•			•		•				•		•
Danelli et al,[63] 2009	3	•			•	•	•				•		•
Dhir and Ganapathy,[64] 2008	2	•					•	•					
Dingemans et al,[65] 2007	2	•			•		•	•			•		•
Dolan et al,[66] 2008	4		•				•						
Dolan et al,[28] 2009	2		•				•						
Domingo-Triado et al,[67] 2007	3	•			•	•	•	•			•		
Dufour et al,[68] 2008	4	•			•		•	•			•		
Fredrickson and Kilfoyle,[69] 2009	N/A	•									•		
Fredrickson et al,[70] 2009	3	•			•		•				•		
Gurkan et al,[22] 2008	2	•			•	•	•						•
Kapral et al,[71] 2008	2	•				•	•	•			•		•
Liu et al,[72] 2005	2	•			•	•	•				•		•
Liu et al,[23] 2009	3	•			•		•				•		
Macaire et al,[21] 2008	2	•			•	•	•				•		•
Marhofer et al,[73] 1997	1	•				•	•						•
Marhofer et al,[74] 1998	2	•				•	•						•
Marhofer et al,[31] 2004	3	•		•		•	•	•					
Mariano et al,[75] 2009	3	•			•		•						•
Morros et al,[76] 2009	1	•				•	•	•					•
Oberndorfer et al,[32] 2007	4	•		•			•	•			•		•
Orebaugh et al,[47] 2009	N/A	•								•	•		•
Perlas et al,[77] 2008	4	•			•	•	•				•		•
Ponde and Diwan,[78] 2009	3	•		•			•	•					
Redborg et al,[79] 2009	5	•			•		•				•		
Redborg et al,[80] 2009	5	•			•		•				•		

(Continued on next page)

TABLE 3. *(Continued)*

Author, Year	Jadad Score	Comparative Technique: Peripheral Nerve Simulation	Comparative Technique: Other Localization Technique	Comparative Technique: Pediatric	Block Characteristics: Block Performance Time	Block Characteristics: Block Onset	Block Characteristics: Block Success	Block Characteristics: Block Duration	Complications: Hemidiaphragmatic Paresis	Complications: Local Anesthetic Toxicity	Complications: Neurologic Symptoms	Complications: Pneumothorax	Complications: Vascular Puncture
Renes et al,[52] 2009	2	•					•		•				
Renes et al,[53] 2009	4	•					•		•			•	
Sauter et al,[24] 2008	3	•			•	•	•					•	•
Sites et al,[81] 2006	3		•		•	•	•				•		
Soeding et al,[82] 2005	1		•			•	•	•		•	•		
Taboada et al,[83] 2009	3	•			•	•	•	•			•		•
Tedore et al,[84] 2009	2		•		•		•				•		
Van Geffen et al,[27] 2009	3	•			•	•	•	•					
Weintraud et al,[29] 2009	5		•	•			•			•			
Williams et al,[55] 2003	2	•			•	•	•	•			•	•	
Willschke et al,[30] 2005	3		•	•			•	•			•		•
Willschke et al,[36] 2006	2		•	•	•		•	•					•
Yu et al,[85] 2007	3		•										•

N/A indicates not applicable.

valuable information for this project came from studies that compared specific block characteristics or complications as a function of UGRA versus another form of nerve localization. Studies that satisfied those criteria and their Jadad scores are listed in Table 3.

DISCUSSION

The literature of UGRA is a heterogeneous mix of generally small studies that compare ultrasound guidance with another form of nerve localization, usually peripheral nerve stimulation (PNS). Direct comparison of outcomes between studies is impossible because of variability in their chosen definitions for outcomes such as block performance time or success. Some studies compared the relative attributes of 2 or more approaches to a nerve or plexus block, all performed under ultrasound guidance. Other studies examined the ability to achieve neural blockade using differing volumes of local anesthetics. Although the latter 2 study methodologies contributed to our analysis, they were not used to infer any advantage or limitation of UGRA versus another form of nerve localization. What follows is a block-specific summary of results, discussion, and listing of recommendations when appropriate.

Upper-Extremity Blocks

Nineteen studies met inclusion criteria for comparing UGRA to other methods of nerve localization for upper-extremity block; most of these comparisons were made with PNS. Although these studies represent level Ib evidence, their quality varied widely (Jadad score, 1–5; median, 3). We qualitatively defined a study as "positive" if any measure of UGRA block characteristic was statistically superior to the compared technique, "negative" if the compared technique was statistically superior to ultrasound, or "no net difference" if the techniques were statistically indistinguishable or split between comparison groups. This distinction is important in that we did not quantify the magnitude of time difference for a specific block characteristic. Thus, the clinician is left to decide, for example, whether a 4- to 12-min faster onset time is relevant to their practice, particularly if equipment setup time was not included or if overall block success was not different between techniques.[19,20] Of the 19 studies, 15 were positive for ultrasound, 3 showed no net difference,[21] and 1 demonstrated faster block performance time in the PNS group.[22] Tables within the supporting articles detail the myriad comparisons that were made by individual studies, thereby giving readers a sense of the actual time advantage within the context of other measures of success. In addition to time-related block characteristics, 3 studies[19,23,24] reported a reduced number of needle passes in the ultrasound group, yet this potential advantage did not consistently translate to improved patient satisfaction or block-related complication rates. Six upper-extremity UGRA studies compared 2 or more ultrasound-guided approaches. The results of these studies were mixed, with most but not all reporting higher success rates and lower complication rates (Horner syndrome and HDP) with infraclavicular or axillary block versus supraclavicular block. Lower success rates with the supraclavicular approach were consistently related to failure to anesthetize the lower trunk.[11]

Under the conditions of our analysis, there is level Ib, grade A evidence that ultrasound guidance results in faster sensory block onset and higher surrogate rates of block success, based on 6 of 7 conclusive studies for onset and 8 of 8 conclusive studies for success. Successful block, variously defined as sensory or motor anesthesia of 1 or more nerves, was reported positive for ultrasound as compared with the control technique: 75%

to 86% versus 47% to 63%, respectively.[10] Although higher success rates were shown for block onset and success when defined by nerves anesthetized, there was less distinction between groups when block success was defined by perhaps more clinically relevant measures such as readiness for surgery or the ability to complete surgery without block supplementation or provision of general anesthesia. When analyzed by these "block quality" indicators, about 20% of RCTs reported less need for rescue block, and ~10% found less need for supplemental analgesia in the ultrasound study groups.[10] Specific recommendations cannot be made for other block characteristics such as performance time or duration—most studies represent Ib evidence, but are either conflicting in their results or too few in numbers to justify definitive recommendations. Block performance time is noteworthy in that earlier studies often failed to include time for prescanning or equipment setup. However, 2 recent high-quality (Jadad score, 5) studies[20,25] have shown shorter block performance times that include ultrasound prescanning and setup as compared with PNS.

Lower-Extremity Blocks

The effect of ultrasound guidance on lower-extremity block characteristics has been evaluated in fewer studies as compared with the upper extremity; these studies support slightly more patients benefiting from the use of ultrasound guidance in terms of block success. Inclusion criteria were met by 4 RCTs (240 patients) that evaluated 3-in-1, femoral, and fascia iliaca blocks; 5 RCTs examined popliteal sciatic nerve block (214 patients); and 2 RCTs assessed combined ultrasound and PNS. Median Jadad score was 3 (range, 1–4). Perhaps reflecting the primarily analgesic use of these blocks in clinical practice, success of surgical anesthesia was rarely measured.[15]

The same criteria as described for upper-extremity block were used to judge lower-extremity UGRA as being positive, negative, or no difference compared with other localization techniques. Using these qualitative criteria to describe the superiority of ultrasound guidance to traditional techniques, 5 of 7 studies supported faster block onset, whereas 1 of 7 reported slower onset using ultrasound. Regarding block quality, there was no difference in the need for rescue anesthesia or supplemental analgesia, but 5 of 8 studies documented more complete block of all studied nerves in the ultrasound groups (97%–100% with ultrasound vs 71%–75% with other techniques). Three of 3 studies reported no difference in lower-extremity block duration.[10] Two studies demonstrated the ability of UGRA to reduce the amount of local anesthetic necessary to achieve adequate block as compared with PNS guidance (absolute mean reductions of 9 mL for femoral block[26] and 20 mL for sciatic block[27]). These data support level Ib, grade A recommendations in favor of ultrasound for increasing sensory block success and allowing a reduced volume of local anesthetic to achieve adequate block. Similar evidence (Ib, A) supports the use of ultrasound to decrease sensory block onset time by an average of 11 to 14 mins. Catheter placement block performance times were faster in the ultrasound groups for popliteal sciatic nerve block. Investigations of lower-extremity blocks lacked sufficient power to allow definitive recommendations regarding quality of sensory block, number of needle punctures and redirections, patient discomfort during the block, or block duration.[15]

Truncal Blocks

Truncal blocks include paravertebral, intercostal, transversus abdominis plane (TAP), rectus sheath, and ilioinguinal/iliohypogastric (II/IH) blocks. The literature of ultrasonically guided truncal blocks largely consists of case series, audits, or anatomic studies that establish feasibility. Three RCTs compare rectus sheath[28] or II/IH blocks[29,30] to landmark-based techniques.

There currently are insufficient data to address the usefulness of ultrasound guidance for intercostal nerve block. Several case series and an anatomic study establish the feasibility of using ultrasound for paravertebral blocks (IIb, B), but there are no data available from which to compare the success or safety of paravertebral blocks using ultrasound versus traditional techniques (IV).[9] Ultrasound guidance might be expected to reduce the incidence of visceral organ injuries and intraperitoneal needle placements linked to TAP blocks. However, the evidence for ultrasound-guided TAP blocks is limited to cadaver studies, retrospective audits, and noncomparative opioid-sparing studies. Although these studies establish feasibility and high success rates, there are no level I or II data that address the relative benefit of ultrasound-guided TAP to traditional approaches.[9]

Two small case series of pediatric patients established feasibility of ultrasound-guided rectus sheath block. A recent RCT compared the performance of trainees using ultrasound versus loss-of-resistance (LOR) technique. Given the inexperience of trainees with both approaches, it is notable that the needle was placed in the correct tissue plane twice as often using ultrasound. Intraperitoneal needle placement occurred in 21% of the LOR subjects[28] (Ib, A). An RCT that compared ultrasound-guided to landmark-based II/IH block reported higher success for anesthesia and analgesia in those children randomized to ultrasound.[30] Although there is insufficient evidence to demonstrate increased safety with ultrasound, this study establishes a limited (Ib, A) recommendation for ultrasound-guided II/IH block in children.

In summary for truncal blocks, limited RCT evidence supports the recommendation for ultrasound as the preferred localization technique for rectus sheath and II/IH blocks (Ib, A). There is insufficient evidence from which to judge the relative contributions of ultrasound to TAP, intercostal, and paravertebral blocks.[9]

Neuraxial Blocks

The body of literature examining the role of ultrasound in neuraxial anesthetic techniques is smaller than that for PNBs. Seventeen studies met inclusion criteria and can be generally categorized as addressing (1) ultrasound-assisted techniques or (2) real-time ultrasound-guided techniques.

Ultrasound-assisted neuraxial techniques involve preprocedural scanning to determine midline, targeted interspace, or depth from skin to the epidural or subarachnoid spaces before performing the procedure using traditional methods. In adults, these basic measurements are often difficult to obtain because of intervening soft tissues or acoustic shadowing from bone and/or calcification. Nevertheless, ultrasound is superior to physical examination, but inferior to radiologic imaging, for correctly identifying spinal interspace levels (IIa). Ultrasound is highly accurate for predicting skin-to-epidural space depth in the cervical spine (adults) and the lumbar spine (adults and children) (Ib). The clinical relevance of these findings is uncertain. For instance, when ultrasound was compared with landmark-based examination before placement of labor epidurals, the anesthesiologist using ultrasound was able to complete epidural placement using fewer attempts at fewer interspaces, yet the success rate for labor analgesia was no different. Higher success was achieved if the operator was a trainee[14] (Ib).

A single real-time ultrasound-guided neuraxial study of combined spinal epidural anesthesia in obstetric patients noted

fewer attempts to successfully place the needle in the ultrasound group, but equal block success (Ib). There are no safety studies of ultrasound-facilitated versus traditional neuraxial techniques. Unfortunately, ultrasound guidance is likely to be most useful in patients who present challenging neuraxial anatomy secondary to obesity, spinal deformity, or previous spine surgery. However, there is often more difficulty obtaining images on these groups of patients, and data are still lacking at this early stage.[14]

Pediatrics

The use of UGRA in pediatrics is of particular interest because children are often anesthetized before block placement and therefore unable to provide feedback related to needle-to-nerve contact or symptoms of local anesthetic intravascular injection. Existing studies are too small to address these patient safety issues. Twelve studies (6 RCTs and 6 case series) have assessed pediatric ultrasound-guided PNB, and 12 others (1 RCT, 1 comparative study, and 10 case series) have evaluated pediatric neuraxial block. The median Jadad score for these studies was 3 (range, 2–5).[16]

For PNB, a single study of infraclavicular block showed that the onset of sensory block was, on average, 6 mins faster with UGRA versus PNS,[31] but the success of surgical anesthesia was not different (Ib, B). Conversely, ultrasound improved block success for pediatric anterior truncal blocks, which are typically performed using tactile or landmark-based techniques[29,30] (Ib, A). Ultrasound guidance modestly prolonged neural blockade, as measured by duration time or decreased pain scores, in infraclavicular, sciatic, and/or femoral block models[31,32] (Ib, A). Three studies demonstrated that ultrasound reduced the volume of local anesthetic required for various pediatric blocks, but limited duration of follow-up (4 hrs) and instances of early presentation of pain confound interpretation of these results with regard to whether reduced volumes can maintain or improve block quality and duration[33–35] (Ib, A).

Real-time ultrasound-guided neuraxial blocks have proven valuable in pediatric patients whose smaller body mass allows the use of high-resolution linear transducers to image neuraxial structures. Feasibility studies demonstrate real-time observation of injectate spread through epidural needles, epidural catheter insertion, and final catheter position (III).[14] Several investigations confirm the usefulness of UGRA for visualizing the ligamentum flavum and particularly the dura mater in neonates, infants, and children up to 12 years of age (Ib, A). Preprocedural scanning offers a moderate prediction of depth from skin to expected LOR.[16] A comparison of ultrasound guidance to LOR for epidural placement found that ultrasound reduced the number of bone contacts and facilitated faster placement of the catheter, but did not affect analgesia or complications[36] (Ib, B).

In summary, a modest body of literature addresses UGRA in the pediatric population. Similar to adults, studies show that sensory block onset is often faster, but ultrasound equipment setup time is typically not reported. Feasibility studies demonstrate the ability of ultrasound to identify dura mater and ligamentum flavum, particularly in neonates and young children, but to date there are little data linking this to actual clinical advantage in terms of improved block success or safety. The ability to use smaller volumes of local anesthetic is particularly appealing in children because of their small-size–related susceptibility to local anesthetic toxicity. Although smaller local anesthetic volumes are indeed possible in these patients, there is limited evidence regarding how this might affect block quality and no evidence regarding serious complications such as seizure. The common practice of placing blocks in anesthetized or heavily sedated children[37,38] is another instance where neural visualization presents a theoretical advantage of ultrasound guidance, but nerve injury has not been studied in this group.

Chronic Pain Medicine: Interventional Procedures

Ultrasound guidance might offer similar benefits to pain physicians as it does for surgical and acute pain medicine practice,[39] but acoustic shadowing and obesity make neuraxial imaging particularly difficult in adults. Compared with fluoroscopy or other radiographic imaging techniques, ultrasonography reduces radiation exposure to the patient and operator. The evidence base for interventional pain medicine is quite limited, with most reports classified as feasibility studies; that is, cadavers and/or noncomparative patient models are used to explore the potential for ultrasound guidance to facilitate block procedures. Preliminary feasibility studies support the use of ultrasound guidance for cervical selective nerve root block[40] and stellate ganglion block.[41] No data exist to compare the efficacy of ultrasound to fluoroscopic guidance for lumbar facet injection, lumbar nerve root injection, or cervical selective nerve root injection.

The single RCT within this topic area compared ultrasound with computed tomography guidance for lumbar facet joint intra-articular injection. Ultrasound was superior to computed tomography with regard to time for block placement and less radiation exposure, but there was no difference in pain relief between groups[42] (Ib). A nonrandomized crossover trial of lumbar facet medial branch blocks noted that ultrasound-guided blocks (administered 1 month after a fluoroscopically guided block) were 95% successful for establishing proper needle placement. This study may not be applicable to Western populations because of the small physical stature (mean, 51 kg) of its subjects.[43]

Patient Safety

As compared with other nerve localization methods, UGRA has the advantage of directly visualizing the target nerve, surrounding tissues, and injectate spread. It is reasonable to speculate that these advantages might reduce complications such as nerve injury, LAST, pneumothorax, or HDP. Unfortunately, the most serious of these complications (permanent nerve injury and severe LAST) are so rare as to defy statistical proof that ultrasound might affect their occurrence.[13]

Twenty-two RCTs and 4 large case series that together encompass ~17,000 patients showed no difference in the frequency of PONSs as a function of localization technique. This finding is supported by a recent meta-analysis and systematic review.[44,45] Two large audits found no statistical difference in the incidence of PONSs regardless of nerve localization by ultrasound or PNS.[46,47] Importantly, the frequency of PONSs after UGRA (0.4/1000; 95% confidence interval [CI], 0.08–1.1/1000)[46]does not appear to be significantly different from historical frequencies reported using PNS techniques. However, cases of peripheral nerve injury have been reported after ultrasound-guided PNB.[13,48]

Seventeen RCTs and 2 large case series (~15,000 patients) showed a reduction in the incidence of vascular puncture when ultrasound guidance was used. However, data are conflicting with regard to subsequent reduction in the occurrence of LAST—one audit showed no reduction as a function of localization technique,[46] whereas another audit[47] noted fewer seizures in the ultrasound group. Case reports[49,50] describe seizures despite the use of ultrasound. The overall frequency of LAST after UGRA (95% CI, 0.42–1.9/1,000) is remarkably similar to that previously reported using PNS guidance.[13,51]

Three RCTs[52–54] evaluated the potential for UGRA to reduce the incidence of HDP after above-the-clavicle block. Ultrasound-facilitated local anesthetic volume reduction caused less frequent and intense HDP, but HDP still occurred unpredictably (95% CI, 0.00%–0.14% for supraclavicular block[53]), which likely limits absolute reliance on small-volume, ultrasound-guided blocks in those patients for whom a potential 30% reduction in pulmonary function would be relatively contraindicated. Three RCTs[24,53,55] and a case series[56] report no pneumothoraces associated with UGRA (upper limit 95% CI, 0.5%), although pneumothorax associated with UGRA has been reported after single-injection and continuous techniques.[57,58]

In summary, there is no evidence that UGRA results in less frequent peripheral nerve injury than that historically reported using PNS guidance. Because of the extreme rarity of this complication, a statistically significant difference between nerve localization techniques, if indeed any difference exists, will likely never be realized (III). Ultrasound reduces the frequency of vascular puncture (Ia), but there is conflicting evidence whether this results in true reduction of LAST (III). Although the use of ultrasound and low local anesthetic volume reduces the frequency and intensity of HDP (Ia), it does so unpredictably, which may limit the usefulness of this technique in those patients most likely to benefit from it (IV). Finally, pneumothorax has been reported despite the use of ultrasound guidance (III).

Concluding Comments

The evidence base for UGRA as a nerve localization tool is expanding rapidly. Although existing studies are hampered by small numbers of subjects and varying definitions of block characteristics and success, their quality has improved substantially over the past 5 years. Current assessments of the advantages and limitations of ultrasound are hampered by (often unavoidable) methodological limitations. For instance, most studies were performed by ultrasound experts, which may limit the ability to generalize results to less experienced practitioners. Conversely, these same investigators are often highly skilled in the comparator technique, which should promote fairer comparison. More problematic are those studies that compare ultrasound to a less-than-ideal version of the comparator, such as not using the optimal number of PNS-guided injections or motor responses.[59]

Despite the literature's limitations, several general conclusions can be made. First, most studies found UGRA to be superior or equal to the comparator technique, and none showed that ultrasound guidance was clearly inferior or dangerous. Second, ultrasound offers statistically, but perhaps not clinically, proven advantages in block characteristics, particularly reduced onset time and improved intermediate measures of success. These advantages need to be qualified in that they are often block specific, and surrogate measures of block success are more likely to favor ultrasound guidance than do those measures that rely on supplement-free surgical anesthesia. Third, there is no evidence that ultrasound eliminates complications; indeed, the limited existing data suggest that complication rates are similar to historical norms reported using traditional nerve localization tools. There is reason to at least consider that poorly performed ultrasound guidance, such as failure to image the needle, misinterpretation of artifacts,[7,8] or novice behavior,[60,61] might actually increase the risk of injury. Furthermore, ultrasound is but another form of nerve localization, all having a potential role in the multifactorial process of nerve injury, which is also affected by local anesthetic neurotoxicity, underlying patient conditions, and surgical-related insults. The literature is silent with regard to patient- or situation-specific safety outcomes where ultrasound may prove to be particularly useful. For example, there is reason to suspect that UGRA may reduce the frequency of LAST more in children than in adults, or that preventing nerve injury may be more relevant in patients at increased risk for nerve injury (diabetes, chemotherapy-induced neuropathy, etc) as compared with the overall population.

