Ultrasound-Guided Regional Anesthesia and Analgesia

A Qualitative Systematic Review

Spencer S. Liu, MD, Justin E. Ngeow, BA, and Jacques T. YaDeau, MD, PhD

Abstract: Ultrasound guidance has become popular for performance of regional anesthesia and analgesia. This systematic review summarizes existing evidence for superior risk to benefit profiles for ultrasound versus other techniques. Medline was systematically searched for randomized controlled trials (RCTs) comparing ultrasound to another technique, and for large (n > 100) prospective case series describing experience with ultrasound-guided blocks. Fourteen RCTs and 2 case series were identified for peripheral nerve blocks. No RCTs or case series were identified for perineural catheters. Six RCTs and 1 case series were identified for epidural anesthesia. Overall, the RCTs and case series reported that use of ultrasound significantly reduced time or number of attempts to perform blocks and in some cases significantly improved the quality of sensory block. The included studies reported high incidence of efficacy of blocks with ultrasound (95%–100%) that was not significantly different than most other techniques. No serious complications were reported in included studies. Current evidence does not suggest that use of ultrasound improves success of regional anesthesia versus most other techniques. However, ultrasound was not inferior for efficacy, did not increase risk, and offers other potential patient-oriented benefits. All RCTs are rather small, thus completion of large RCTs and case series are encouraged to confirm findings.

Key Words: ultrasound, peripheral nerve block, epidural anesthesia.

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Use of ultrasound to guide placement of needles and catheters for regional anesthesia and analgesia has become increasingly popular. Recent review articles on this topic have been published in major anesthesia journals,[1–5] and many anesthesiology meetings offer lectures and workshops on the use of ultrasound including the 2008 annual meetings of the American Society of Regional Anesthesia and Pain Medicine (http://www.asra.com/education/ASRA-brochure-2008.pdf) and the International Anesthesia Research Society (http://www.iars.org/documents/2008%20Program.pdf). Increased popularity of ultrasound may be due to multiple reasons such as dissatisfaction with success rates of traditional block techniques,[6] preference for a visual endpoint, increased familiarity with ultrasound, overall increased exposure to regional anesthesia,[7] or a belief in increased safety with use of ultrasound guidance. As with any new technology, it becomes critical during evolution of use to provide evidence for superior risk/benefit profiles over existing methods to justify evidence-based adoption of a new technology. This systematic review will summarize existing evidence and suggest future directions.

From the Department of Anesthesiology, Hospital for Special Surgery and Weill Medical College of Cornell University, New York, NY.
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Address correspondence to: Spencer S. Liu, MD, Department of Anesthesiology, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021 (e-mail: liusp@hss.edu).

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METHODS

The National Library of Medicine's Medline database was searched for the time period 1966 to November 2007. Two authors (S.S.L. and J.T.Y.) performed independent searches. Search strategies included the terms "ultrasound," "nerve block," continuous," "epidural anesthesia," "epidural analgesia," and "spinal anesthesia." This initial search identified 430 potential articles for systematic review. All of the above abstracts were reviewed for potential inclusion in the systematic review. Only the following types of articles were included: randomized controlled trials (RCTs) comparing ultrasound guidance to an alternative technique, and large prospective case series that could provide estimates of efficacy and safety as defined for the described ultrasound guidance technique. We defined a "large" case series as >100 patients. Assuming an approximately 90% efficacy rate, then this sample size allows a 95% confidence interval of ±5% of true incidence. For the purpose of this review, we defined efficacy or success as not requiring conversion to an alternative anesthetic technique (e.g., general anesthesia). After selecting the initial articles, the reference list of each of the analyzed articles was checked for any additional studies, as were the authors' personal files for additional references that met all inclusion criteria.

RESULTS

Peripheral Nerve Blocks

Randomized controlled trials for ultrasound-guided upper extremity anesthesia. Seven RCTs for adults that compared ultrasound guidance to an alternative technique were identified (Table 1).[8–14] All RCTs reported some clinical benefit with ultrasound guidance; however, none reported a statistically significant difference in block efficacy in terms of failed block requiring general anesthesia. Six of 7 RCTs reported no significant differences between techniques in requiring supplemental analgesia.[8,9,11–14] No persistent complications were observed in any RCT. Two RCTs measured patient satisfaction without noting any differences in techniques.[8,12]

Five studies examined axillary block for upper extremity procedures.[8–12] Four of 5 RCTs measured block performance and all reported either fewer needle passes or faster time for block performance (<5 minutes difference).[8–11] Four of 5 RCTs reported faster or more complete early onset of sensory or motor block, however, no RCTs reported a significant difference in onset of surgical anesthesia.[8–10,12] Soeding et al. examined interscalene block for shoulder surgery and also reported more complete early sensory and motor block without any difference in anesthetic success or duration of analgesia.[12] Williams et al. examined supraclavicular block with either ultrasound alone or ultrasound with nerve stimulator, and noted faster block performance time (5 minutes difference) without a difference in onset or success of sensory and motor block.[13] No differences

TABLE 1. Randomized Controlled Trials with Ultrasound-Guided Upper Extremity Peripheral Nerve Block