In closing, the panel wishes to emphasize its belief that ultrasound guidance is a significant advance in the practice of regional anesthesia and pain medicine. At this early stage, the volume of evidence-based UGRA literature has already matched or arguably exceeded that for transesophageal echocardiography. Future studies will most certainly improve our understanding of its strengths and weaknesses. However, the use of ultrasound is but a single component of the practice of regional anesthesia. Ultrasound guidance does not remove traditional requirements for physician judgment, training, anatomic knowledge, and experience. Most importantly, ultrasound does not lessen the practitioner's responsibility for using time-proven strategies to improve block quality and patient safety—including proper anesthetic selection and dosing, aspiration for blood, appropriate test dosing, patient- and procedure-appropriate sedation, and vigilant intrablock and postblock monitoring.

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Ultrasound-Guided Regional Anesthesia and Patient Safety

An Evidence-Based Analysis

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Abstract: The role of ultrasound-guided regional anesthesia (UGRA) in reducing the frequency of regional anesthetic–related complications is difficult to ascertain from analyzing the limited literature on the topic. This evidence-based review critically evaluates the contributions of UGRA to improved patient safety, particularly as compared with standard nerve localization tools. Randomized controlled trials that compared UGRA with another form of neural localization and case series of more than 500 patients were used to compare safety parameters. The quality of studies and strength of evidence were graded. Of those randomized controlled trials identified by our search techniques, 22 compared the incidence of postoperative nerve symptoms, 17 assessed local anesthetic systemic toxicity parameters, and 3 studied hemidiaphragmatic paresis. Statistical proof for meaningful reduction in the frequency of extremely rare complications, such as permanent peripheral nerve injury, is likely unattainable. Although there is evidence for UGRA reducing the occurrence of vascular puncture and the frequency of hemidiaphragmatic paresis, as yet there is at best inconclusive scientific proof that these surrogate outcomes are linked to actual reduction of their associated complications, such as local anesthetic systemic toxicity or predictable diaphragmatic impairment in at-risk individuals. This evidence-based review thus strives to summarize both the power and the limitations of UGRA as a tool for improving patient safety.

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Ultrasound-guided regional anesthesia (UGRA) is the latest in a series of tools designed to optimize localization of neural targets before the deposition of local anesthetic or other drugs. Because ultrasonography (US) 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. Furthermore, it can be challenging to determine precisely when US is directly responsible for safety improvements, that is, consequent to the visualization of target structures, versus indirectly beneficial, that is, by facilitating an altered needle approach that is inherently safer than a traditional approach, but not unique to UGRA. What follows is an analysis of the limited evidence for the role of UGRA in enhanced patient safety. The analysis focuses on 4 major complications—peripheral nerve injury, LAST, hemidiaphragmatic paresis (HDP), and pneumothorax. Also considered are potential mechanisms by which US might indirectly reduce the frequency of certain complications inherent to regional anesthetic practice.

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METHODS

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 these 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).[1] Strength of evidence (Table 3) was based on a recognized grading schema from the US Agency for Health Care Policy and Research.[2]

The literature search for this analysis was conducted for the 20-year period 1990 through September 2009 using standard search engines, including the National Library of Medicine's PubMed, the Cochrane Database for Systematic Reviews, Ovid, ScienceDirect, 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 abstracts translated into English were identified. The bibliographies of identified articles were perused for sources not procured through the search engines.

RESULTS

Twenty-two RCTs totaling 1863 subjects compared postoperative neurologic symptoms associated with UGRA (either UGRA alone or in combination with PNS) versus other techniques for nerve localization—PNS (18 studies), transarterial (2 studies), surface landmark (1 study), or fascial click (1 study). The median quality (Jadad score) of these studies was 3 (range, 2–5). These RCTs reported the incidence of immediate or transient paresthesia (<7 days) and/or the incidence of postoperative nerve injury (24 hrs to 2 months). Seven RCTs simply reported "none" for neurologic complications, whereas 15 RCTs reported actual incidence with or without statistical significance (Table 1). Four large case series reported incidences of postoperative neurologic symptoms from a combined total of 15,145 peripheral nerve blocks (Table 2).

TABLE 1. Randomized Controlled Trials of Ultrasound-Guidance Versus Other Nerve Localization Techniques

Reference (Year)	Jadad Score	Block	US, n	USNS, n	PNS, n	Vascular Puncture, n (%)	Paresthesia, n (%)	Nerve Injury, n (%)
Casati et al[39] (2007)	4	Femoral	30		30		0 US 0 PNS at 24 hrs	
Casati et al[47] (2007)	3	Axillary	30		29			None at 24 hrs
Chan et al[58] (2007)	5	Axillary	64	62	62	None	US 13 (20%) USNS 9 (15%) PNS 13 (21%) Transient (<5 d)	None
Danelli et al[59] (2009)	3	Popliteal sciatic	22		22	US 0 (0%) PNS 5 (22%)	US 0 (0%) PNS 5 (22%)	None at 24 hrs
Dingemans et al[60] (2007)	2	Infraclavicular	36	36		US 2 (6%) PNS 1 (3%)	US 1 (3%) Transient (<7 d)	
Domingo-Triado et al[61] (2007)	3	Midfemoral sciatic		30	31			PNS 1 neuropathic pain Resolved at 10 d
Dufour et al[62] (2008)	4	Popliteal sciatic		26	25			US 0 PNS 0
Fredrickson et al[63] (2009)	3	Continuous interscalene	41		40			US 1 (2%) PNS 4 (10%) Resolved 8 wk (NS)
Gurkan et al[64] (2008)	2	Lateral sagittal infraclavicular	40		40	US 0 (0%) PNS 3 (8%)		
Kapral et al[65] (2008)	2	Interscalene	80		80	None	None	None
Liu et al[66] (2005)	2	Axillary	60		30	US 0 (0%) PNS 3 (10%)	US 0 (0%) PNS 3 (10%)	
Liu et al[33] (2009)	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[67] (2008)	2	Median and ulnar nerves	30		30	None	None	None
Marhofer et al[68] (1997)	1	3-in-1	20		20	US 0 (0%) PNS 3 (15%)		

Marhofer et al[69] (1998)	2	3-in-1	20		40	US 0 (0%) PNS 4 (10%)		
Marhofer et al[70] (2004)	3	Infraclavicular	20		20	None		None
Mariano et al[71] (2009)	3	Continuous popliteal sciatic	20		20	US 0 (0%) PNS 2 (10%) (NS)		
Oberndorfer et al[72] (2007)	4	Femoral/sciatic	23		23	None	None	None
Perlas et al[73] (2008)	4	Popliteal sciatic	37		33	US 0 (0%) PNS 0 (0%)		US 0 (0%) PNS 0 (0%) At 7 d
Redborg et al[31] (2009)	5	Tibial nerve ankle	18		18			1 dysesthesia with US (improving after 2 mo)
Sauter et al[6] (2008)	3	Lateral sagittal infraclavicular	40		40	US 2 (5%) PNS 13 (33%) ($P = 0.001$)		
Sites et al[74] (2006)	3	Axillary	28		28*			None At 1–2 wk
Soeding et al[20] (2005)	1	Axillary and interscalene	20		20†	No seizure	US 1 (5%) Landmark 5 (25%) ($P = 0.012$)	None
Taboada et al[75] (2009)	3	Coracoid infraclavicular	35		35	US 1 (3%) PNS 1 (3%)		US 0 PNS 0 After block
Tedore et al[19] (2009)	3	US-infraclavicular	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[7] (2003)	2	Supraclavicular		40	40			US 2 (5%) PNS 1 (3%) Paresthesia resolved at 2 wk
Willschke et al[76] (2005)	3	Ilioinguinal/iliohypogastric	30		30§	None		None
Yu et al[77] (2007)	3	Axillary	40	40		US 0 (0%) PNS 16 (40%) ($P < 0.001$)		

*Transarterial.
†Landmark based.
‡Transarterial axillary.
§Fascial click.
LE indicates lower extremity; NS, not statistically significant; PONS, postoperative neurologic symptoms; TA, transarterial; US, ultrasound; USNS, ultrasound + nerve stimulation.

TABLE 2. Large Case Series of Ultrasound-Guided Regional Anesthesia With or Without Other Localization Techniques

Reference (Year)	Block	US, n (%)	USNS, n (%)	PNS, n (%)	Vascular Puncture, n (%)	LAST, n (%)	Nerve Injury, n (%)
Barrington et al[23] (2009)	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)
Fredrickson and Kilfoyle[28](2009)	1010 Single and continuous blocks Upper and lower extremity US +/− PNS						New, all-cause neurologic symptoms: Day 10—8.2% 1 mo—3.7% 6 mo—0.6%
Orebaugh et al[27] (2009)	Retrospective quality-assurance database (5436 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 EMG and NCS; 2 of 3 improving
Perlas et al[8] (2009)	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)

EMG indicates electromyogram; NCS, nerve conduction studies; LAST, local anesthetic systemic toxicity; UE, upper extremity; US, ultrasound; USNS, ultrasound + nerve stimulation.

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

Peripheral nerve injury (III)
• Proving statistical differences in nerve injury as a function of nerve localization technique is likely futile.
• Underpowered results from RCTs and large case series find no difference in surrogate markers of nerve injury, such as paresthesia during or immediately after block placement, or temporary postoperative neurologic symptoms.
• UGRA seems to be associated with perioperative nerve injury at an incidence similar to historical reports of nerve injury after PNS.
Local anesthetic systemic toxicity (Ia and III)
• Compared with PNS, UGRA lowers the risk of unintended vascular puncture, a surrogate outcome for LAST (Ia).
• The weight of conflicting evidence is that UGRA does not affect the incidence of local anesthetic–induced seizures (III).
HDP (Ia and IV)
• RCTs confirm the ability of low-volume UGRA to reduce (but not eliminate) the incidence and severity of HDP using the interscalene approach. The incidence of HDP is nearly 0% using the supraclavicular approach with ultrasound guidance (Ia).
• No RCTs or case reports address whether patients at risk for pulmonary compromise can undergo above-the-clavicle regional anesthetic block. Because HDP can still occur unpredictably, caution remains warranted in any patient unable to withstand a 30% diminution of pulmonary function (IV).
Pneumothorax (III)
• No adequately powered studies directly address the risk of pneumothorax with UGRA.
• Pneumothorax has occurred despite the use of UGRA (III).

HDP indicates hemidiaphagmatic paresis; LAST, local anesthetic systemic toxicity.

Seventeen RCTs totaling 1279 subjects recorded vascular puncture. Six of these studies simply reported vascular punctures as "none," whereas 11 provided actual incidence figures, with or without statistical significance. One study (40 patients) reported "no seizure." The median Jadad score of these studies was 3 (range, 1–5; Table 1). Two case series reported the frequency of vascular puncture and/or LAST in 13,625 peripheral nerve blocks (Table 2).

The effect of ultrasound guidance on the frequency and severity of HDP has been reported in 3 RCTs totaling 65 UGRA patients.[3–5] Jadad scores for these 3 studies were 2, 3, and 5. The absence of pneumothorax was mentioned in 3 RCTs totaling 110 UGRA patients[5–7] and 1 case series of 510 supraclavicular blocks.[8]

No RCTs were identified that directly addressed issues of patient safety using ultrasound-guided neuraxial techniques.

DISCUSSION

Peripheral Nerve Injury

Needle or catheter-induced disruption of a peripheral nerve's structural integrity, particularly the fascicles and their protective perineurium, is thought to contribute to peripheral nerve injury.[9] Ultrasonography may impact this potential injury mechanism by facilitating direct visualization of needle-to-nerve proximity. Ironically, UGRA research has furthered our understanding of more traditional forms of nerve localization such as PNS and paresthesia-seeking techniques and has confirmed previous research that demonstrates their low sensitivity for accurately identifying needle-to-nerve contact. Indeed in human axillary nerve block, US visualization demonstrates that paresthesia is only 38% sensitive and motor response only 75% sensitive in confirming needle-to-nerve contact.[10] This relatively low sensitivity of PNS has been confirmed in another study of human supraclavicular block, wherein a motor response at 0.2 mA or less was indicative of intraneural needle placement as confirmed by US, but a motor response of greater than 0.2 to 0.5 mA or less could not rule out intraneural needle placement.[11] Monitoring injection pressures may also aid in preventing intrafascicular injection, but this modality has been studied only in animals and, like other tools, is neither completely sensitive nor predictive of injury.[12,13] Conversely, ultrasound is a sensitive tool for demonstrating intraneural injection in porcine models, as manifested by consistent nerve expansion observed with 1-mL injectate or less.[13–15] However, although nerve expansion was correlated with histologic injury, concomitant functional injury was not observed.[15] Human correlation has been reported with axillary block, wherein no patient had a nerve injury despite clearly observed nerve expansion after the injection of 2 to 3 mL local anesthetic during UGRA.[16] Although these results suggest that PNS- or paresthesia-guided needles are likely placed within nerves much more frequently than previously realized, and that the usual absence of injury is likely explainable by the relative ease of placing needles into connective tissue rather than into a fascicle, in vitro studies of human sciatic nerve nevertheless demonstrate that sharp needles, in fact, enter fascicles 3.2% of the time, thereby potentially causing injury.[17] Moreover, as one proceeds proximal to distal, the amount of nonneural connective tissues present within the cross-sectional area of the brachial plexus increases,[18] suggesting that the interscalene area may be less forgiving of subepineurium needle placement compared with the axillary or supraclavicular areas. Thus, US is a more sensitive indicator of needle-to-nerve contact than either paresthesia or PNS, but it is unknown if this advantage translates to actual reduction of nerve injury. Adding balance to this observation is that current acoustic resolution limits our ability to consistently discern nerve microanatomy and that there are differences in technical skills between operators.

Of the 22 RCTs (Table 1) that compared UGRA, alone or in combination with PNS, with other forms of nerve localization, two found a statistically different incidence of paresthesia during block placement in dissimilar patient groups—26% in a US-infraclavicular group versus 40% in a transarterial axillary group ($P = 0.035$, 220 patients)[19] and 25% using landmarks versus 5% using UGRA in interscalene and axillary blocks ($P = 0.012$, 40 total patients).[20] The remaining 20 RCTs reported no difference in terms of transient paresthesia or short-lived postoperative neurologic symptoms, which is in agreement with a meta-analysis[21] and a qualitative systematic review.[22]

Several large case series (Table 2) confirm that serious nerve injury is rare. In the largest of these, Barrington et al[23] report a prospective audit of more than 7000 peripheral nerve

blocks from the Australasian Regional Anaesthesia Collaboration. Unintended paresthesia during block placement (16.8/1000) and block-related late neurologic deficit (0.4/1000; 95% confidence interval [CI], 0.08–1.1 per 1000) did not differ between UGRA and PNS techniques. The incidence of late neurologic deficit (0.04%) was similar to that reported for PNS-guided peripheral nerve blocks by Auroy et al[24] (0.02%) and for continuous catheter blocks by Capdevila et al[25] (0.21%, all deficits resolved by 10 weeks). These comparisons suggest, but do not prove, that the incidence of late postoperative neurologic symptoms, that is, those lasting weeks to months after the block, has not been altered by the introduction of UGRA.[26] In a retrospective quality assurance review of 5436 peripheral nerve blocks performed with PNS or US with PNS, Orebaugh et al[27] noted 3 neurophysiologic study–documented nerve injuries, all in the PNS group (not statistically significant). Fredrickson and Kilfoyle[28] reported new neurologic symptoms (from any cause) in a cohort of 1010 patients undergoing single or continuous peripheral nerve blocks under UGRA with or without confirmatory PNS. The incidences of neurologic symptoms were 8.2% at 10 days and 3.7% at 1 month, which are similar to those reported by Borgeat et al[29] using PNS localization. The 0% to 0.1% (95% CI, 0%–0.56%) incidence of prolonged (>6 months) nerve injuries judged to be block related in the Fredrickson and Kilfoyle[28] study compared favorably with other reports of injury in continuous catheter patients.[28] Perlas et al[8] noted transient numbness (several weeks) after 510 UGRA supraclavicular blocks (0.4%; 95% CI, 0.1%–1.4%). To date, there are 2 reported cases of prolonged nerve injury associated with UGRA—a permanent brachial plexopathy in a patient with underlying multiple sclerosis and potential surgical causes of injury,[30] and a volunteer who had a dysesthesia of the tibial nerve, which was present but improving after 2 months (this subject is included in the RCTs).[31] In summary, limited literature and small patient numbers suggest 3 findings concerning peripheral nerve injury and UGRA: (1) block-related paresthesia, a surrogate outcome at best, was not reduced when similar block groups were compared; (2) RCTs and large case studies report no permanent neurologic injuries, nevertheless; and (3) peripheral nerve injury associated with, but arguably unrelated to, UGRA has been reported. Because the examined RCTs were not powered to assess nerve injury, the best data on this topic come from the large case series, thereby providing level III strength of evidence (Table 3).

It is important to understand that the relationship of nerve localization technique and peripheral nerve injury is unlikely to ever reach statistical resolution. For example, if one assumes a moderate incidence of early, nonpermanent peripheral nerve injury (3%),[32] a study would require 3000 patients per group to have 80% power (β) to prove a 50% reduction to 1.5%.[33] However, the number of subjects would expand exponentially if one intends to analyze long-term injury (6–12 months), which is estimated to occur in only 0 to 4 per 10,000 blocks.[23,24,26] Furthermore, recent analysis of block-related permanent nerve injury (>12 months) noted only one such injury reported in 65,092 blocks[32] (upper limit 95% CI, ~0.5/10,000).

Local Anesthetic Systemic Toxicity

Local anesthetic systemic toxicity (LAST) ranges from mild subjective symptoms to seizure and cardiac arrest. Ultrasound guidance has the potential to limit LAST by at least 3 mechanisms—identifying the absence of injectate spread around the target, visualizing turbulence or other intravascular anomaly during local anesthetic injection,[34] and facilitating reduced volume of injected local anesthetic. The 17 RCTs reviewed herein add credence to a meta-analysis that showed US can reduce the risk of aspiration-proven vascular puncture compared with other localization techniques (pooled risk ratio, 0.16; 95% CI, 0.05–0.47).[21] Although recognition of unintended vascular puncture is a necessary step toward eliminating LAST, it is only a surrogate outcome for seizure or cardiac arrest. Indeed, various case reports and correspondence document loss of consciousness, agitation, and cardiac arrest despite UGRA.[35–37] Barrington et al[23] found that although US significantly lowered the incidence of unintended vascular puncture as compared with PNS, the incidence of actual LAST (0.98/1000; 95% CI, 0.42–1.9 per 1000) did not differ as a function of localization technique. This incidence is very similar to the 0.8-per-1000 figure reported by Auroy et al[24] using PNS. Conversely, Orebaugh et al[27] reported more seizures ($P = 0.044$) in their upper-extremity blocks that involved PNS rather than UGRA. Thus, UGRA consistently reduces the likelihood of unintended vascular puncture, but case reports and most case series fail to link this advantage to an actual reduction in LAST. The strength of evidence for UGRA reducing the rate of vascular puncture as compared with PNS is level Ia, but only level III for its effect on the incidence of seizure.

The literature does not answer whether using less local anesthetic volume will reduce the frequency of LAST. Although 1 study showed no significant reduction in the volume of local anesthetic used for ultrasound-guided supraclavicular block,[38] several others have shown that UGRA reduces minimum effective local anesthetic volume (MEV) as compared with PNS. For instance, Casati et al[39] were able to lower the MEV using PNS-guided femoral nerve block from 26 to 15 mL using UGRA. However, the US MEV (15 mL; 95% CI, 7–23 mL) remains capable of causing LAST, particularly if injected intravascularly. Importantly, UGRA has been linked to faster absorption and higher maximum plasma concentrations of local anesthetic,[40] which suggests that lowering the local anesthetic volumes used during UGRA is not just possible, but perhaps well considered.

Hemidiaphragmatic Paresis

Hemidiaphragmatic paresis is a universal occurrence with landmark- and nerve stimulator-based interscalene blocks, becoming progressively less frequent as blocks are placed below the clavicle and farther distal along the brachial plexus. Particularly with the more proximal approaches, some patients may experience reduced spirometric measures of pulmonary function, and even fewer may suffer respiratory compromise. For these reasons, above the clavicle blocks are relatively contraindicated in patients unable to withstand a 25% decrease in pulmonary function.[9] Reducing the volume of injected local anesthetic to 20 mL does not limit the occurrence of HDP using traditional approaches, but because UGRA facilitates the use of even smaller local anesthetic volumes, 2 investigatory teams have examined whether this attribute could lower the incidence and severity of HDP without compromising anesthetic quality. One study[4] performed interscalene UGRA with 20 versus 5 mL ropivacaine 0.5% and lowered the incidence of HDP 1 hour after surgery to 90% and 33%, respectively, without compromising sleep or analgesia over the first 24 hrs. Another group[3] compared UGRA with PNS-guided interscalene block with 10 mL ropivacaine 0.75%, similarly lowering the incidence of complete or partial HDP to 13% and 93%, respectively, without affecting block success or early morphine requirements. The same group[5] then compared US- to PNS-guided supraclavicular block using 20 mL ropivacaine 0.75%. The incidence of HDP was 0% (95% CI, 0.00–0.14) versus 53% ($P < 0.0001$), respectively. Spirometric measures of pulmonary function were reduced 20%

or greater in the PNS patients with complete HDP (level Ia strength of evidence; Table 3). Despite the relative success of these UGRA/low-dose local anesthetic techniques, HDP continued to occur unpredictably in both interscalene studies, suggesting that this approach remains relatively contraindicated in those patients most at risk for pulmonary compromise (level IV strength of evidence). Although the supraclavicular study[5] suggests that the risk of HDP is very low using ultrasound guidance and 20 mL ropivacaine, the study was too small to detect a true incidence of HDP using this approach. A large series of UGRA supraclavicular blocks (n = 510) noted symptomatic HDP in 1% of patients (95% CI, 0.4%–2.3%) using 33 ± 8 mL local anesthetic.[8]

Pneumothorax

Ultrasonography enables the anesthesiologist to directly visualize the pleura and lung, which intuitively lessens the risk of pneumothorax. Three RCTs[5–7] and 1 case series[8] of patients undergoing the supraclavicular or lateral sagittal infraclavicular approaches report no pneumothorax in 575 patients (upper limit 95% CI, 0.5%). Nevertheless, a pneumothorax has been reported after UGRA lateral sagittal infraclavicular block[41] and an interscalene continuous catheter block,[42] plus an unreported pneumothorax complicated an attempted UGRA supraclavicular/infraclavicular approach at the author's institution (level III strength of evidence; Table 3).

Indirect Effects of UGRA on Patient Safety

If the incidence of a major complication can be reduced, the direct versus indirect association with UGRA might be seen as immaterial semantics. Yet, a critical review should attempt to differentiate between improved outcomes directly attributable to a unique trait of UGRA versus an indirect benefit that results from a change in technique facilitated by, but not unique to, UGRA. For instance, UGRA interscalene block changes the traditional needle-toward-midline technique of Winnie[43] to a more shallow posterior/lateral-to-anterior/medial needle trajectory that is superficial to the deep borders of the scalene muscles and that theoretically lessens the potential for unintended neuraxis contact. This approach, which should reduce the risk of direct neuraxial spread of local anesthetic and/or needle injury to the spinal cord, is not unique to UGRA; a modified lateral PNS-based approach has been described also by Borgeat et al.[29] Another example pertains to UGRA-facilitated reduction in local anesthetic volume, which may lessen the incidence of LAST. Whereas UGRA may instill the confidence to use smaller volumes of local anesthetic, the tendency for practitioners to use excessive local anesthetic doses for peripheral nerve blocks has been demonstrated by multiple studies,[9] including the ability to substantially reduce median effective volumes by using stimulating perineural catheters.[44] Another indirect (and unique) benefit of UGRA is preprocedural scan of the target area, which may reveal and thus avoid unanticipated findings such as vascular anomalies,[45] neurofibromatosis, or ventriculoperitoneal shunts.[46] Therefore, without diminishing the importance of improving patient safety by whatever tactic, future studies and critical assessments of UGRA should acknowledge both its direct and indirect benefits.

Limitations and Future Directions

Just as it may be important to differentiate direct from indirect benefits of UGRA, in the future it may be possible to link UGRA to patient safety issues that are not obvious from current data. For instance, several RCTs demonstrate fewer needle passes with UGRA versus PNS-guided techniques.[33,47] Although perhaps intuitive to link reduced needle passes to less nerve injury and vascular puncture, current data obtained from normal subjects cannot support this linkage. However, US may particularly improve nerve localization and perhaps reduce nerve injury in patients with diabetes mellitus, in whom PNS- or paresthesia-guided localization is insensitive, and whose nerves have an altered response to local anesthetics.[48,49] Fewer needle passes and vascular punctures may also limit hematoma formation in anticoagulated patients, in whom deeper peripheral nerve blocks are relatively contraindicated.[50] Finally, UGRA-facilitated reduction in local anesthetic volume may have a much greater benefit for the pediatric patient than the adult patient. Thus, future UGRA studies, if performed in patients at risk for specific complications, might reveal benefits not currently apparent in normal patients.

Just as the literature offers no proof that UGRA successfully improves patient safety with regard to rare devastating injuries, there is also no proof that UGRA indeed does not increase the likelihood of injury. Balancing the positive effects of UGRA is the recognition that characteristics of ultrasound machines vary,[51] acoustic resolution is limited, and that operator skill, training, and experience are an unquantifiable component of patient safety. Key to ultrasound safety is keeping the needle tip in view during advancement and injection, yet needle visualization can be challenging.[52] Furthermore, the most common mistakes made by novices include failure to identify the needle tip before injection and failure to recognize maldistribution of injected local anesthetic,[53,54] both of which negate the advantages of UGRA and conceivably lead to injury. Although difficult to quantify, it is likely that even the best ultrasound technology cannot improve safety without properly trained and skilled operators.[55–57] As investigators and everyday operators become well trained in UGRA, data regarding the impact of UGRA on patient safety should become more plentiful and reliable.

CONCLUSION

After a decade of critical appraisal, the science of UGRA remains in its infancy, particularly with regard to how it impacts patient safety. There are no RCT data that unequivocally support superior safety outcomes consequent to the use of UGRA. Statistical proof of improved outcomes for extremely rare events such as peripheral nerve injury is likely unattainable. Data from inadequately powered comparative studies show no differences in surrogate outcomes such as paresthesia during block placement or temporary neurologic symptoms. Improved surrogate safety outcomes such as vascular puncture or less frequent HDP are apparent with the use of UGRA, but there are no definitive data that confirm an actual reduction in true outcomes such as LAST or predictable elimination of HDP in normal patients. Case reports emphasize that absolute elimination of these serious complications has not occurred. Further research is necessary, particularly in those patients at increased risk for specific complications and for whom UGRA may be more likely linked to improved safety profiles.

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Evidence Basis for Ultrasound-Guided Block Characteristics

Onset, Quality, and Duration

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Background and Objectives: This systematic review summarizes existing evidence for superior onset, quality, and duration of block for ultrasound (US) guidance versus other techniques for nerve localization.
Methods: MEDLINE was systematically searched from 1966 to September 2009 for randomized controlled trials (RCTs) comparing US guidance to another technique for peripheral nerve blocks.
Results: Sixteen RCTs were identified for upper-extremity peripheral nerve blocks and 8 for lower extremity. Jadad scores for quality of RCT ranged from 1 to 5, with a median of 2. For upper-extremity blocks, 9 (60%) of 15 RCTs reported faster onset of block, 4 (25%) of 16 reported better quality of block, and 1 (17%) of 6 reported longer duration of block with US. Only 1 RCT reported that US was inferior in any outcome. For lower-extremity blocks, 5 (71%) of 7 RCTs reported faster onset, 5 (63%) of 8 reported better quality, and none of 3 RCTs reported longer duration of blocks. No RCTs reported that US was inferior in any outcome.
Conclusions: There is level 1b evidence to make a grade A recommendation that US guidance provides a modest improvement in block onset and quality of peripheral nerve blocks. Ultrasound is rarely inferior to other techniques.

(*Reg Anesth Pain Med* 2010;35: S26–S35)

This systematic review summarizes existing evidence for potential benefits of ultrasound (US)–guided peripheral nerve blocks such as increased speed of onset of block, improved quality of surgical block, and prolonged duration of block.

METHODS

The National Library of Medicine's MEDLINE database was searched for the period 1966 to September 2009. Search strategies included the terms "ultrasound" and "nerve block," limited by the terms English, human, and randomized controlled trial (RCTs). This initial search identified 72 potential articles for systematic review. All of the abstracts searched were reviewed for potential inclusion in the systematic review, but only RCTs comparing US 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. 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 quality of a clinical trial. Two additional points may be added or deducted to the score; thus, a maximal score is 5.

RESULTS

Sixteen RCTs for upper-extremity blocks (Table 1)[1–16] and 8 RCTs for lower-extremity blocks (Table 2)[17–24] were identified that compared US guidance with an alternative technique. One additional RCT was identified that compared US with nerve stimulator for femoral nerve block.[25] 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. Jadad scores ranged from 1 to 5, with a median of 2. Multiple outcomes were often measured in the same RCT for onset, quality, or duration of block. Thus, an individual RCT was considered positive for US guidance onset, quality, or duration of block if any one sub-outcome was statistically improved. Not all RCTs measured onset, quality, and duration of blocks; thus, denominators do not always equal 16 for upper-extremity RCTs and 8 for lower-extremity RCTs.

Onset of Block

For the upper-extremity RCTs, there was good evidence for hastened onset of block with US, as 9 of 15 RCTs reported a positive finding, 5 of 15 found no difference, and only 1 RCT reported slower onset with US.

- Time until onset of block: 6 of 16 RCTs reported this outcome: 2 of 6 reported faster onset by 4 to 12 mins, 3 of 6 reported no difference, and 1 of 6 reported slower onset by 2 mins.
- Percentage of successful block at preset time points: 13 of 16 RCTs reported this outcome: 8 of 13 reported greater success rates of 75% to 86% with US versus 47% to 63% with control technique, and 5 of 13 reported no difference.

For the lower-extremity RCTs, there was again good evidence for hastened onset of block with US, as 5 of 7 RCTs reported a positive finding, 2 of 7 found no difference, and no RCT reported slower onset with US.

- Time until onset of block: 5 of 8 RCTs reported this outcome: 3 of 5 reported faster onset by 11 to 14 mins, and 2 of 5 reported no difference.

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TABLE 1. Summary of RCTs Comparing US 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	Axillary block
		Distal arm, forearm, or hand surgery	Forearm and hand surgery	Upper-limb surgery	Hand surgery
		40: US + NS (US)	30: US single injection (US)	20: US (13: interscalene, 7: axillary)	28: Transarterial (TA)
		40: NS	30: US double injection (UD)	20: Landmark-based (11: interscalene, 9: axillary)	28: 3 injection (US)
		1:1 bupivacaine 0.5% + lidocaine 2% with 1:200,000 epinephrine	30: NS double injection (ND)	*3 mg/kg ropivacaine*	*10 mL 1.5% lidocaine + 5 μg/mL epinephrine*
			0.5 mL/kg 1.5% lidocaine with 5 μg/kg 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 time points	Similar rate of partial or complete sensory block in all nerve territories after 30 mins; group US vs group NS: 95% vs 85%	Similar efficacy in all 3 groups in blocking all 7 sensory and motor nerves after 40 mins; groups US and ND vs group UD: 70% vs 73%	**More complete sensory and motor block at 10 and 20 mins after block 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 mins) Similar rate of complete motor block between US vs TA at all intervals **except at 15 and 25 mins 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 mins***	**Significantly faster in Groups UD and US vs group ND: 6.7 ± 1.3 and 6.5 ± 1.3 vs 8.2 ± 1.5 mins***	N/A	**Significantly faster in group US vs Group TA: 7.9 ± 3.9 vs 11.1 ± 5.7 mins***
		End point for performance: interval between first needle insertion and final needle withdrawal	*End point for performance: time from needle puncture or US application on skin to the completion of the LA injection*		*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 mins (55% vs 65%)	No significant difference between US and ND vs UD at 40 mins (70% vs 73%)	N/A	N/A
Duration	Duration of block, min	N/A	N/A	Similar duration vs group US vs group landmark (10.3 vs 11.2 hrs)	N/A
	Time to 1st analgesic, min	Similar duration for group US vs NS: 846 ± 531 vs 652 ± 473 mins *Defined as interval between block completion and ingestion of the first postoperative analgesic*	N/A	N/A	N/A

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TABLE 1. *(Continued)*

Jadad score		3	5	2	3
Groups (n: technique)		Axillary block Forearm, wrist, and hand surgery 30: 4 nerve branches, injection US 30: 4 nerve branches, injection NS *20 mL 0.75% ropivacaine*	Axillary block Hand surgery 64: 3 injection US 62: 3 injection NS 62: 3 injection combined USNS *42 mL 2% lidocaine + 0.5% bupivacaine*	Infraclavicular block Hand, forearm, and distal arm surgery 36: US-guided perivascular (US) 36: single injection US-guided NS (NS) *0.5 mL/kg (max. of 40 mL) of 1:3 0.5% bupivacaine, 2% lidocaine with 1:200,000 epinephrine*	Lateral sagittal infraclavicular block Elective hand or forearm surgery 40: NS 40: US *Presurgery: oral paracetamol 1.5 g, IV alfentanil 0.5 mg, midazolam 1 mg.* *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%–95%	Powered to detect a difference of 1.6 min in performance between the 2 techniques	Powered to detect a difference of 5 mins between 2 techniques
Onset time	Time of onset	**Sensory onset faster for US vs NS: 14 ± 6 vs 18 ± 6 mins*** but no difference in onset of motor block: 24 ± 8 vs 25 ± 8 mins	N/A	N/A	No significant difference in onset time for US vs NS: 13.9 ± 5.8 vs 13.7 ± 6.6 mins
	Success at set time points	N/A	**More complete sensory block for US and USNS vs NS at 30 mins (83% and 81% vs 63%)*** Similar rate of complete motor block btw US and USNS vs NS at 30 min	**More complete sensory and motor blocks for US vs NS at 30 mins (86% vs 57%)** In group US, no., injections (single vs multiple did not affect rate of complete block)	Similar rate of complete sensory block between US vs NS at 30 mins (95% vs 85%)
	Time necessary to perform block, min	N/A	**Significantly faster in group US vs group NS vs group USNS: 9.3 ± 4.0 mins vs 11.2 ± 4.4 mins vs 12.4 ± 4.8 mins*** *End point for performance: time from palpation of axillary artery (NS) or US application (US) to the end of local anesthetic injection*	**Significantly faster in group US vs group NS: 3.1 ± 1.6 vs 5.2 ± 4.7 mins*** *End point for performance: interval between skin puncture and withdrawal of the needle after injection*	No significant difference between group US vs group NS: 4.1 ± 1.3 vs 4.3 ± 1.3 mins *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, hrs	N/A	N/A	Similar duration for group US vs group NS (7 ± 3 vs 8 ± 5 hrs)	N/A

Study		Gürkan et al[9] (2008)	Macaire et al[10] (2008)	Kapral et al[11] (2008)	Dhir and Ganapathy[12] (2008)
Groups (n: technique)		Lateral sagittal infraclavicular block	Combined median and ulnar nerve block	Interscalene brachial plexus block	Infraclavicular brachial plexus block using non-stimulating catheter (ST)
		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: ST
		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%*	22: Ultrasound guidance (US) *Titration of fentanyl (50–150 μg) and midazolam (1–3 mg), 40 mL of 15 mg/mL mepivacaine with 2.5 μg/mL adrenaline*
Primary outcome		Powered to detect a score of 12 for sensory evaluation at 20 mins with a statistical power of 0.9	Powered to detect at least 20-sec 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) mins	Powered to detect that US guidance would increase success rate from 60%–95%
Onset time	Time of onset	No significant difference in onset time for US vs NS: 20 vs 20 mins	Slower onset of median block for US vs NS: median (range) 371 (252–465) vs 254 (210–300) secs* Slower onset of ulnar block for US vs NS: 368 (246–430) vs 241 (210–310) secs*	**Faster onset time for US vs NS: median (range): 10 (6–13) vs 22 (11–28) mins**	N/A
	Success at set time points	Similar efficacy of block at 30 mins for group US vs group NS (95% vs 92.5%)	N/A	**Significantly better sensory and motor block quality at 30 mins for US vs NS***	**Significantly better sensory and motor block quality after 20 mins 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 mins*** *End point for performance: N/A*	**Significantly faster for median and ulnar block in group US vs group NS: 55 vs 100 and 58 vs 80 secs*** *End point for performance: time between beginning of specific procedure (median, ulnar nerve block) and end of local anesthetic injection*	N/A	N/A
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 mins 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 mins (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) mins***	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	*1.5% mepivacaine with 1:300,000 epinephrine and NaCO3.*	*Premedication with 1–2 mg midazolam, 40 mL*	109: TA
		30 mL ropivacaine 0.5%		*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 neurologic 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) mins	N/A
	Success at set time points	N/A	**More complete motor block in the biceps for US vs NS at 5 mins***	Similar efficacy of sensory and motor block at 30 mins for group US vs group NS (91% for both, 89% vs 91%)	Similar efficacy of motor block at 5 and 10 mins for US vs TA. Similar efficacy of sensory block at 5 mins **Significantly better quality sensory block at 10 mins for US vs TA (75% vs 47%)***
	Time necessary to perform block, min	**Significantly faster in group US vs group NS: 78 (65–101) vs 108 (94–129) secs*** *End point for performance: time from the moment the needle tip penetrated the skin until exiting the skin over the interscalene catheter*	No significant difference between group US vs group NS: 5 ± 3 mins for both *End point for performance: time from needle insertion to final needle withdrawal*	**Significantly faster in group US vs group NS: 3 (1) vs 6.2 (2.4) mins*** *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 mins
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 mins)	N/A
	Time to 1st analgesic, min	N/A	N/A	N/A	N/A

*Statistically significant.

NS indicates nerve stimulator.

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

Study		Marhofer et al[17] (1997)	Marhofer and Chan[18] (1998)	Domingo-Triado et al[19] (2007)	Perlas et al[20] (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 mid-femoral 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 number 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 mins***	**Significantly faster onset for US vs NS: 13 ± 16 (A) vs 27 ± 12 (B) and 26 ± 13 (C) mins***	No significant difference in onset time between US vs NS	**Significantly faster onset for US vs NS at 10 mins and every 5 mins afterward***
	Success at set time points	**More successful block from 30 to 60** mins **for US** vs **NS: sensation at 15% ± 10%** vs **27% ± 14% of initial value***	**More successful block during 1st hr 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 mins 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) mins for both *End point for performance: time from the first needle insertion to successful nerve location (NS) or from the beginning of* US *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* US *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 mins 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 hr: 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) hrs Motor: 20 (7–24) vs 17 (11–24) hrs	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[21] (2008)	van Geffen et al[22] (2009)	Mariano et al[23] (2009)	Redborg et al[24] (2009)
Jadad score		4	3	3	2
Groups (n: technique)		Popliteal sciatic nerve block	Distal sciatic block at popliteal fossa	Popliteal-sciatic perineural catheter	Tibial nerve block
		Foot surgery	Foot or ankle surgery	Foot or ankle surgery	Ankle surgery
		25: NS only (NS)	20: NS	20: Electrical stimulation (ES)	18: US
		26: US + NS (US)	20: US	20: NS	18: Landmark (LM)
		Premedication with hydroxyzine 50 mg 1 hr before arrival in operating room. 10 mL of levobupivacaine 0.5% administered separately on the tibial and common peroneal nerves (20 mL total)	*Premedication with IV midazolam 2 mg. Up to 40 mL lignocaine 1.5% with epinephrine 5 μg/mL (dose-response study)*	*40 mL 1.5% mepivacaine with epinephrine 2.5 to 5.0 μg/mL*	*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: 10 (11) vs 12.5 (10) mins; 10 (9) vs 15 (19) mins	N/A	N/A
	Success at set time points	**More successful sensory and motor block at 30 mins for US vs NS (85% vs 32%; 65% vs 16%)***	N/A	N/A	**More successful sensory and motor block at 30 mins 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 secs	No significant difference between US vs NS: 6 ± 1.9 vs 7.6 ± 3.7 mins	**Significantly faster in group US vs group ES: 5.0 (3.9–11.1) vs 10.0 (2.0 vs 15.0) mins***	**Significantly slower in group US vs group LM: 158 (110–242) vs 79 (39–131) secs**
		End point for performance: interval between the first needle insertion and its removal at the end of the block	*End point for performance: interval between the first 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*	*End point for performance*: time from when the US probe (US) or catheter-placement needle (ES) first touched the patient to when the catheter placement needle was removed	*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) mins Motor: 210 (90) vs 210 (165) mins	N/A	N/A
	Time to 1st analgesic, min	No significant difference in time to first analgesic for US vs NS: 16.6 ± 2.9 vs 17.1 ± 3.7 mins	N/A	N/A	N/A

*Statistically significant. Text in bold also indicates statistically significant.

N/A, not applicable; NS, nerve stimulator.

- Percentage of successful block at preset time points: 5 of 8 RCTs reported this outcome. All 5 RCTs reported greater success rates of 17% to 89% with US versus 0% to 61% with control technique.

Quality of Block

For the upper-extremity RCTs, there was little evidence for improved quality of block with US, as 4 of 16 RCTs reported a positive finding and 12 of 16 found no difference with US. The 4 RCTs that reported better quality with US compared this technique with nerve stimulator and transarterial injection.

- Need for rescue anesthetic: 14 of 16 RCTs reported this outcome: 3 of 14 RCTs reported greater success rates of 96% to 100% with US versus 58% to 91% with control technique.
- Need for supplemental analgesia: 11 of 16 RCTs reported this outcome: 1 of 11 reported greater success rates of 92% with US versus 74% with control technique, and 10 of 11 reported no difference.
- Complete block of all studied nerves: 7 of 16 RCTs reported this outcome: 1 of 7 reported greater success rates of 87% with US versus 27% to 68% with control technique.

For the lower-extremity RCTs, there was some evidence for improved quality of block with US, as 5 of 8 RCTs reported a positive finding and 3 of 8 found no difference.

- Need for rescue anesthetic: 3 of 8 RCTs reported this outcome. All reported no difference.
- Need for supplemental analgesia: 2 of 8 RCTs reported this outcome. All reported no difference.
- Complete block of all studied nerves: 6 of 8 RCTs reported this outcome: 5 of 6 reported greater success rates of 97% to100% with US versus 71% to 75% 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 US, as 1 of 6 RCTs reported a positive finding, whereas 5 of 6 found no difference with US.

- Time until first request for analgesia: 2 RCTs reported this outcome and reported no difference.
- Time until resolution of block: 4 RCTs reported this outcome: 1 reported 220-min greater duration with US, whereas the other RCT reported no difference.

For the lower-extremity RCTs, there was no evidence for prolonged duration of block with US, as 3 of 3 RCTs found no difference.

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

DISCUSSION

Overall, RCTs comparing US guidance to another technique are small and diverse in terms of type of block, anesthetic

TABLE 3. Summary of Advantages of US 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	9	5	1
		Soeding et al[3] (2005), Sites et al[4] (2006), Casasti 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)	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)	Macaire et al[10] (2008)
	Lower-extremity RCTs	5	2	0
		Marhoffer 1997, Marhoffer 1998, Perlas et al[20] (2008), Dufour et al[21] (2008), Redborg et al[24] (2009)	Domingo-Triado et al[19] (2007), van Geffen et al[22] (2009)	
Quality	Upper-extremity RCTs	4	12	0
		Sites et al[4] (2006), Dingemans et al[7] (2007), Dhir and Ganapathy[12] (2008), Kapral et al[11] (2008)	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 2008, Macaire et al[10] (2008), Fredrickson et al[13] (2009), Liu et al[14] (2009), Taboada et al[15] (2009), Tedore et al[16] (2009)	
	Lower-extremity RCTs	5	3	0
		Marhoffer 1997, Marhoffer 1998, Domingo-Triado et al[19] (2007), van Geffen et al[22] (2009), Redborg et al[24] (2009)	Perlas et al[20] (2008), Dufour et al[21] (2008), Mariano et al[23] (2009)	
Duration	Upper-extremity RCTs	1	5	0
		Kapral et al[11] (2008)	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)	
	Lower-extremity RCTs	0	3	0
			Domingo-Triado et al[19] (2007), Dufour et al[21] (2008), van Geffen et al[22] (2009)	

agents, and comparative control techniques. Most RCTs compared US with nerve stimulator, but other techniques included fascial pops, transarterial, surface landmarks, and US combined with nerve stimulator. A further confounding factor for review was diversity in number of injections used for both US 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,[26] 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.[1,7,19] Finally, most RCTs were performed at institutions with high proficiency with US, and results may differ with less-expert practitioners. Table 4 summarizes recommendations, levels of evidence, and grade of recommendation.

Does US Guidance Improve Onset of Block?

For the upper and lower extremities, use of US resulted in faster initial onset of block. Ultrasound may have produced faster onset of block because of closer needle approximation and local anesthetic distribution to the target nerves. Time savings from faster onset of block are difficult to categorize, as RCTs used varied outcome measures. In addition, only 2 RCTs specifically mentioned including time needed for US setup time before scanning.

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

Does Ultrasound Improve Quality of Block?

Randomized controlled trials on upper-extremity blocks offer modest evidence for superior quality of block, as only 4 of 16 upper-extremity RCTs reported superiority in at least 1 measure of block quality. Evidence for improved quality was stronger for lower-extremity RCTs, as 5 of 8 RCTs reported better quality of some measure. Again, US was never inferior to control groups for either upper- or 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 US to allow closer targeting of nerves provided more obvious advantage than upper-extremity RCTs.

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

Does Ultrasound Prolong Duration of Block?

Duration was infrequently measured, and only 1 of 8 RCTs noted prolonged duration for US. Again, US was never inferior to control groups for either upper- or lower-extremity RCTs.

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

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

CONCLUSION

Based on a systematic review of RCTs, there is level 1b evidence to make a grade A recommendation that US guidance provides a modest improvement in block onset and quality. The variety of study techniques makes meta-analysis difficult. Importantly, US is rarely inferior to control techniques. Reasons for the modest separation between US and control techniques may be the currently high published success rates with nerve stimulator in expert hands (90%–99%),[26] the continuing evolution and learning curve for US,[27] and small sample sizes of current RCTs.

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Evidence Basis for the Use of Ultrasound for Upper-Extremity Blocks

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Abstract: This article qualitatively assesses and summarizes randomized, controlled studies regarding benefits of ultrasound (US) for brachial plexus block and also examines those studies that have compared different brachial plexus block techniques using US.

Studies were identified by a search of PUBMED and EMBASE databases using the MeSH terms *anesthetic techniques*, *brachial plexus*, and *ultrasound*. Included studies were limited to randomized trials that compared a US technique with another accepted method of performing brachial plexus block or those studies that compared 2 different US-guided techniques. Studies were further classified according to methodological quality using accepted methods. Quality scores were compared using Mann-Whitney *U* test, and significance assumed at $P < 0.05$.

Twenty-five studies met inclusion criteria, with 19 studies comparing US techniques with other nerve location methods and 6 studies comparing different US techniques. Of the former, there was convincing evidence to support the use of US, with 15 of 19 studies demonstrating improved outcomes compared with existing techniques.

Ultrasound provides significant advantages when performing brachial plexus block including faster sensory block onset and greater block success.

(*Reg Anesth Pain Med* 2010;35: S10–S15)

The ability to accurately localize a nerve or plexus and successfully place local anesthetic around that structure is both an art and science. Existing techniques for brachial plexus blocks such as landmark techniques, paresthesia, and nerve stimulation have success rates varying from 60% to 95%, depending on site and practitioner expertise. However, upper-limb blocks can fail even when performed by experienced practitioners.

The use of ultrasound (US) for brachial plexus block has generated excitement because, for the first time, the practitioner can visualize anatomy, needle placement, and local anesthetic spread. The use of traditional techniques for upper-limb anesthesia has often been restricted to the expert or enthusiast, but the use of US has attracted many nonregional anesthesiologists to once again learn these very beneficial techniques for their patients. Since 1994, and particularly over the last 5 years, there have been an increasing number of high-quality randomized studies that have examined whether US actually does provide any advantage when performing brachial plexus block. This article will qualitatively assess and summarize randomized, controlled studies in the literature regarding benefits of US for brachial plexus block and also examine those studies that have compared different brachial plexus block techniques, both using US guidance.

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METHODS

Search Strategy

Studies were identified in a search of PUBMED and EMBASE (between July 1991 and August 2009) by using the MeSH terms *anesthetic techniques*, *brachial plexus*, and *ultrasound*. The reference section of eligible articles was then examined for relevant publications. Relevant studies that examined the use of US for upper-extremity blocks were reviewed. Inclusion criteria included any randomized trial that had compared the use of US with any preexisting technique for upper-extremity block or any randomized trial that had compared 2 different techniques of US-guided brachial plexus block. Randomized studies where different local anesthetic volumes were assessed or different blocks using different nerve location methods for each block were not included. Letters to the editor, abstracts, non–peer-reviewed studies, case reports, and case series where no comparison was made were not included.

Three reviewers independently performed the literature searches and assessed all identified full articles for inclusion. These criteria included independently assessing each article with regard to type of randomization, blinding, 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), and procedure-related pain and other adverse effects. Studies were classified supportive of the US technique if any of the above measured end points demonstrated a significant difference between groups favoring that group and negative if no difference between groups was observed or if the study favored the alternative (non-US) technique. The criteria for assessing quality of reports as described by Jadad et al[1] were used; however, the minimum criterion for inclusion in the review was a randomized study. The minimum and maximum scores were therefore 1 and 5, respectively. For studies that compared US against existing methods of nerve location, the quality scores between supportive and negative studies were examined using the Mann-Whitney *U* test and reported as median (range). Significance was assumed at $P < 0.05$. In addition, a grade of recommendation was assigned based on the number of studies supporting individual outcomes according to the US Agency for Health Care Policy and Research.

RESULTS

A total of 25 randomized studies met the inclusion criteria and are detailed in Tables 1 and 2. Nineteen studies compared US against another nerve location method,[2–20] and 6 studies[21–26] compared 2 (or more) different US-guided approaches. All studies were randomized studies representing level 1b evidence but varied in study quality (median, 3; range, 1–5).

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

Author (Year)	Jadad Score	Block	n	Study Type	Method	LA	Major Findings	Conclusion
Liu et al[2] (2009)	3	ISB	219	R	US vs PNS	45–55 mL Mepivacaine 1.5% + epinephrine	Less needle passes (1 vs 3; $P < 0.001$) and faster motor onset ($P = 0.04$) in US group	US better
Morros et al[3] (2009)	1	AXB	129	R	US + PNS vs PNS multistimulation	40 mL Mepivacaine 1%	Greater block time in US/PNS group (350 vs 291 secs; $P < 0.05$); faster onset and less vascular puncture (8% vs 28%; $P = 0.01$) in US/PNS group	No difference
Brull et al[4] (2009)	5	ICB	103	R, DB	US vs dual end-point PNS	15 mL Bupivacaine 0.5% and 15 mL lidocaine 2%	Greater surgical readiness at 20 mins in US group (85 vs 65%; $P = 0.04$); faster block performance in US group (5 vs 10.5 mins; $P < 0.001$)	US better
Ponde and Diwan[5] (2008)	4	ICB	50	R, DB	US vs PNS	0.5 mL/kg 0.5% Bupivacaine	Greater success in US group (96% vs 64%)	US better
Taboada et al[6] (2009)	3	ICB	35	R, SB	US vs PNS (radial end point)	40 mL 1.5% Lidocaine	Shorter procedure time in US group (3 vs 6 mins; $P < 0.0001$)	US better
Sauter et al[7] (2008)	3	ICB	80	R, SB	US cranioposterior to axillary artery with 1–3 injections; only single injection in PNS	Mepivacaine 1.5% 0.6 mL/kg 2.5 μg/mL	No difference in block success; fewer needle passes in US group (1 vs 3; $P < 0.001$)	No difference
Dhir et al[9] (2008)	2	ICB	66	R	Nonstimulating catheter with PNS; stimulating catheter with PNS; US + PNS catheter	Mepivacaine 1.5% 2.5 μg/mL 40 mL	Greater primary (96% vs 58%) and secondary (91% vs 83%; $P < 0.001$) block success in US group	US better
Macaire et al[10] (2008)	2	Wrist	59	R, SB	PNS vs US for median and ulnar nerve block at wrist	Mepivacaine 1.5% 4 mL each nerve	Faster block onset in PNS group; overall no difference for block performance + onset time	No difference
Gürkan et al[11] (2008)	2	ICB	80	R, SB	US + PNS n = 40 vs PNS n = 40 lateral sagittal ICB (same puncture point)	40-mL Mixture levobupivacaine 0.5% 20 mL + lidocaine 2% 20 mL	Faster block performance in PNS compared with US/PNS group (6.4 vs 7.2 mins; $P < 0.05$).	PNS better
Kapral et al[12] (2008)	2	ISB	160	R, SB	US vs PNS	Ropivacaine 0.75% 20 mL	Greater surgical anesthesia (99% vs 91%; $P < 0.01$) and prolonged duration (899 vs 679 mins; $P < 0.05$) with US	US better
Yu et al[13] (2007)	3	AXB	80	R	US vs PNS	Ropivacaine 0.75% + lidocaine 2%; Total, 32 mL	Faster performance (5.2 vs 14.6 mins; $P = 0.000$), greater success (100% vs 77.5%; $P = 0.005$), and less vascular puncture (0 vs 40%; $P = 0.000$) in US group	US better
Chan et al[14] (2007)	5	AXB	188	R, DB	PNS, US, US + PNS	Lidocaine 2% + bupivacaine 0.5% 5 μg/mL (total 42 mL); 14 mL per nerve	Faster block performance (9.3 vs 11.4 mins; $P < 0.01$) comparing US vs PNS groups; greater block success in US (82.8%) and US/PNS (80.7%) groups compared with PNS alone (62.9%; $P = 0.03$)	US better
Casati et al[15] (2007)	3	AXB	60	R, SB	Injection of all 4 nerves by US or PNS	Ropivacaine 0.75% 20 mL	Reduced needle passes (4 vs 8; $P = 0.002$) and shorter sensory block onset (14 vs 18 mins; $P = 0.01$) in US group	US better
Dingemans et al[16] (2007)	2	ICB	72	R	US vs US/PNS	Lidocaine 1.5% + bupivacaine 0.125% + 0.5 mL/kg	Faster performance (3.1 vs 5.2 mins; $P = 0.006$); greater success in US-alone group (86 vs 57%; $P = 0.007$)	US alone better
Sites et al[8] (2006)	3	AXB	56	R, SB	US perivascular injection compared with transarterial block	Lidocaine 1.5% 30 mL	Greater success (100% vs 71%; $P < 0.01$) and faster performance (7.9 vs 11.1 mins; $P < 0.05$) in the US group	US better

(Continued on next page)

TABLE 1. *(Continued)*

Author (Year)	Jadad Score	Block	n	Study Type	Method	LA	Major Findings	Conclusion
Soeding et al[17] (2005)	1	ISB/AXB	40	R	US vs landmark, and superficial cervical plexus block for shoulder surgery	Ropivacaine 0.75% for ISB; 0.6% for AXB of 3 mL/kg	Better sensory ($P = 0.01$) and motor block ($P = 0.002$) and less paresthesia in US group ($P = 0.01$)	US better
Liu et al[18] (2005)	2	AXB	90	R, SB	PNS 2 injections vs US 2 injections vs US single injection	Lidocaine 1.5% 5 μg/mL of 0.5 mL/kg	Shorter procedure time in US groups (6.7 vs 8.2 mins; $P < 0.01$); greater complications in NS group (20% vs 0%; $P = 0.03$)	US better
Marhofer et al[19] (2004)	3	ICB	40	R, SB	US lateral approach vs PNS	Ropivacaine 0.5% 0.5 mL/kg	Less procedure pain ($P = 0.03$), faster sensory onset (9 vs 15 mins; $P < 0.001$), and prolonged block in US group (384 vs 310 mins; $P < 0.001$)	US better
Williams et al[20] (2003)	2	SCB	80	R	US + PNS vs PNS (perivascular approach)	Ropivacaine 0.25% + lidocaine 1% 0.5 mL/kg; max 40 mL	Shorter procedure time (5 vs 9.8 mins; $P = 0.0001$) in US group	US better

R indicates randomized; DB, double-blind; LA, local anesthetic; SB, single-blind.

Studies Comparing US Against Another Nerve Location Technique

Overall, these studies (Table 1) are strongly supportive of the use of US, with 15 studies demonstrating beneficial outcomes including faster block performance, faster block onset, and greater block success. Three studies showed no clear difference, and only 1 study was supportive of the use of peripheral nerve stimulation (PNS) with a faster block performance time in the PNS group. The quality score of positive studies was not different from negative studies (positive: median, 3 [range, 1–5]; negative: median, 2 [range, 1–3]). Eight studies examined infraclavicular block (ICB), 7 studies examined axillary block (AXB), 3 studies examined interscalene block (ISB), 1 study examined supraclavicular block (SCB), and 1 study examined wrist block.

The 3 studies demonstrating no difference included 1 study examining AXB,[3] one examining ICB,[7] and another examining wrist block.[10] The study that favored PNS involved ICB.[11]

Studies Comparing Between Different US-Guided Brachial Plexus Blocks

Six studies compared US-guided brachial plexus techniques (Table 2). Four studies compared SCB with ICB block[21,23–25]; 1 study compared SCB, ICB, and AXB[22]; and 1 study compared SCB with AXB.[26] Two of the studies comparing ICB with SCB found that sparing of the inferior trunk with the SCB led to a higher incidence of block failure in those groups.[21,23] Two studies also found a significantly greater incidence of complications[21,22] with SCB when compared with both ICB and AXB. One study[26] found that the SCB produced better block quality when compared with AXB, although a more recent study found no difference between SCB, ICB, and AXB.[22]

DISCUSSION

The results of this review suggest that use of US for brachial plexus block provides significant benefits for patients including faster brachial plexus block onset and greater block success. Of the 19 studies comparing US against other nerve location methods, 15 demonstrated significant benefit with US, whereas only 1 study favored PNS (Table 1). Commonly identified benefits of US included surrogates of block performance such as faster block performance time[4,6,8,10,13,14,16,18,20] and reduced number of needle passes[2,7,15] and surrogates of better quality block including faster sensory onset time[3,4,8,9,12–14,16,20] and greater block success.[5,8,9,12–14,16,20] It should be noted, however, that of the 8 studies that found faster block performance with US, 4 studies[6,13,16,20] did not include the US scan time required before needle insertion. A fair comparison of block performance time was therefore deemed not to have been made for these studies, and they have been classified as inconclusive (Table 3). However, the highest-quality studies[4,14] have demonstrated a clinically and statistically significant reduction in performance time even when scan time was included.

Overall, there were 4 negative studies (3 found no difference,[3,7,10] 1 favored PNS[11]), and a number of factors may explain these findings. Early pioneers of US-guided peripheral nerve block techniques hypothesized that the combination of US and PNS would speed block performance time. However, in this review, a number of studies demonstrated that the combination group (US + PNS) had the slowest performance time. Two studies compared a group using PNS with another group using both US and PNS[3,11] and found slower performance time in the US/PNS group. In the study by Chan et al,[14] where US was compared against both PNS and combined US/PNS for

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

Author	Jadad Score	Block	n	Study Type	Method	LA	Major Findings	Conclusion
Koscielniak-Nielsen et al[21] (2009)	3	US ICB vs SCB	120	R, SB	US SCB vs ICB	Ropivacaine 0.75% + mepivacaine 2%	Greater success in ICB group (93% vs 78%; $P = 0.017$) and greater diaphragm paresis in SCB group	ICB better than SCB
Tran et al[22] (2009)	2	US SCB vs ICB vs AXB	120	R, SB	Perivascular spread technique for all blocks	Lidocaine 1.5% 35 mL	Longer procedure duration in AXB group (8.5 vs 6–6.2 mins; $P < 0.008$); greater Horner syndrome in SCB group (37.5% vs 0%–5%; $P < 0.001$)	No difference
Fredrickson et al[23] (2009)	4	US SCB vs ICB	60	R, DB	US (no PNS) SCB (corner pocket) vs ICB (triple-point injection)	Lidocaine 2% 30 mL (weight <65 kg use 25 mL)	Greater surgical anesthesia in ICB compared with SCB (93% vs 67%; $P = 0.01$) due to ulnar insufficiency	ICB better than SCB
De Jose Maria et al[24] (2008)	2	US SCB vs ICB	80	R	SCB (in plane) vs ICB (out of plane) in children under general anesthesia	Ropivacaine 0.5% up to max 0.5 mL/kg	No proven difference in block success in SCB vs ICB (95% vs 88%; $P = 0.39$)	No overall difference
Arcand et al[25] (2005)	3	US + PNS for ICB vs SCB	80	R	PNS <0.6 mA and US for all blocks	Bupivacaine 0.5% + lidocaine 2% (1:3 volume); total, 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[26] (1994)	1	US SCB vs AXB	40	RCT	Lateral paravascular SCB approach	Bupivacaine 0.5% 30 mL + 10 mL radiopaque dye	Greater anesthesia in SCB group due to missed musculocutaneous nerve in AXB group	SCB better than AXB

R indicates randomized; DB, double-blind; LA, local anesthetic; SB, single-blind.

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)
Block performance time	I	4/4*/3†
No. needle passes	I	3/0/0
Vascular puncture	I	2/0/0
Procedure pain	I	1/0/0
Sensory onset	A: Supportive for US	6/0/1‡
Motor onset	I	1/0/0
Block success	A: Supportive for US	8/0/0
Block duration	I	2/0/0

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[6,13,16,20] 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. Macaire et al[10] 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[10] in which faster onset time in the PNS group was associated with intraneural injection.

AXB, the combination group had a slower time to perform the block than either the US or PNS group. The reason may be that using both methods for nerve localization may cause operator distraction and prolong performance time. In addition, false-negative responses frequently occur with nerve stimulation where no motor twitch occurs despite apparent proximity of the needle tip to the nerve.[27,28] This may be a cause of increased block performance time as the anesthesiologist tries to seek both US and nerve stimulation end points.

Macaire et al[10] compared US against PNS for wrist block and found faster block performance time in the US group, but faster block onset time was seen in the PNS group. The authors subsequently demonstrated in several patients that intraneural injection may have been responsible for the faster block onset in the PNS group.

Of the 6 studies that compared US-guided brachial plexus block techniques, 4 compared ICB with SCB.[21,23–25] Two of these studies[21,23] demonstrated the block success is greater with ICB compared with SCB, and this is mainly related to the increased failure to anesthetize the inferior trunk in the SCB group. In addition, 2 of the 4 studies[21,22] found greater block-related complications in the SCB group including Horner syndrome and phrenic block. These results are somewhat surprising given the recent upsurge in the popularity of the US-guided SCB technique related to the purported high block success with a single injection of local anesthetic. However, the position of the inferior trunk immediately above the pleura may explain the difficulty in achieving adequate local anesthetic spread to this area. Further studies and case series are required before definitive conclusions can be drawn regarding the efficacy and adverse effects of the US-guided SCB technique.

Several limitations of this review need to be acknowledged. First, although several of the included studies were performed by experts, in many studies the level of expertise is hard to define. This is especially so for those studies where blocks were performed by both residents and consultant staff. At present, no high-quality randomized studies exist that examine the learning of US by novices alone, and this area needs further investigation. Data regarding complications with US 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.

Finally, it should be noted that a higher-than-normal number of inconclusive recommendations have been made because we assessed only randomized studies as a minimum requirement for inclusion in this review, and several studies of lower methodological quality do exist but were not included. Had we included these studies, further recommendations may have been possible.

It should be emphasized that US is only one component of the successful and safely performed brachial plexus block and that preexisting basic rules of safe regional anesthesia practice remain very important. These include good training, knowledge of anatomy, and careful technique including slow injection of local anesthetic with regular syringe aspiration and maintenance of verbal contact with the patient.[29]

In conclusion, this review demonstrates that US-guided brachial plexus block techniques demonstrate several advantages (Table 3) when compared with preexisting nerve location methods including faster onset and greater block success. Future studies should examine use of US in the hands of novices and whether US has any effect on the incidence of serious complications of brachial plexus block.

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Ultrasound and Review of Evidence for Lower Extremity Peripheral Nerve Blocks

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Abstract: This qualitative systematic review summarizes existing evidence from randomized controlled trials (RCTs) comparing ultrasound (US) to alternative techniques for lower extremity peripheral nerve block. There were 11 RCTs of sufficient quality for inclusion. Jadad scores ranged from 1 to 4 with a median of 3. For femoral nerve blocks, US provided shorter onset and improved quality of sensory and motor block, as well as a decrease in local anesthetic requirements. For sciatic nerve blocks, US resulted in a higher percentage of patients with complete sensory and motor block, as well as decreased local anesthetic requirements. In 2 of the studies for sciatic nerve block, US resulted in a shorter time to successfully complete the procedure. No study was powered to detect a difference in surgical block success. Overall, there was significant heterogeneity in the definitions of successful sensory and motor block. In 2 studies, the optimal peripheral nerve stimulation technique may have not been used, resulting in a potential bias. No RCT reported US as inferior to alternative techniques in any outcome. There is level Ib evidence to make a grade A recommendation that US guidance provides improvements in onset and success of sensory block, a decrease in local anesthetic requirements, and decreased time to perform lower extremity peripheral nerve blocks.

(*Reg Anesth Pain Med* 2010;35: S16–S25)

This qualitative systematic review will summarize the existing evidence for the potential benefits of ultrasound (US) guidance compared with an alternative form of peripheral nerve localization for lower extremity peripheral nerve block. The alternative forms of peripheral nerve localization include peripheral nerve stimulation (PNS) or fascial plane localization using a double loss of resistance (LOR) for fascia iliaca compartment block. In addition, the evidence for the potential benefits of combined US guidance with PNS compared with PNS alone for lower extremity peripheral nerve block will be reviewed.

METHODS

The National Library of Medicine's MEDLINE database was searched for the period of January 1990 to November 2009. Search strategies included the terms "ultrasound" and "peripheral nerve block." A 2-stage search was performed using additional keywords to capture studies not initially identified and included the terms "ultrasound" with "lumbar plexus," "3-in-1," "fascia iliaca," "femoral nerve," "lateral femoral cutaneous nerve," "obturator nerve," "sacral plexus," "sciatic nerve," and "popliteal." The author assessed whether articles met the following predefined inclusion criteria: prospective data collection, randomization, and direct comparison of US with either PNS or LOR techniques for lower extremity peripheral nerve block in human adults. Studies comparing combined US guidance with PNS techniques to PNS techniques alone were also included to define the potential advantages and disadvantages of each technique. Studies on evidence for US guidance for pediatric regional anesthesia are addressed in a separate systematic review. For the purposes of this review, the primary outcomes of interest included block onset, block success, local anesthetic requirements, and block procedure time. There were no studies that defined "block success" as the ability to provide surgical anesthesia as the primary outcome. Secondary outcomes of interest included block failures (defined as the inability to localize the target nerve within a prespecified duration of time, requiring crossover to the alternative technique), number of needle redirections or needle passes, and patient's comfort during the block procedure. A Jadad score was used to grade each randomized controlled trial (RCT) for study quality.

RESULTS

3-in-1, Femoral Nerve, and Fascia Iliaca Blocks

There were 2 randomized controlled studies directly comparing US to PNS for the 3-in-1 block,[1,2] 1 study comparing US with PNS for femoral nerve block,[3] and 1 study directly comparing US to LOR for the fascia iliaca block,[4] for a total of 240 patients (Table 1). None of these studies directly compared US with PNS using the presence of a surgical block as the primary outcome. In the first study, Marhofer et al[1] compared US guidance with PNS after injection of 20 mL of bupivacaine 0.5% in both groups, and the primary outcome was onset of sensory block (defined as a subjective reduction in pinprick sensation in the sensory distribution of the femoral, lateral femoral cutaneous, and obturator nerve to 30% of baseline sensation, compared with the contralateral leg). There was no description of the end point for the PNS group in terms of an evoked motor response (EMR) or minimal current threshold. The block onset time was decreased by 11 mins in the US group (16 versus 27 mins) and had an improved quality of complete sensory block compared with PNS. In the second study by Marhofer et al,[2] the same methodology was used to perform the blocks and assess the block characteristics. In this study, an additional PNS group was added, characterized by an increase in the local anesthetic dose (from 20 to 30 mL of bupivacaine 0.5%). The primary hypothesis was that US could provide equivalent block onset and quality using a reduction in local anesthetic dose. In this study, the US group (20 mL of bupivacaine 0.5%) provided 13 to 14 mins of reduction in block onset compared with either PNS group (20 and 30 mL of bupivacaine 0.5%). The Jadad scores were low (1 and 2, respectively) for both of these studies and neither performed a power analysis.

Casati et al conducted a well-designed RCT comparing the efficacy of US guidance to potentially decrease the minimum

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TABLE 1. Summary of RCTs Directly Comparing US Guidance Versus Alternative Technique for Femoral Nerve (or 3-in-1) Block

Study	Jadad Score	Treatment Groups (n: Technique)	Primary Outcome (Hypothesis)/ Power Analysis	"Block Success" (Surgical Block)	Procedure Time	Block Characteristics	Complications
Marhofer 1997	1	3-in-1 block	Block onset: subjective reduction of pinprick sensation (compared with contralateral leg) to 30% of initial value in all 3 nerves of the lumbar plexus, beginning at *30 mins after block* and every 10 mins through 60 mins	N/A	N/A	Shorter block onset for US (16 ± 14 min) versus NS (27 ± 16 min)	None
		Preoperative analgesia for hip fractures	No power analysis	Block for postoperative analgesia		Better quality of complete sensory block from 30 to 60 mins with US versus NS (15 ± 10% versus 27 ± 14% of initial pinprick sensation)	
		20: US, 20 mL of bupivacaine 0.5%				No difference in complete block @ 60 between US (95%) versus NS (85%)	
		20: PNS, 20 mL of bupivacaine 0.5%					
Marhofer 1998	2	3-in-1 block	Block onset: subjective reduction of pinprick sensation (compared with contralateral leg) to 30% of initial value in all 3 nerves of lumbar plexus, beginning at *30 mins after block* and every 10 mins through 60 mins	N/A	N/A	Shorter block onset for US (16 ± 14 min) versus 20 mL NS (27 ± 12 min) and 30 mL NS (26 + 13 min) groups.	None
		Preoperative analgesia for hip fractures	Could US provide equivalent onset and quality of sensory block with 33% reduction local anesthetic dose?	Block for postoperative analgesia		Better quality of complete sensory block at 60 min with US (4 ± 5%) versus NS (21 ± 11% and 22 ± 19%, respectively)	
		20: US, 20 mL of bupivacaine 0.5%	No power analysis			No difference in complete block at 60 min between US (95%) versus NS (80% both groups)	
		20: PNS, 20 mL of bupivacaine 0.5%					
		20: PNS, 30 mL of bupivacaine 0.5%					

(Continued on next page)

TABLE 1. *(Continued)*

Study	Jadad Score	Treatment Groups (n: Technique)	Primary Outcome (Hypothesis)/ Power Analysis	"Block Success" (Surgical Block)	Procedure Time	Block Characteristics	Complications
Casati 2007	4	Femoral nerve block (FNB) with preceding subgluteal double-injection sciatic nerve block (12 mL mepivacaine 2%).	3-mL difference in $MEAV_{50}$. Up and down staircase methodology based on the presence of surgical block at *30 mins after local anesthetic injection*	N/A	N/A	$MEAV_{50}$ (SD) 42% lower with US	None
		Knee arthroscopy	Surgical block defined as complete loss of femoral nerve pinprick sensation and complete quadriceps motor block	Designed to measure 50% effective dose with 50% planned failure rate		$MEAV_{50}$ US: 15 ± 4 mL	
		FNB with variable volumes of ropivacaine 0.5%		No difference in percentage of patients with failed surgical block at 30 mins. US (50%) versus NS (56%)		$MEAV_{50}$ NS: 26 ± 4 mL	
		30: US 30: PNS					
Dolan 2008	4	Preoperative fascia iliaca block for postoperative analgesia in unilateral total hip arthroplasty (THA) or total knee arthroplasty (TKA).	Increase in success of sensory block of medial thigh from 40% to 70%, *30 mins after local anesthetic injection*	N/A	N/A	Increased percentage of patients with sensory block in US (95%) versus NS (60%)	None
		40: Landmark-based loss of resistance	Sensory block defined as decreased or complete loss of sensation to ice in comparison to contralateral extremity	Block for postoperative analgesia		Increased percentage of patients with "complete sensory block" (anterior, medial, and lateral thigh) in US (82%) versus NS (47%)	
		40: US guidance injection deep to fascia iliaca	Motor block of FN defined as inability to extend affected leg with hip passively flexed			Increased percentage of FN motor block in US (90%) versus NS (63%)	
		30-mL equal volume of bupivacaine 0.5% and lidocaine 2% in both groups					

effective anesthesia volume in 50% of patients ($MEAV_{50}$) for femoral nerve block compared with PNS in patients undergoing knee arthroscopy with a preexisting subgluteal sciatic nerve block. Using 12 mL as the starting volume for a femoral nerve block and the up-and-down methodology,[4] it was demonstrated that US resulted in a 42% reduction in the $MEAV_{50}$ of ropivacaine 0.5% (15 ± 4 versus 26 ± 4 mL) compared with PNS. In this study, the PNS technique end point was a single EMR of quadriceps contraction at an accepted current threshold less than 0.4 mA, followed by injection of the entire volume of local anesthetic. In contrast, US guidance was described as a "moving needle technique," where the needle tip position was adjusted in real time to obtain circumferential spread of the designated local anesthetic volume around the femoral nerve. In an earlier RCT using the same up-and-down study design,[5] this same group was able to demonstrate a significant reduction in the $MEAV_{50}$ for a femoral nerve block with ropivacaine 0.5% using a multiple-injection (14 mL, 95% confidence interval [CI], 12–16 mL) versus a single-injection (23 mL; 95% CI, 20–26 mL) PNS technique.

Dolan et al[6] compared US guidance with double LOR for fascia iliaca block intended for postoperative analgesia in patients undergoing hip or knee arthroplasty in which both groups received 30-mL equal volumes of bupivacaine 0.5% + lidocaine 2%. The power analysis was based on the primary hypothesis that US would increase the success of sensory block in the medial thigh from 40% to 70%, 30 mins after completion of local anesthetic injection. Block success was defined as decreased or complete loss of sensation to cold (ice) in the respective sensory distributions. In addition, motor block as a secondary outcome was defined as the inability to extend the blocked leg at the knee with the hip passively flexed. Ultrasound-guided fascia iliaca block resulted in a significant increase in block success at the medial thigh (95% versus 60%) compared with LOR. Ultrasound also improved secondary outcomes of increased percentage of patients with a "complete 3-in-1 block" (82% versus 47%) and femoral nerve motor block (90% versus 63%) compared with LOR. No studies reported any long-term complications of peripheral nerve injury, infections, or systemic toxicity.

Sciatic Nerve Block

There were 3 studies[7–9] directly comparing US to PNS for popliteal sciatic nerve block, 1 study directly comparing US to PNS for subgluteal sciatic nerve block,[10] and 1 study[12] directly comparing US with PNS (with a stimulating catheter technique) for popliteal sciatic perineural catheter placement for a total of 214 patients (Table 2). None of these studies directly compared US with PNS using surgical block as the primary outcome. All 5 studies were of good quality with Jadad scores of either 3 or 4 and appropriate power analyses.

The primary outcome in the study by Perlas et al[7] was powered to detect an increase in sensory block success from 70% to 95% with the use of US compared with PNS, beginning 30 mins after completion of local anesthetic injection. Sensory block success was rigorously defined as complete loss of pinprick sensation in both the tibial nerve (TN) and common peroneal nerve (CPN) sensory distributions of the sciatic nerve. Ultrasound resulted in significantly higher block success (89.2% versus 60.6%) compared with PNS. Secondary outcome improvements with US included a more rapid onset of complete sensory and motor block of the TN and CPN during a 60-min data collection period but no difference in the surgical block success (92% for US versus 75% for PNS) or time to complete the block procedure (8.1 versus 8.3 mins). A criticism of this study was the potential for bias against the PNS technique. Ultrasound guidance was again described as a "moving needle technique" in contrast to PNS with a fixed needle position after obtaining a minimum current threshold of 0.5 mA or less, with a potential bias against PNS of accepting any 1 of 4 EMR (dorsiflexion or eversion indicating CPN stimulation, plantar flexion indicating TN stimulation, and inversion indicating simultaneous stimulation of both branches). It has been demonstrated that inversion may be the optimal single EMR to maximize the onset and success of sciatic nerve block.[15,16]

The study by van Geffen et al[8] was powered to detect a minimum 10-mL reduction in the volume of lidocaine 1.5% with epinephrine 5 μg/mL to block the sciatic nerve. In contrast to the more rigorous up-and-down study design, the US group was designed to administer the minimum local anesthetic volume to obtain a circumferential spread around the sciatic nerve. Conversely, the PNS group was allowed to administer a "minimum of 25 mL and a maximum of 40 mL" after obtaining the appropriate EMR based on "clinical experience needed to obtain a successful PNS-guided sciatic nerve block," potentially biasing against this technique. Ultrasound guidance resulted in a significantly lower local anesthetic volume (17 ± 5 versus 37 ± 5 mL) compared with PNS, with no difference in the percentage of patients with successful surgical block, time to perform the block, onset, or duration of sensorimotor block. Of note, 2 patients in the PNS group were excluded from analysis owing to the failure to elicit an appropriate EMR within 15 mins.

The study by Danelli et al[9] attempted to minimize the potential bias against single-injection sciatic nerve block PNS technique by comparing US guidance (with 20 mL of ropivacaine 0.75%) to a double-injection (with 10 mL each at the TN and CPN) PNS technique for popliteal sciatic nerve block. The study was powered to detect a minimum 5-min difference in the onset of sensory and motor block in both sciatic nerve branches. Block success was defined as complete loss of sensation to pinprick and complete absence of movement in both the TN and CPN distributions. Although there was a significantly faster onset of sensory block in the CPN with US compared with PNS (12.2 ± 4.8 versus 17.9 ± 8.5 min), onset of sensory block in the TN and onset of motor block in both branches was not significantly different between techniques. There was no significant difference in the percentage of complete sensory or motor blocks or surgical block success. Ultrasound guidance did result in decreased block procedure time (2 versus 5 mins), fewer skin punctures and needle redirections, and less subjective discomfort during the block compared with PNS.

Danelli et al[10] conducted a well-designed RCT comparing the efficacy of US guidance to potentially decrease the minimum effective anesthesia volume in 50% of patients ($MEAV_{50}$) for subgluteal sciatic nerve block compared with PNS in patients undergoing knee arthroscopy with a preexisting US-guided femoral nerve block. Effective sciatic nerve block was defined as a complete loss of sharp sensation using pinprick testing in both the TN and CPN distributions and the complete inability to move the foot. Using 12 mL as the starting volume for subgluteal sciatic nerve block[11] and the up-and-down methodology,[4] it was demonstrated that US (12 mL; 95% CI, 10–13 mL) resulted in a 37% reduction in the $MEAV_{50}$ of mepivacaine 1.5% compared with PNS (19 mL; 95% CI, 15–23 mL). In this study, the PNS technique end point was a single TN-mediated EMR (plantar flexion of the foot or toes or inversion of the foot) at a current threshold higher than 0.2 mA but less than 0.4 mA followed by injection of the entire volume of local anesthetic. In contrast, US guidance was described as a "moving needle technique," where the needle tip positioned was adjusted in real

TABLE 2. Summary of RCTs Directly Comparing US Guidance Versus Alternative Technique for Sciatic Nerve Block

Study	Jadad Score	Treatment Groups (n: Technique)	Primary Outcome (Hypothesis)/Power Analysis	"Block Success" (Surgical Block)	Procedure Time	Block Characteristics	Complications
Perlas 2008	4	Popliteal sciatic nerve block	Increase in sensory block success from 70% to 95% with US at *30 mins after local anesthetic injection*	No statistically significant difference with US (92%) versus PNS (76%%)	No difference; 8.1 versus 8.3 mins	Significantly higher block success for US (89.2%) versus PNS (60.6%)	None
		Major ankle or foot surgery	Sensory block defined as complete loss of pinprick sensation in both TN and CPN distributions			Faster onset for increased sensory and motor block of TN and CPN for US versus NS from 10 to 60 mins	
		33: US					
		37: PNS					
		30-mL equal volume of bupivacaine 0.5% and lidocaine 2% in both groups					
		Saphenous block: 10 mL of lidocaine 2% with 5 μg/mL as needed in both groups					
van Geffen 2009	3	Popliteal sciatic nerve block.	Reduction of local anesthetic volume from "standard daily practice" of 35 to 25 mL	No statistically significant difference with US (100%) versus PNS (83%)	No difference in 6.1 versus 7.6 mins (excluding the 2 patients in PNS group where EMR could not be obtained after 15 mins)	Significantly lower injected volume of local anesthetic with US (17 ± 5 mL) versus PNS (37 ± 5 mL).	None
		Major ankle or foot surgery					
		Dose range study of lidocaine 1.5% with epinephrine 5 μg/mL	US: minimum volume required to obtain circumferential spread around sciatic nerve.			Significantly higher block failure (25%) with PNS: 2 failed to elicit desired EMR within 15 mins, 3 required opioid supplementation and/or alternative anesthetic to complete surgery.	
		20: US	PNS: 25–40 mL based on judgment of attending anesthesiologist with a minimum of 25 mL and a maximum of 40 mL			No difference in onset of duration of sensory or motor block	
		20: PNS					
		Saphenous block: 5 mL of lidocaine 1.5% as needed in both groups					

Danelli 2009	3	Popliteal sciatic nerve block. Major ankle or foot surgery 22: US (20 mL of ropivacaine 0.75%) 22: PNS (10 mL of ropivacaine 0.75% after separate EMR of TN and CPN) No saphenous block performed	5-min reduction on sciatic nerve sensory and motor block onset with US compared with PNS Sensory block defined as complete loss of pinprick in TN and CPN distributions Motor block defined as complete lack of movement in TN and CPN distributions	No statistically significant difference with US (73%) versus PNS (36%)	Significantly lower with US (2 mins; range, 2–5 mins) versus PNS (5 mins; range, 2–15 mins)	Significantly decreased onset of sensory block with US (12.2 ± 4.8 mins) versus PNS (17.9 ± 8.5 mins) only for CPN motor block. No difference for other onset times. No difference in percentage of patients with complete sensory and motor blocks of TN and CPN US resulted in fewer skin punctures, needle redirections, and less pain during block performance	None
Mariano 2009	3	Continuous popliteal perineural sciatic catheter placement Major ankle and foot surgery 20: US 20: PNS (stimulating catheters) 40 mL of mepivacaine 1.5% with epinephrine 2, 5 or 5.0 μg/mL via needle (US) or catheter (PNS)	5-min reduction for successful insertion of popliteal sciatic catheter. Maximum of 30 mins allowed for catheter placement US: US probe first touched patient until removal of catheter placement needle PNS: Stimulating first needle touched patient until removal of catheter placement needle	US: 20/20 had successful placement and subsequent surgical block PNS: 16/20 had successful placement and subsequent surgical block	Less time to place sciatic catheters with US (median time, 5 min; 10%–90%, 3.9–11.1 mins) versus PNS (median time, 10 mins; 10%–90%, 2.0–15.0 mins) 4/20 failures in PNS group	US group experienced less pain during catheter placement compared with PNS No difference in postoperative pain scores	None
Danelli 2009	4	Subgluteal sciatic nerve block (SNB) with preceding US-guided FNB (20 mL of mepivacaine 1.5%)	2-mL difference in $MEAV_{50}$. Up-and-down staircase methodology based on the presence of successful block at *20 mins after local anesthetic injection*	N/A	N/A	$MEAV_{50}$ 37% lower with US versus NS	None

(Continued on next page)

TABLE 2. *(Continued)*

Study	Jadad Score	Treatment Groups (n: Technique)	Primary Outcome (Hypothesis)/Power Analysis	"Block Success" (Surgical Block)	Procedure Time	Block Characteristics	Complications
		Knee arthroscopy	Successful block defined as complete loss of pinprick sensation and inability to move the foot in both the TN and CPN distributions	Designed to measure 50% effective dose with 50% planned failure rate		$MEAV_{50}$ US: 12 mL (95% CI, 10–13 mL)	
		SNB with variable volumes of mepivacaine 1.5%		No difference in percentage of patients with failed surgical block at 20 mins: US (50%) versus NS (56%)		$MEAV_{50}$ NS: 19 mL (95% CI, 15–23 mL)	
		30: US 30: PNS					

time to obtain circumferential spread of the designated local anesthetic volume around the sciatic nerve.

In the only investigation directly comparing US with PNS for continuous perineural catheter placement, Mariano et al[12] powered their study to detect a 5-min difference in successful popliteal sciatic catheter placement (allowing a maximum of 30 mins before crossing over to the other technique). Time for catheter placement began when the US probe (US group) or catheter placement stimulating needle (PNS group) first touched the patient and ended when the catheter placement needles were removed after catheter placement. Ultrasound resulted in significantly less time to successfully place the sciatic catheter (median, 5 versus 10 min) compared with PNS with a stimulating catheter technique. All 20 catheters were successfully placed with US guidance. In contrast, 4 of 20 catheters could not be placed with PNS (3 owing to the inability to obtain an appropriate EMR via the stimulating needle [within 15 mins] and 1 via the stimulating catheter [within 30 mins]). These patients subsequently underwent successful catheter placement with US guidance. There was less subjective pain associated with US-guided catheter placement. There was no difference in the quality of postoperative analgesia in all patients with successful catheter placement, regardless of technique. No studies reported any long-term complications of peripheral nerve injury, infections, or systemic toxicity.

Combined US Guidance and PNS

Combined US guidance and PNS stimulation techniques may provide the theoretical advantage of providing both anatomic and neurophysiologic end points. There have been 2 studies designed to evaluate the potential advantage US guidance in combination with PNS to localize the sciatic nerve via a lateral midfemoral approach[13] and posterior popliteal approach[14] for a total of 112 patients. Neither of these 2 studies evaluated surgical block success as the primary outcome. Both studies were of good quality with Jadad scores of 3 and appropriate power analyses.

The primary outcome in the study by Domingo-Triado et al[13] was powered to detect a 25% difference in the number of attempts (defined as the number of needle passes before successfully evoking an adequate EMR at 0.5 mA) to perform the technique between the combined US-PNS group and the PNS-alone group. In the combined US-PNS technique, the needle was advanced until it was within 1 to 2 mm of the sciatic nerve and then the PNS was turned on. Once an adequate sciatic nerve EMR at 0.5 mA was obtained, the needle tip was not adjusted and the entire local anesthetic volume (35 mL of ropivacaine 0.5%) was injected on one side of the sciatic nerve with US visualization to assess its perineural distribution. The PNS-alone technique was similar except for lack of US guidance and lack of assessment of local anesthetic distribution.

Combined US-PNS (1; range, 1–2) resulted in significantly fewer median numbers of needle attempts compared with PNS alone (2; range, 1–4), although there was no significant difference in the median time from initial needle insertion to successful sciatic nerve localization or reported patient discomfort during the block. The frequency of patients with complete sciatic nerve sensory block to pinprick (96.7% versus 71%) and tolerance to a pneumatic tourniquet above the ankle (93.3% versus 48.4%) was significantly higher with combined US-PNS compared with PNS alone. There was no difference in the onset of sensorimotor block or duration of postoperative analgesia between the 2 techniques.

The primary outcome in the study by Dufour et al[14] was powered to detect a 25% reduction in the time to complete a

TABLE 3. Summary of Evidence of US Guidance Versus PNS for Lower Extremity Peripheral Nerve Block

	Primary Outcomes: Advantages of US Compared With PNS	Secondary Outcomes: Advantages of US Compared With PNS
Type of Nerve Block	**Recommendation and Level of Evidence**	**Insufficient Power to Provide Recommendations.**
Femoral, fascia Iliaca, "3-in-1" blocks	1. Decreased time for onset of complete sensory block of femoral, obturator, and lateral femoral cutaneous nerves. **Grade A** recommendation based on **Level 1b** evidence.	1. Improved quality of complete sensory blocks.
	2. Reduction in local anesthetic volume. **Grade A** recommendation based on **Level 1b** evidence.	2. Increased percentage of complete sensory blocks.
	3. Increased in success of sensory block. **Grade A** recommendation based on **Level 1b** evidence.	3. Increased percentage of successful femoral nerve motor block.
Popliteal sciatic nerve block	1. Increase in sensory block success. **Grade A** recommendation based on **Level 1b** evidence.	1. Faster onset of sensory and motor block.
	2. Reduction in local anesthetic volume. **Grade A** recommendation based on **Level 1b** evidence.	2. Fewer skin punctures and needle redirections.
	3. Decreased time to perform block (single injection and placement of sciatic perineural catheter). **Grade A** recommendation based on **Level 1b** evidence.	3. Less patient discomfort.
		4. Higher block failure (inability to obtain adequate EMR) with PNS.
		5. No difference in duration of sensory block (single injection) or quality of postoperative analgesia (continuous perineural sciatic catheter).

posterior popliteal sciatic nerve block with double injection (of both the TN and CPN) between combined US-PNS compared with PNS alone. Block time was defined as the interval between initial needle insertion and its removal at the end of local anesthetic injection. In the PNS-alone group, the needle tip was adjusted until either a TN or CPN EMR was obtained at minimal current threshold of 0.5 mA or less followed by injection of 10 mL of levobupivacaine 0.5%. The needle tip was then repositioned to obtain the appropriate second EMR at a current threshold of 0.5 mA followed by injection of 10 mL of levobupivacaine 0.5%. In the combined US-PNS group, the needle tip was advanced out-of-plane toward both the TN and CPN, with subsequent adjustment of the current output from the PNS down to 0.5 mA or less. If the needle tip appeared to be in contact with either the TN or the CPN and current out was more than 0.5 mA, the needle was not further repositioned. For each 10-mL injection of levobupivacaine 0.5%, the spread of local anesthetic was simply observed, but the needle tip was not repositioned in an attempt to improve distribution around the nerve. A maximum of 420 secs was allowed to locate both components of the sciatic nerve and perform the 2 injections in both groups. Block success was defined as the complete loss of cold sensation to ice in both the TN and CPN distributions and total immobility of the foot 30 mins after completion of the block.

There was no difference in the time to complete the block procedure between combined US-PNS (304 ± 94 secs) and the PNS-alone (261 ± 75 secs) groups. Of 30 patients in the PNS-alone group, 5 were excluded because the procedure time exceeded 420 secs. Of 30 patients in the combined US-PNS group, 3 were excluded because the CPN could not be visualized within 420 secs. Thus, the final sample size fell short of the a priori power analysis, raising the possibility of a type 2 error for the primary outcome of interest. At 30 mins, the percentage of patients with a successful block was significantly higher in the combined US-PNS group (65% versus 16%) compared with the PNS-alone group. There was no difference in the duration of postoperative analgesia or the patient satisfaction with the block technique.

DISCUSSION

Overall, the available data from RCTs comparing US guidance to PNS are limited with significant heterogeneity in the methodology (local anesthetic, comparative techniques to US, and definition of block success) and primary study outcomes. In contrast to brachial plexus blockade where a single injection (or least a single anatomic location) can effectively produce surgical anesthesia, blocks of the lumbar plexus (the femoral nerve in particular) or sacral plexus (sciatic nerve) rarely have the ability to provide surgical anesthesia without blockade of the other nerve. Thus, surgical anesthesia as a primary outcome is difficult to study when comparing US to PNS, especially with the simplicity and efficacy of neuraxial techniques for major lower extremity surgical procedures. This is reflected in the heterogeneity of the definitions of block success, block onset, and subsequent choice of primary outcomes for lower extremity RCTs.

Another conflicting factor is the inherent difference in the basic technique of US compared with PNS (or even LOR). By definition, US provides the inherent advantage of real-time assessment of nerves, perineural structures, the advancing needle, and, most importantly, the relationship of local anesthetic spread around the target neural structures. It is possible with US guidance to "move the needle tip" in real time to obtain circumferential distribution around the target nerves, which may explain the observed advantages in block onset, block quality, reduction in local anesthetic requirements, and block procedure time. In contrast, the majority of PNS techniques rely on eliciting a specific EMR at a defined minimum current threshold as a surrogate of needle tip to nerve proximity. This premise has several inherent limitations: First, although RCTs[5,17] have demonstrated that eliciting multiple EMRs decreases block onset and increases block quality and block success, they are

not used as frequently as single EMR (injection) techniques, perhaps because of perceptions of increased complexity, time to complete the procedure, and relative lack of expertise in multiple stimulation techniques. Thus, the consistent lack of use of multiple stimulations/injections for the PNS groups may have potentially decreased the efficacy these techniques compared with US. Second, there is growing evidence of the lack of correlation with the current threshold and needle-tip to-nerve distance, even to the point of lack of sensitivity of detecting needle tip-to-nerve contact[7] or intraneural needle location.[18] Thus, the lack of sensitivity of PNS may lead to unnecessary attempts at needle redirection potentially leading not only to increased block performance time but also to the potential for increased patient discomfort, nerve injury, and vascular trauma.

In addition, the RCTs are often performed in academic medical centers with substantial expertise in both PNS and US. Thus, with the high success rate inherent with PNS, it may be difficult to demonstrate significant improvements with a new technology, especially in the developmental and evolving stages of US guidance for peripheral nerve blocks. Conversely, the high success rates with US reported in these clinical trials might not be generalizable to daily clinical practices that lack experience or expertise. However, US may potentially benefit the daily clinical practice where success with PNS techniques may be lower than what is demonstrated in these RCTs. Another potential benefit of US is to increase our awareness and hopefully understanding of the inconsistency of the EMR and current threshold associated by performing combined US-PNS–guided techniques.

Although the technique of combined US-PNS resulted in fewer needle passes compared with PNS alone in 1 study,[13] there was no difference in the time to complete the block or patient perception of block discomfort between groups in either study.[13,14] The combined use of US-PNS may allow for more efficient needle tip-to-nerve placement compared with the conventional techniques of surface anatomic landmarks with PNS alone. The use of PNS to confirm the identity of a target nerve (or a specific part of a nerve bundle or plexus) in question when using US may provide potential advantages. However, the combined use PNS-US may only add to the complexity of peripheral nerve blocks, especially when the target nerve structures are clearly visualized. In addition, the growing evidence of the lack of correlation between needle tip-to-nerve proximity and current output to obtain an EMR with PNS brings into question the practice of attempting to obtain a "minimum current threshold" with a combined US-PNS technique.[18] In contrast, the ability to elicit a familiar EMR may provide reassurance to the novice user of US or may confirm the location of target nerves in question when the appearance of the US anatomy may be difficult owing to the lack of acoustic impedance mismatch or acoustic attenuation with deeper structures. Thus, a more useful application may be to use PNS as a qualitative tool ("yes or no") at higher current outputs in conjunction with US.

There is clearly a need to better define what the most important primary outcomes should be in future RCTs to increase the homogeneity of future systematic reviews and meta-analysis. There is currently lack of evidence to demonstrate that US guidance increases block success, specifically defined as the ability to provide surgical depth of anesthesia. Furthermore, there needs to be increased standardization in the design of future RCTs regarding the clinically relevant definitions of block success, especially when a surgical anesthetic is not the primary outcome. Future comparative studies should also identify and directly compare "optimal techniques" for US (moving needle technique with circumferential distribution) and PNS (single versus multiple EMR and optimal EMR) to provide a more objective basis for advantages and disadvantages of the 2 techniques. Future RCTs should also include the potential benefits of US guidance for lower extremity peripheral nerve block at other anatomic locations such as the lateral femoral cutaneous nerve, obturator nerve, saphenous nerve, and especially at more proximal (and potentially deeper) locations of the lumbar plexus (psoas compartment) and sciatic nerve (gluteal levels) where the increased tissue depth may not consistently provide adequate images of target nerves. Lastly, there is a need to further investigate the potential advantages of US guidance in placement of continuous lower extremity peripheral nerve catheters.

In conclusion, there is level Ib evidence to make a grade A recommendation that US guidance provides improvements in the onset and success of sensory block, a decrease in local anesthetic requirements, and decreased time to perform the lower extremity peripheral nerve blocks (Table 3). The increased quality of sensory block may not be clinically relevant unless it results in an increased percentage of patients with a block of sufficient depth to provide surgical anesthesia or improved and/or prolonged duration of postoperative analgesia. Future studies investigating the possible advantages of faster onset of sensory and motor block or decreased performance time with US guidance must also define "total anesthesia time" (such as turning on and positioning the US machine and sterile preparation of the US transducer probe versus palpation and marking of external anatomic landmarks with PNS before needle placement). Although several of the studies demonstrated a significant decrease in local anesthetic requirements with US compared with PNS,[2,5,8,10] it will require significantly larger studies to demonstrate if this will result in clinically relevant reductions in the incidence of systemic local anesthetic toxicity.

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Evidence-Based Medicine

Ultrasound Guidance for Truncal Blocks

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Abstract: We performed a systematic search of the medical literature and reviewed the evidence examining success rates and incidence of complications of ultrasound (US) guidance relative to traditional techniques for the following blocks: paravertebral, intercostal, transversus abdominis plane, rectus sheath, and ilioinguinal/iliohypogastric. We included studies of sufficient methodologic quality for review and excluded poor-quality studies. We then rated the strength of evidence for US guidance for each block using a system developed by the United States Agency for Health Care Policy and Research. Although relatively few studies have compared US guidance with established techniques, the available evidence suggests that the use of US guidance is a safe and effective means to facilitate correct needle placement and adequate spread of local anesthetic for truncal blocks. Further studies are needed to directly compare US guidance to traditional techniques and to clarify potential benefits and limitations of US guidance for truncal blocks.

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Anesthesia and/or analgesia of the trunk can be achieved with perineural injections, which have several advantages compared with neuraxial blockade. These include reduced sympathectomy,[1] less severe consequences of infection or bleeding at the injection site,[2–4] minimal interference with bladder and bowel function,[1,5] and decreased incidence of lower extremity motor weakness,[6–8] allowing early ambulation and home discharge.

Thoracic paravertebral or intercostal nerve blocks (ICNBs) of T1 to T6 can provide anesthesia and/or analgesia of the chest wall. Thoracic paravertebral blocks from T6 to L1, transversus abdominis plane (TAP) blocks, rectus sheath blocks, or ilioinguinal (II)/iliohypogastric (IH) nerve blocks can provide anesthesia and/or analgesia of the abdominal wall.

Recent developments including refinements in continuous catheter techniques and use of ultrasound (US) guidance have increased the clinical applications for truncal blocks. We sought to review the evidence for US guidance for truncal blocks and make recommendations for use of US based on the strength of available data.

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METHODS

We systematically searched MEDLINE, the Cochrane Central Register of Controlled Trials, Ovid, and Google Scholar databases for articles published between January 1, 1990, and August 1, 2009, using the following keywords: ultrasound with paravertebral, intercostal, transversus abdominis plane, TAP, rectus sheath, ilioinguinal, and iliohypogastric. We then searched the references of eligible articles for additional studies. Randomized controlled trials, nonrandomized experimental studies, and large case series were included for review. Case reports, small case series (<10 patients), and letters to the editor were excluded. Because of the limited amount of published data, cadaver anatomic studies and letters reporting significant findings were included for discussion. However, these were not used for making evidence-based recommendations. Methodologic quality of the studies included was rated using a validated scoring system described by Jadad et al.[9] For all of the blocks we evaluated, the evidence examining use of US guidance was rated using an evidence-based system developed by the United States Agency for Health Care Policy and Research. A summary of studies pertaining to US guidance for these truncal blocks is shown below in Table 1.

DISCUSSION

Thoracic Paravertebral Blocks

Background

Thoracic paravertebral blocks have been used to provide surgical anesthesia for many types of surgical procedures involving the chest and/or abdomen,[10–18] as well as to provide analgesia for painful conditions such as rib fractures.[19–22] In addition, paravertebral blocks may be associated with a decreased rate of recurrence after surgical excision of malignant breast lesions.[23] Specific risks of paravertebral blocks include epidural[24] or intrathecal[25] spread of anesthetic, systemic local anesthetic toxicity,[26] and hemo/pneumothorax.[27–29] Standard techniques use surface landmarks and can be combined with either nerve stimulation or loss-of-resistance (LOR).[30–32] Although US visualization of the paravertebral space may be challenging owing to the overlying bony structure such as the ribs and transverse processes, use of US to measure the distance from skin to the transverse processes or for real-time image guidance during needle placement could potentially decrease the risk of puncturing the pleura with the needle during block placement.

Ultrasound Data

There is a paucity of data on US guidance for the thoracic paravertebral block. Recently, Pusch et al[33] demonstrated that the depth of the transverse process and the pleura could be reliably measured at T4 before block placement in a series of 22 patients. More recently, Hara et al[34] reported a cohort study of 25 patients who underwent an US-guided paravertebral injection at T4 and T1 with 25 of 25 and 22 of 25 successful blocks, respectively. However, they only imaged the needle until the

transverse process was contacted, then continued needle advancement using an LOR technique. Luyet et al[35] studied the placement of catheters in the paravertebral space of cadavers. Twenty catheters were placed in 10 cadavers, and placement was confirmed by evaluating the spread of contrast dye using computed tomography. Although the paravertebral space was easy to visualize and placement of the needle tip within this space was accomplished easily, contrast injected through the catheters was frequently (9/20 catheters) visualized in the pleural, epidural, or prevertebral spaces. The catheters used in this study were styleted and advanced 5 cm past the needle tip. To date, no randomized controlled trial (RCT) has compared US guidance to conventional techniques such as anatomic landmarks, LOR, or nerve stimulation for placement of either single-shot or continuous paravertebral blocks.

Recommendations

We give a Grade B recommendation for the use of US to place paravertebral blocks, based on Level IIb (2 small case series) evidence. The available literature suggests that thoracic paravertebral blocks may be performed with a high probability of block success using US guidance as an adjunct to traditional techniques. The use of styleted catheters or blind advancement of the catheter more than 2 cm past the needle tip may contribute to catheter misplacement during US-guided placement of thoracic paravertebral catheters (based on results of 1 cadaver anatomic study). At this time, there is insufficient evidence to show that US guidance improves block success rates or reduces the risk of complications compared with traditional techniques for performing single-shot or continuous paravertebral blocks.

Intercostal Nerve Blocks

Background

Intercostal nerve blocks are most commonly used as an alternative to epidural or paravertebral block to provide analgesia for painful conditions of the chest wall or after thoracic or upper abdominal surgery.[36–39] Risks of ICNBs are similar to those for thoracic paravertebral blocks.[40–48] Traditional techniques for performing ICNBs generally involve use of surface anatomic landmarks to guide needle placement.[49] Although the intercostal neurovascular bundle may not be visualized with US owing to acoustic shadowing from the overlying rib, use of US guidance could be useful for performing ICNBs because imaging the pleura and needle tip in real-time potentially could reduce the risk of puncturing the pleura during block placement.

Ultrasound Data

There are minimal data available for US-guided ICNBs. One small descriptive case series (4 patients)[50] has reported successful use of US-guided cryoablation of intercostal nerves to treat chronic postthoracotomy pain. To date, no RCTs or large case series have been published to report success rates or the rate of complications for US-guided ICNBs or to compare US guidance with traditional techniques.

Recommendations

On the basis of the minimal available Level III (1 very small case series) evidence, we give US guidance for ICNB a Grade C recommendation. At this time, there is insufficient evidence to comment on the rates of block success or complications for US-guided ICNBs relative to those performed using traditional techniques. Thus far, the literature only establishes proof of the concept that US guidance can be used to perform ICNBs.

Transversus Abdominis Plane Blocks

Background

The ventral rami of spinal nerve roots T6-L1 course through the lateral abdominal wall within a potential space defined superiorly by the costal margin, inferiorly by the iliac crest, medially by the lateral border of the rectus abdominis muscle, superficially by the internal oblique muscle, and deep by the transversus abdominis muscle. Rafi[51] first described in 2001 a landmark-based technique of accessing this TAP percutaneously via the lumbar triangle of Petit to deposit local anesthetic solution and produce analgesia of the anterolateral abdominal wall. The landmark-based technique relies on a "2-pop" end point to determine correct positioning of the needle tip beneath the fascia overlying the transversus abdominis muscle.[52] The primary indication for the TAP block is to provide analgesia after major surgical procedures of the anterolateral abdominal wall.[53–56] To date, use of the TAP block for surgical anesthesia has not been reported.

Intraperitoneal catheter placement without both visceral organ injury[57] and liver injury from the block needle[58] has been reported for TAP blocks performed using traditional techniques. Because US-guided techniques allow real-time visualization of the needle and the spread of local anesthetic, the use of US may decrease the risk of complications for the TAP block. In addition, an in-plane US-guided approach may confirm additional safety because it involves an oblique needle trajectory, possibly decreasing the risk of advancing the needle into the peritoneal cavity.

Ultrasound Data

In a cadaver study, Tran et al[59] demonstrated that the spread of injectate was limited to the T9-L1 nerve roots for US-guided TAP blocks performed at a level similar to that for traditional techniques. Shibata et al[60] and Hebbard[61] performed separate retrospective audits of patients with US-guided TAP blocks and suggested that traditional TAP blocks may not reliably provide analgesia for procedures above the level of the umbilicus. However, traditional techniques may eventually result in blocks extending as high as the T7 dermatomal level owing to "extensive communication between adjacent segmental thoracolumbar nerves."[62] Hebbard[61] described a modified subcostal US-guided approach and reported a mean block height of 85% the distance from the symphysis pubis to the xiphoid process in a series of 26 patients.

El-Dawlatly et al[56] recently described a technique for US-guided TAP block that is essentially identical to those previously reported.[60,63,64] In addition, they performed an RCT comparing intraoperative narcotic requirements and postoperative analgesia in patients undergoing laparoscopic cholecystectomy with and without bilateral TAP blocks. They found that patients with TAP blocks had substantially lower perioperative opioid consumption than patients in the control group. However, this study did not include any patients with TAP blocks performed using traditional techniques for comparison. To date, no study has directly compared landmark-based approaches with US-guided techniques. At this time, no complications have been reported for US-guided TAP blocks.

Recommendations

We give US guidance for TAP blocks a Grade B recommendation based on available Level IIb (1 RCT, no traditional technique TAP block group included for comparison) evidence.

TABLE 1. Characteristics of Studies Describing US-Guided Truncal Blocks

First Author (Year Published)	Study Design	Comments	n	Success Rate	Complications	Jadad Score (Max, 5)	Level of Evidence/ Recommendation
Paravertebral: Grade B							
Pusch (2000)	Case series	Correlation of distances measured during US prescan and needle depth on contacting transverse process during landmark-based block at T4 level	22	22/22 transverse process and pleura identified 21/22 block success	NR	NA	IIb
Hara (2009)	Case series	T1 and T4 blocks. US prescan to identify transverse process, pleura. Needle advanced only to transverse process with real-time US guidance, blocks completed with LOR technique	25	T4: 25/25 transverse process and pleura identified T1: 25/25 transverse process 22/25 pleura identified	NR	NA	IIb
Intercostal: Grade C							
No large series or controlled trials currently available.							
TAP: Grade B							
El-Dawlatly (2009)	RCT comparing GA ± TAP	No landmark-based TAP blocks included for comparison	42	N/A	None	2	IIb
Rectus sheath: Grade A							
Willschke (2006)	Sonoanatomic study, case series	Part 1: Sonoanatomic study, 30 children without umbilical hernia Part 2: 20 consecutive children for umbilical hernia repair under GA. Ultrasound-guided rectus sheath blocks for postoperative analgesia	20	100% (patients required no supplemental analgesics, but motor/sensory block not formally assessed)	None	NA	III
de Jose Maria (2007)	Case series	Children scheduled for umbilical hernia repair under GA	10	100% (patients required no supplemental analgesics, but motor/sensory block not formally assessed)	None	NA	III
Dolan (2009)	RCT	US-guided versus landmark-based blocks performed by trainees	81	89% (US) versus 45% (landmarks), $P < 0.001$	None (21% of landmark-based injections intraperitoneal)	2	Ib
II/IH: Grade A							
Willschke (2006)	Dose-finding study	Up-and-down dose-finding study of LA volume necessary to produce a block using US-guided technique	40	100% with 0.075 mL/Kg	None	NA	IIb

Willschke (2005)	RCT	US guidance versus landmark-based fascial click technique in anesthetized children	100	Intraoperative analgesics: 6% (US) versus 26% (fascial click), $P < 0.001$ Postoperative analgesics: 6% (US) versus 40% (fascial click), $P < 0.001$	None	2	Ib
Weintraud (2009)	RCT	US guidance versus Landmark technique, effect on pharmacokinetics of LA. Higher serum levels with US-guided blocks	66	NR	NR	3	Ib

GA indicates general anesthesia; LA, local anesthetic; NA, not applicable; NR, none/not reported.

At this time, no definitive statements can be made with regard to the rate of block failure or complications from US-guided TAP blocks relative to those performed using traditional techniques. However, the existing case series do indicate high success rates for TAP blocks performed with US guidance. Although no prospective clinical studies have directly compared traditional (landmark-based or US-guided) to subcostal approaches to the TAP, case series (2 small series), and anatomic studies (1 cadaver study) suggest differences in the distribution of sensory blockade for the various approaches.

Rectus Sheath Blocks

Background

The central portion of the anterior abdominal wall is innervated by the ventral branches of spinal nerve roots T6-L1, which lie between the belly of the rectus abdominis muscle and the posterior rectus sheath and enter the rectus muscle near the midline. The superior and inferior epigastric vessels run longitudinally through the medial portion of the muscle. The tendinous intersections of the rectus muscle are not fused to the posterior rectus sheath, which allows local anesthetic to spread cephalocaudad within the ipsilateral compartment from a single injection site.

The rectus sheath block has been used to provide surgical anesthesia as well as postoperative analgesia for surgical procedures involving a vertical midline laparotomy incision as well as for laparoscopic procedures.[65–67] Traditionally, this block is performed using "pops" or "scratching sensations" to determine proper positioning of the needle's tip. Potential advantages of US guidance for rectus sheath blocks are similar to those for TAP blocks.

Ultrasound Data

Few data exist regarding the use of US guidance for rectus sheath blocks. Willschke et al[68] and de Jose Maria et al[69] reported case series of 20 and 10 pediatric patients, respectively. Patients in both series had rectus sheath blocks placed for postoperative analgesia after abdominal surgery performed under general anesthesia. Both groups reported 100% success in the ability to visualize the spread of anesthetic between the belly of the rectus abdominis muscle and the posterior rectus sheath. Although neither study formally assessed the patients for motor or sensory block, no patient in either series required additional analgesic medication during surgery or before discharge home. No complications were reported for either series.

Recently, Dolan et al[70] performed an RCT comparing the accuracy of local anesthetic deposition during rectus sheath blocks performed by trainees using either LOR or US guidance. They found that anesthetic was placed in the correct plane in only 45% of cases using LOR and in 89% of cases using US guidance ($P < 0.001$). In addition, this difference between groups became more pronounced as patient body mass index increased. Of additional concern was their finding that 21% of blocks performed using LOR had an initial anesthetic injection deep to the rectus sheath (intraperitoneal). Although no complication resulted, they stopped the trial after enrollment of 81 patients because of their concern for potential intra-abdominal injury with blocks performed using LOR. However, this frequency of intraperitoneal injection may not be representative of that for practitioners with extensive experience performing rectus sheath blocks using traditional techniques as all blocks in this study were performed by trainees with no previous experience performing rectus sheath blocks using either US or LOR.

Recommendations

We give use of US guidance for rectus sheath block a Grade A recommendation based on available Levels Ib (1 RCT) and III (2 small case series) evidence. The current evidence indicates that US guidance is more likely than traditional techniques to produce a successful block. Although the studies conducted to date lack statistical power to demonstrate any safety advantage conferred by use of US, the high rate of intraperitoneal injection observed during blocks performed using traditional techniques is concerning. More RCTs involving more patients will help to clarify the potential benefits and limitations of US guidance for rectus sheath blocks.

Ilioinguinal/Iliohypogastric Nerve Blocks

Background

The II nerve provides sensation to the upper medial part of the thigh and the upper part of the genitalia. The IH nerve provides sensation to the buttock and abdominal wall above the pubis. Traditional landmark-based techniques vary but share a theme of relying on facial "clicks."[71] Traditional techniques may be unreliable, however, because US imaging has demonstrated infrequent placement of local anesthetic around the intended muscle planes and nerves after landmark-based II/IH blocks in children.[72]

Most II and IH blocks are placed for analgesia after inguinal hernia repair, often in children. The II/IH blocks have also been shown to provide similar analgesia to caudal blocks during orchidopexy[73,74] while eliminating adverse effects of motor block and urinary retention. The II and IH blocks have been also successfully used to provide surgical anesthesia for herniorrhaphy and to improve analgesia following a variety of lower abdominal procedures in adults.[75–79] Risks specific to the II/IH block include bowel hematoma,[80] bowel puncture,[81,82] pelvic hematoma,[83] femoral nerve block,[84,85] and high serum local anesthetic concentration.[86,87] Potential advantages of US guidance for II/IH blocks are similar to those for rectus sheath and TAP blocks.

Ultrasound Data

One RCT has been conducted comparing US guidance to a landmark-based technique.[88] One hundred children scheduled for inguinal hernia, orchidopexy, or hydrocele repair under general anesthesia were prospectively randomized to receive either US-guided or landmark-based II/IH blocks for postoperative analgesia. Because formally assessing motor and sensory block can be difficult in young children, the authors used validated, predefined, objective parameters to guide administration of supplemental analgesics during surgery (increase in heart rate or mean arterial pressure >10%) and postoperatively (the objective pain scale, a validated measure of objective behavioral variables). They reported statistically significant differences in the number of patients responding to surgical incision (6% US group versus 22% fascial click group, $P < 0.0001$) and requiring supplemental analgesic medication during recovery (6% US group versus 40% fascial click group, $P < 0.0001$). Upon US scanning of patients who had received blocks by the fascial click method, only 50% of those patients demonstrated LA deposited around the II/IH nerves compared with 100% in the US group. It is important to note that for this study, the anesthesiologists were not blinded to patient group allocation, creating a potentially significant source of bias. The same group of investigators also conducted a dose-comparison analysis using an up-and-down dosing method to determine the amount of local anesthetic necessary to achieve complete success in an interventional group.[89] They demonstrated an effective local anesthetic dose of 0.075 mL/kg for US-guided blocks compared with standard doses of 0.3 to 0.5 mL/kg for landmark-based II/IH blocks.

Although reduced amounts of local anesthetic may be necessary to perform II/IH blocks, serum levels of local anesthetic may be higher for US-guided blocks. In a controlled study, Weintraud et al[90] describe higher serum ropivicaine levels in US-guided patients receiving equal amounts of local anesthetic to those receiving landmark-based blocks. Therefore, it is probably warranted to reduce the volume of local anesthetic when performing US-guided II/IH blocks because less local anesthetic is necessary to achieve successful blocks, and there may be a higher serum absorption of local anesthetic, possibly because local anesthetic is often deposited near a perforating branch of the deep circumflex iliac artery using an US-guided technique.

Recommendations

We give the use of US for II/IH blocks a Grade A recommendation based on available Levels Ib (2 RCTs) and IIb (1 dose-finding study) evidence. The available data indicate that compared with traditional techniques, US-guided II/IH blocks have a higher probability of block success and require a lower volume of local anesthetic. However, there are currently not enough data to demonstrate any safety advantage for US guidance over traditional techniques. Ultrasound-guided II/IH blocks may also result in higher plasma concentrations than those performed with traditional techniques using similar volumes of local anesthetic.

CONCLUSIONS

Relatively few large studies have been conducted to evaluate the role of US guidance for truncal blocks. Only 2 prospective RCTs have been performed to compare US guidance to standard landmark-based approaches, so at this time, no definitive statements can be made regarding improvements in success rates or reductions in the frequency of complications. The strongest evidence in favor of US guidance for truncal blocks is for II/IH and rectus sheath blocks. There is sparse evidence in favor of US guidance for TAP blocks and minimal evidence to support US guidance for thoracic paravertebral and ICNBs. Further studies are required to clarify the potential benefits of US guidance for truncal blocks.

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Evidence for the Use of Ultrasound in Neuraxial Blocks

Anahi Perlas, MD, FRCPC

Goals: To summarize the existing evidence behind the role of ultrasonography in neuraxial anesthesia techniques.

Methods: A literature search of the MEDLINE, PubMed, ACP Journal Club databases, and the *Cochrane Database of Systematic Reviews* was performed using the term ultrasonography combined with each of the following: spinal, intrathecal, epidural, and lumbar puncture. Only studies related to regional anesthesia or acute pain practice were included. Case reports and letters to the editor were excluded. Seventeen relevant studies were identified and included in this review.

Results: Neuraxial ultrasonography is a recent development in regional anesthesia practice. Most clinical studies to date come from a limited number of centers and have been performed by very few and highly experienced operators. The existing evidence may be classified in 2 main content areas: (*a*) ultrasound-assisted neuraxial techniques and (*b*) real-time ultrasound-guided neuraxial techniques.

(a) *Ultrasound-assisted neuraxial techniques*: Two scanning planes have been identified to offer useful acoustic windows for the assessment of spinal sonoanatomy providing complementary information: A parasagittal scanning plane (paramedian, longitudinal window) and an axial plane (transverse midline window). A preprocedure ultrasound can more accurately determine the location of a specific vertebral interspace than physical examination alone. The epidural and intrathecal spaces may be identified by ultrasonography, and the skin-to-epidural space or skin-to-intrathecal space distances may be accurately predicted. The use of a preprocedure ultrasound is associated with a lower number of attempts and a lower number of interspaces attempted by experienced anesthesiologists inserting an epidural catheter for labor analgesia. It may improve learning curves of junior trainees.

(b) *Real-time ultrasound-guided neuraxial techniques*: Fewer and more recent studies report the use of this modality, mostly in the pediatric population. When performed by experienced anesthesiologists on selected patients with otherwise normal anatomy, the resulting efficacy is similar to that of standard techniques, but it may result in a shorter procedure time and less instances of "bony contact." A paucity of data exists in the nonobstetric adult population and on the impact of ultrasound use on safety profile.

Conclusions: Neuraxial ultrasonography has been recently introduced to regional anesthesia practice. The limited data available to date suggest that it is a useful adjunct to physical examination, allowing for a highly precise identification of regional landmarks and a precise estimation of epidural space depth, thus facilitating epidural catheter insertion. Further research is needed to conclusively establish its impact on procedure success and safety profile, particularly in the adult nonobstetric population.

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In the last decade, there has been a growing interest in the use of bedside 2-dimensional ultrasonography to assess neuraxial anatomy and to aid in the performance of neuraxial interventional procedures. This article reviews the existing evidence that evaluates the role of ultrasonography in neuraxial regional anesthesia techniques. The main question addressed in this review is as follows: What is the evidence that ultrasound-assisted neuraxial techniques are more effective than traditional landmark-based techniques?

METHODS

A literature search was conducted of the following databases: MEDLINE, PubMed, ACP Journal Club, and the *Cochrane Database of Systematic Reviews*. Search terms included ultrasonography and each of the following terms: spinal, intrathecal, epidural, and lumbar puncture. Search was limited to human studies but not to the English language. For the purpose of this review, only studies relating to regional anesthesia or acute pain practice have been included. Studies relating to chronic pain interventional procedures of the spine were excluded because they are covered in a separate section. Letters to the editor and case reports were also excluded. Only prospective, preferably comparative studies (where available) that compare either ultrasonography with a landmark-based technique or ultrasound-assisted versus ultrasound-guided techniques were included in this review. Seventeen studies are included in the review.

DISCUSSION

This is an area of recent development; the earliest publications are dated within the last 8 years. Most studies come from a small number of centers and most procedures have been performed by a small number of experienced anesthesiologists. On the basis of these limited early data, it would be premature to make recommendations for practice. Instead, the evidence has been reviewed, summarized, and classified according to its strength based on the US Agency for Health Care Policy and Research scale for Evidence Statements. The existing evidence may be classified in 2 main content areas: (*a*) ultrasound-assisted neuraxial techniques and (*b*) real-time ultrasound-guided neuraxial techniques.

(a) Ultrasound-assisted neuraxial techniques

Most clinical studies in adult patients to date report the use of a preprocedure ultrasound examination to establish neuraxial anatomy before inserting an epidural catheter. A preprocedure ultrasound allows the anesthesiologist to accurately determine the location of a target lumbar interspace and the midline and to mark these on the skin, as well as to estimate the depth of the epidural and intrathecal spaces before the procedure, which is then carried out using a traditional loss-of-resistance technique.

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This is often called "ultrasound-assisted epidural anesthesia" to differentiate it from real-time ultrasound-guided insertion techniques. Most published studies to date use this type of "assisted" technique rather than a real-time guided technique.

The epidural and intrathecal spaces are the main targets to the clinical anesthesiologist. These spaces are deeply located in the neuraxis and encased by a complex bony structure that limits the access of ultrasound beams, particularly in the adult patient, in which bones are fully calcified. Because of the depth of location, low-frequency curved array probes (2-5 MHz) are generally required to image the neuraxis in the adult patient. Two scanning planes have been identified to offer useful acoustic windows for the assessment of spinal sonoanatomy: a parasagittal scanning plane (paramedian, longitudinal window; Fig. 1)[1] and an axial plane (transverse midline window; Fig. 2).[2] These 2 scanning planes offer complementary information. A prospective study on 50 patients undergoing x-ray of the lumbar spine suggests that spinal ultrasonography can assist anesthesiologists in identifying the L2-3 to L4-5 interspaces with greater accuracy than by palpation of surface landmarks alone.[3] **(IIa)** Using a plain lumbar radiograph as a criterion standard, fully trained anesthesiologists could determine the location of specific lumbar interspaces accurately in only 30% of patients based on physical examination alone versus 71% of patients when ultrasound examination was used. In a separate study on 17 patients, ultrasonographic location of the L3-4 interspace was correct in 76% of cases when compared with a control magnetic resonance imaging and off by 1 level in the remaining 24%.[4] **(IIb)** Two further studies show that sonography and physical examination differ in the evaluation of lumbar interspaces in 32% to 63% of cases, but they do not compare this technique to an existing criterion standard.[5,6] **(III)** The evidence consistently shows that ultrasonography can identify the epidural space and accurately predict skin-to-epidural space distance. This has been demonstrated at the cervical and lumbar levels in adults[2,7,8] and at the lumbar level in children.[9] **(Ib)** In a study of orthopedic patients undergoing spinal anesthesia, ultrasound examination accurately predicted the depth of the intrathecal space.[10]

Three unblinded randomized controlled trials (RCTs) comprising a total of 452 obstetric patients compared a group of patients undergoing preprocedure ultrasonography versus a control group receiving a standard landmark-based technique.

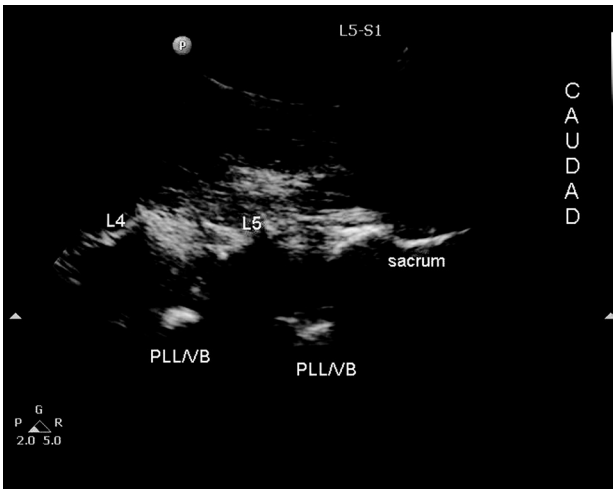

FIGURE 1. Parasagittal scanning plane. L4 indicates lamina of fourth lumbar vertebra; L5, lamina of fifth lumbar vertebra; PLL/VB, posterior longitudinal ligament/vertebral body.

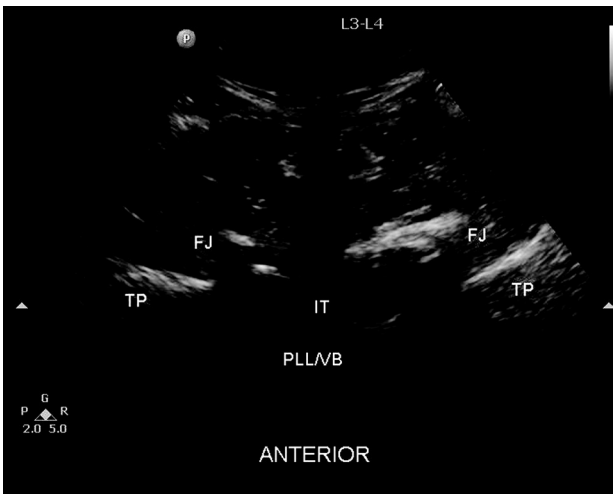

FIGURE 2. Axial scanning plane at the level of L3-4. FJ indicates facet joint; IT, intrathecal space; TP, transverse process.

All 3 studies originate in the same institution (University of Heidelberg) and all procedures were performed by the same experienced anesthesiologist.[8,11,12] Of 3 studies, 1 included only parturients either with a history of difficult epidural insertion or with spinal abnormalities such as scoliosis or kyphosis. All 3 studies report equal overall efficacy (100% epidural success rates in both groups) but a decrease in the number of attempts and a decrease in the number of interspaces attempted before reaching the epidural space. **(Ib)** In a separate study from the same center, 10 junior anesthesiology residents were randomized into 2 groups (with and without preprocedure ultrasound) and were evaluated as they each performed their first 60 obstetric epidural anesthetics.[13] Residents assigned to the ultrasound group showed consistently higher success rates throughout the study. **(Ib)** There is a paucity of data in the nonobstetric population and patients undergoing spinal anesthesia.

(b) Real-time ultrasound-guided neuraxial techniques

Studies on real-time ultrasound-guided neuraxial anesthetic techniques are fewer and more recent in nature. Most of these studies were performed on pediatric patients. Owing to the small body size, linear high-resolution probes can be used in children, with high-resolution images of the neuraxial anatomy obtained in neonates and young infants.[14]

Two prospective series on elective pediatric surgical patients (23 and 35 patients, respectively) suggest that it is feasible to insert an epidural catheter under real-time ultrasonographic guidance from a paramedian scanning position.[15,16] Both studies describe imaging the spread of either saline (loss-of-resistance to saline technique) or local anesthetic as it is injected through an epidural needle into the epidural space in real time, as well as the advancement and final position of the epidural catheter in the epidural space.[15,16] **(III)**

One RCT on 64 pediatric patients compared a real-time guided epidural catheter insertion versus a preprocedure ultrasound followed by a loss-of-resistance technique.[17] Epidural placement was successful in all children in both groups. Real-time ultrasound guidance resulted in a shorter procedure time and less instances of unintentional "bony contact" during the procedure. **(Ib)**

One RCT on 30 obstetric patients assigned to 3 different groups compared the efficacy of combined spinal epidural analgesia with a standard loss-of-resistance technique versus a

preprocedure ultrasound versus a real-time guided technique.[18] All combined spinal epidurals were successful with a lower number of attempts in the 2 ultrasound groups. **(Ib)**

IN SUMMARY

Neuraxial ultrasonography is a recent development in regional anesthesia practice. Most clinical studies to date come from a limited number of centers and have been performed by very few and highly experienced operators. A limited number of RCTs have been published, all in the obstetric or pediatric populations. The limited data available to date seem to suggest the following (Table 1):

- Bedside ultrasonography is a useful adjunct to clinical examination of the lumbar spine before neuraxial anesthesia. It can determine more accurately the location of lumbar interspaces than palpation of surface landmarks alone **(IIa)**. It can predict the depth of the epidural space with a high degree of accuracy. **(Ib)**
- Preprocedure neuraxial ultrasound can be used to guide obstetric epidural anesthesia
  - When performed by experienced anesthesiologists on selected patients with otherwise normal anatomy, the resulting efficacy is similar to that of standard techniques. In these circumstances, ultrasound may result in a lower number of attempts and a lower number of interspaces attempted. **(Ib)**
  - When performed by junior trainees, it may improve learning curves and increase success rates. **(Ib)**
- Real-time ultrasound-guided epidural anesthesia is feasible in neonates and young children. **(III)**
  - When performed by experienced anesthesiologists on selected patients with otherwise normal anatomy, the resulting efficacy is similar to that of standard techniques. **(Ib)** Ultrasound guidance may result in a shorter procedure time and less instances of "bony contact." **(Ib)**
- It is conceivable that obese patients or patients with abnormal spinal anatomy or previous spinal surgery would benefit the most from ultrasound imaging to assist or guide neuraxial techniques. However, it is in these same groups of patients that ultrasonography may be more challenging to perform and evidence remains anecdotal.[19] At the moment, there are no large studies from which to draw insight into the potential benefits and limitations of neuraxial ultrasonography on these groups of patients.
- There are no studies comparing ultrasound-assisted or ultrasound-guided neuraxial techniques with standard landmark-based techniques in terms of safety profile.

TABLE 1. Ultrasound and Neuraxial Anesthesia: Summary of the Evidence

Summary Statements	Level of Supporting Evidence	Jadad Scores of Related Articles
Ultrasound-assisted neuraxial anesthesia		
Bedside ultrasonography can more accurately determine a lumbar interspace than palpation of surface landmarks alone	IIa	N/A
Ultrasonography can predict the depth of the epidural space with a high degree of accuracy	Ib	2
Ultrasound-assisted obstetric epidural insertion by experienced anesthesiologists results in similar success rate but a lower number of attempts and interspaces used	Ib	2
Ultrasound-assisted obstetric epidural insertion may improve success rates of junior trainees	Ib	2
Ultrasound-guided epidural insertion in young children		
Ultrasound-guided epidural insertion by experienced anesthesiologists results in similar success rate but may result in a shorter procedure time and less instances of "bony contact" compared with standard technique	Ib	2

N/A, not applicable.

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Ultrasound-Guided Perineural Catheter Insertion

Three Approaches but Few Illuminating Data

Brian M. Ilfeld, MD, MS, Michael J. Fredrickson, MD,† and Edward R. Mariano, MD, MAS**

As ultrasound-guided regional anesthesia becomes more popular and practiced, a plethora of research involving this relatively new modality is being published—to the degree that *Regional Anesthesia and Pain Medicine* recently added an entire ultrasound-related section to every issue.[1] However, most of these reports involve single-injection peripheral nerve blocks, to the exclusion of perineural catheter insertion.[2] Unfortunately, data from many of these publications cannot be automatically inferred to perineural catheter placement for multiple reasons. First, although the angle between the long axis of the placement needle and nerve is relatively unimportant for single-injection blocks, it is critical for perineural catheter insertion because catheters tend to exit the needle and traverse past any nerve that is perpendicular to the needle itself.[3] Second, a major advantage of ultrasound guidance for single-injection nerve blocks lies in the real-time repositioning of the needle tip to maximize local anesthetic spread, whereas perineural catheter bolus and/or infusion is analogous to a single-point injection.[4] Third, unlike needles, flexible perineural catheters rarely remain within a 2-dimensional ultrasound view, making it difficult to observe catheter tip placement relative to the target nerve.[5] Although it is impossible to include all ultrasound-guided techniques and respective equipment, the purpose of this editorial is to briefly review the major ultrasound-guided catheter insertion approaches along with their relative potential strengths and weaknesses.

ULTRASOUND ORIENTATION

Before engaging in any discussion involving ultrasound, commonly accepted vocabulary must be understood. A needle inserted with its length within a 2-dimensional ultrasound beam is described as "in plane," whereas a needle inserted across a 2-dimensional ultrasound beam is "out of plane."[6] A nerve with its long axis within the ultrasound beam is viewed in "long axis," compared with "short axis" when viewed in cross section.[6]

NEEDLE IN-PLANE, NERVE IN SHORT-AXIS APPROACH

For single-injection peripheral nerve blocks, most reports describe a short-axis view of the nerve because this view allows for easier identification and differentiation from surrounding structures (Fig. 1, left).[6] When the long axis of the needle is inserted within the ultrasound plane, the needle tip location can be more easily identified relative to the target nerve. If the initial local anesthetic bolus is placed through the needle, the spread may be observed and adjustment of the needle tip can be made if desired. Unfortunately, when the perineural catheter is inserted past the needle tip, it has the tendency to bypass the nerve given the perpendicular orientation of the block needle and target nerve,[3] although there are certain anatomic locations that will often allow a catheter to be passed and remain perineural.[7,8] Some practitioners have advocated either passing the catheter a minimal distance past the needle tip (although others have suggested this may result in a dislodged catheter tip as the needle is withdrawn over the catheter, especially by trainees),[9] or advancing the catheter further initially and then, after needle removal, retracting the catheter such that its orifice(s) lie a minimal distance (<2 cm)

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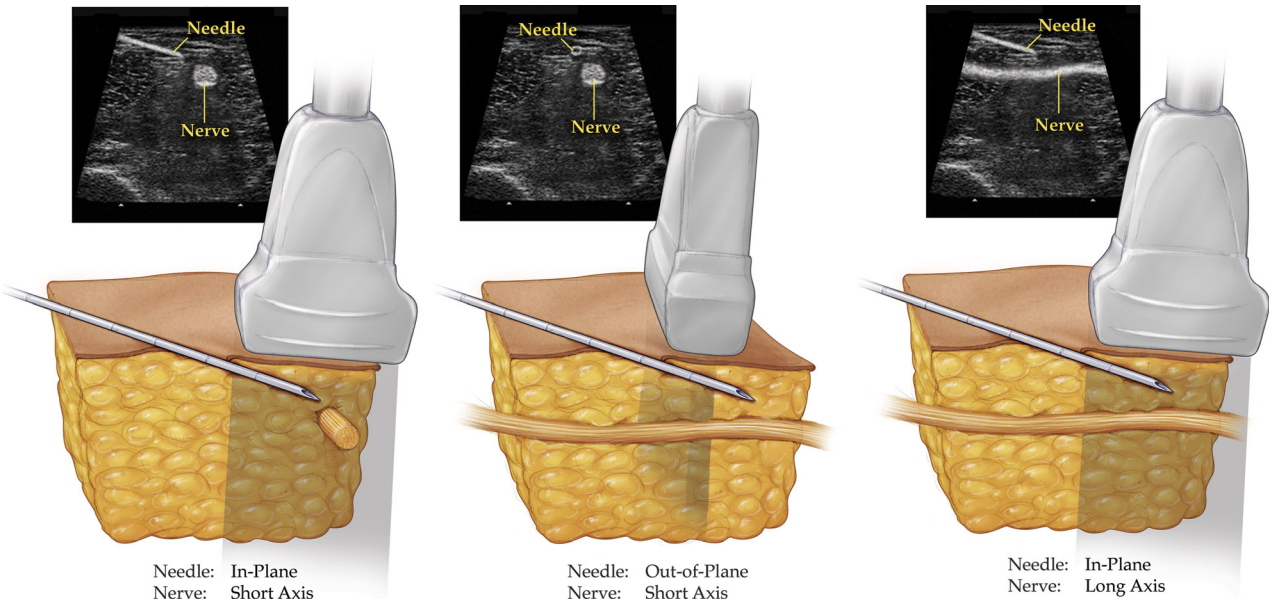

FIGURE 1. Various ultrasound-guided perineural catheter insertion approaches: needle within the ultrasound plane and target nerve in cross section or short axis (left), needle out-of-plane and target nerve in short axis (middle), and both the needle and target nerve within the ultrasound plane (right).

past the original needle tip position. Some advocate using an extremely flexible perineural catheter in an attempt to keep the catheter tip near the target nerve if the catheter is inserted more than a minimal distance.[10–12] Still others describe reorienting the needle from an in-plane to a more parallel trajectory and inserting a stimulating catheter to better monitor catheter tip location.[13]

Proposed benefits include using the same basic technique for both single-injection and perineural catheter placement, simply adding the insertion of a catheter via the placement needle/angiocatheter, and its application in nearly all anatomic catheter locations, even for deeper target nerves.[12] If a 17- or 18-gauge needle is used, the needle tip may be more easily identified and remain within the ultrasound plane owing to its rigidity compared with smaller gauge needles (Fig. 2).[14] Although some have speculated that the use of a large needle is more painful, 7 prospective studies reported a median catheter insertion pain score of 0 to 2 on a 0 to 10 numeric rating scale (10, most pain imaginable) when the needle track was first anesthetized with lidocaine via a 25- to 27-gauge needle.[9,11,12,15–18] In addition, the potential benefits of using a larger needle gauge (fewer needle passes given the relative ease of keeping a rigid, larger-gauge needle in plane and less risk of undesired tissue contact owing to misinterpretation of the needle shaft for the needle tip) must be weighed against the potential risks (increased patient discomfort, increased tissue trauma, and increased injury if a vessel is punctured).

Disadvantages of this approach include the following: new needle entry sites relative to the nerve compared with more traditional nerve stimulation modalities that typically use a parallel needle-to-nerve insertion, challenges keeping the needle shaft in-plane,[19] difficult needle tip visualization for relatively deep nerves,[20,21] and, as noted above, the catheter tip may bypass the target nerve given the perpendicular orientation of the needle and nerve.[3] If an extremely flexible catheter is used in an attempt to minimize this issue, it is sometimes difficult to thread past the tip of the placement needle.

NEEDLE OUT-OF-PLANE, NERVE IN SHORT-AXIS APPROACH

One benefit of this approach is a generally familiar parallel needle-to-nerve trajectory used with traditional nerve stimulation techniques (and also vascular access; Fig. 1, middle). In addition, because the needle is parallel to the target nerve, the

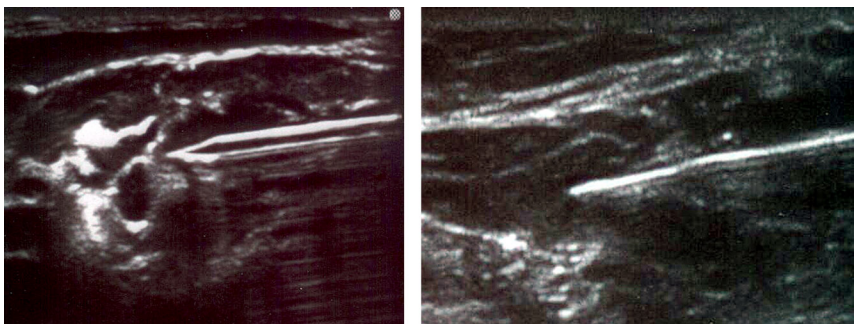

FIGURE 2. Placement needle visualization under ultrasound. A 17-gauge uninsulated Tuohy-type needle (left; FlexTip; Arrow International, Reading, PA) and a 21-gauge insulated B-bevel needle (right; Stimuplex; B. Braun Medical, Bethlehem, PA).

catheter theoretically may remain nearer the nerve, even when threaded more than a centimeter past the needle tip.[9,15] The main disadvantage of this technique is the relative inability to visualize the advancing needle tip,[9,22] which, some speculate, increases the likelihood of unwanted contact with nerves, vessels, peritoneum, pleura, or even meninges[23] (however, others have suggested that the consequent orientation of needle more along the long axis of the target nerve—as opposed to perpendicular—makes nerve penetration very unlikely, especially with a 17- or 18-gauge Tuohy needle). Practitioners often use a combination of tissue movement and hydrolocation in which fluid is injected and the resulting expansion infers the needle tip location (either with or without color Doppler flow).[22,24] Some have suggested that for superficial catheters (eg, interscalene and femoral), the consequent longitudinal orientation of needle with nerve makes precise visualization of needle tip less critical because the needle tip tends to remain relatively close to the nerve if the needle tip is advanced beyond the ultrasound beam. However, for deeper nerves, this technique is not as straightforward as guiding the needle tip to a target nerve as in the in-plane technique described above and may be more difficult to master (and, at times, nearly impossible).[20,21]

NEEDLE IN-PLANE AND NERVE IN LONG-AXIS APPROACH

Theoretically, this technique takes the benefits of both previously described approaches and harbors few of the limitations (Fig. 1, right). The nerve can be viewed along with the needle shaft/tip, and the catheter can be monitored as it exits the needle parallel to the target nerve. The problem is in the execution: keeping 3 structures—the needle, nerve, and catheter—in the ultrasound plane is not only very difficult to learn but also difficult to execute even after mastery.[25] Until now, evidence of this technique's difficulties could be found only indirectly in the scarcity of published reports.[25,26] However, in this issue of *Regional Anesthesia and Pain Medicine*, Wang et al[27] provide data from a well-designed randomized, observer-masked study demonstrating the difficulties of this approach. Fifty patients had a femoral perineural catheter placed using ultrasound guidance with an in-plane needle shaft. Half of the subjects had the nerve imaged in-plane as well (long-axis view; Fig. 1, right), whereas the remainder had the nerve imaged in cross section (short-axis view; Fig. 1, left). For the long-axis view group, catheters were advanced approximately 7 cm along the femoral nerve; for the short-axis view group, catheters were advanced 2 cm past the needle tip, but then withdrawn 2 cm after needle removal, theoretically leaving the catheter tip at the original needle tip perineural position.

For the long-axis treatment group, the investigators had great difficulty in keeping the nerve, needle, and catheter all within the ultrasound plane and "could not advance the catheters with real-time ultrasonographic visualization in the majority of the patients."[27] They "had to resort to some maneuvers including changing the position and direction of the ultrasound probe, tilting the probe, shaking and mild withdrawal of the catheter, and injecting 2 to 5 mL saline to find the tip of the catheter."[27] Even with these maneuvers, 10% of catheters could not be placed within 30 mins, and the mean (SD) time for all insertions was 21 (8) versus 12 (3) mins for the comparison group ($P < 0.01$). A difference of 9 mins for placement was not only statistically significant but also clinically significant in many—if not most—anesthesiology practices and, combined with the increased variability (SD of 8 versus 3 mins), would often prevent perineural catheter insertion based simply on time constraints. There are additional limitations of the long-axis approach that preclude its use in multiple circumstances. To view the nerve in long axis, the nerve itself must be relatively straight; and there can be only 1 target nerve as opposed to multiple branches as found within the brachial plexus. All of these issues combine to make the needle in-plane, nerve in long-axis technique the most challenging of the 3 approaches discussed above. However, this balance may change with advances in catheter and/or ultrasound technology in the future.[28]

The limited length of an editorial precludes a discussion of multiple additional ultrasound-related issues, such as transducer selection, the concomitant use of nerve stimulation (an important tool in a subset of patients),[4] and various methods for catheter tip localization.[5] Although many proponents voice firm opinions based on their personal experience, few clinical data exist comparing aspects of any 1 placement technique with another. This editorial may likely trigger a plethora of letters from practitioners sharing their approaches and experiences, and we believe that sharing of information can only benefit the evolution of perineural catheter insertion techniques. However, only by prospectively comparing various approaches will their relative benefits and drawbacks be truly revealed and the science of perineural infusion advanced. To this end, we applaud the recent publication by Wang et al[27] and eagerly await the results of additional well-designed, randomized, controlled clinical trials, allowing the transition from an editorial highlighting a lack of answers, to practice guidelines based on prospectively collected data.

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