Study	Groups (n: Technique)	Primary Outcome	Block Performance	Onset Time	Efficacy	Complications	Patient Satisfaction
Casati 2007[8]	Axillary block Forearm, wrist and hand procedures 30: 4 nerve branches, injection ultrasound 30: 4 nerve branches, injection NS 20 mL 0.75% ropivacaine	Powered to detect a 5 minute difference in the onset of nerve blockade.	Fewer median (range) needle passes for ultrasound 4* (3–8) versus stimulator 8 (5–13). Endpoint for performance: only forward movement of the needle preceded by a retraction of at least 10 mm counted as a pass.	Sensory onset faster with ultrasound; 14 ± 6 versus 18 ± 6 minutes.* No difference in onset of motor block or readiness for surgery.	No GA: 100% in both groups. No supplement: same for ultrasound (97%) versus NS (94%).	More block-related pain with NS (48%) versus ultrasound (20%). No neurologic complications at 24 hours in either group.	No difference in future acceptance of anesthetic technique (100% ultrasound vs. 93% nerve stimulator).
Chan 2007[9]	Axillary block Hand surgery 64: 3 injection ultrasound 62: 3 injection NS 62: 3 injection both 42 mL 2% lidocaine with 0.5% bupivacaine	Powered to detect an increase in rate of successful block (providing complete sensory anesthesia in the distribution of all 3 target nerves: median, radial, ulnar) from an estimated baseline of 80% to 95%.	Faster block performance with ultrasound versus NS versus both (9.3* vs. 11.2 vs. 12.4 minutes). Endpoint for performance: time from palpation of axillary artery or ultrasound probe application to the end of the local anesthetic injection.	More complete sensory block at 30 minutes with ultrasound and both versus NS (83 vs. 81 vs. 63%).* No difference in onset of motor block.	No GA: same ultrasound versus NS versus both (98 vs. 95 vs. 98%). No supplement: same for ultrasound (95%) versus NS (86%) versus both (92%).	No difference in transient post block paresthesia for ultrasound versus NS versus both (20 vs. 21 vs. 15%). More local bruising with NS versus ultrasound versus both (13* vs. 3 vs. 0%).	N/A
Sites 2006[10]	Axillary block Hand surgery 28: TA 28: 3 injection ultrasound 10 mL 1.5% lidocaine with 5 μg/mL epinephrine	Powered to detect a 20% difference in the rate of failed blocks (blocks not done within 20 minutes or requiring intraoperative conversion to GA).	Faster block performance in ultrasound group versus TA group: 7.9* ± 3.9 versus 11.1 ± 5.7 minutes, respectively. Endpoint for performance: time from completion of sterile preparation to the final withdrawal of the needle.	No differences between groups ultrasound and TA in percent of patients with complete sensory or motor block (5–30 minutes post block) except motor at 15 and 25 minutes.*	Fewer overall failures in ultrasound versus TA: 0% versus 28%.* No GA: ultrasound (0%) versus TA (14%). No supplement: same for both ultasound and TA at 82%.	On 1 to 2 week follow-up, no documented cases of persisting paresthesias.	N/A
Liu 2005[11]	Axillary block Forearm and hand surgery 30: ultrasound single injection 30: UD 30: ND 0.5 mL/kg 1.5% lidocaine with 5 μg/kg epinephrine	Powered to detect a 20% difference in the rate of adverse outcomes.	Faster performance in ultrasound and UD groups versus ND: 6.5 ± 1.3 and 6.7 ± 1.3 versus 8.2* ± 1.5 minutes. Endpoint for performance: time from needle puncture (ND) or ultrasound application on skin to the completion of the local anesthetic injection.	Similar efficacy in all 3 groups at blocking all 7 sensory and motor nerves after 40 minutes: ultrasound and ND, 70%; UD, 73%.	No GA: no differences between ultrasound versus UD versus ND (97 versus 100 versus 100%). No supplement: no differences between ultrasound versus UD versus ND (87 vs. 90 vs.90%).	Combined incidence of adverse events (paresthesia, axillary vessel puncture, and subcutaneous hematoma) in group ND significantly higher than in ultrasound and UD groups: 20%* versus 0% versus 0%.	N/A

Soeding 2005[12]	Interscalene and Axillary block Upper limb surgery 20: ultrasound 13: ISB, 7: axillary 20: surface landmark-based 11: ISB, 9: axillary 3 mg/kg ropivacaine	Not performed.	N/A	More complete sensory and motor block at 10 and 20 minutes post block with ultrasound.*	No GA: no difference ultrasound versus landmark (95 vs. 90%). No supplement: N/A. Similar duration of analgesia for ultrasound versus landmark (10.3 vs. 11.2 hours).	No seizure or neurapraxia in either group.	Similar patient satisfaction scores ultrasound versus landmark (rated on POD 7, 9.2 vs. 8.9, out of 10).
Williams 2003[13]	Supraclavicular block Distal arm, forearm, or hand surgery 40: ultrasound-guided with NS (ultrasound group) 40: NS (NS group) 1:1 Bupivacaine 0.5% with Lidocaine 2% with 1:200,000 epinephrine	Not performed.	Faster block performance in group ultrasound than in group NS: 5.4* ± 2.4 minutes versus 9.8 ± 7.5 minutes. Endpoint for performance: interval between first needle insertion and final needle withdrawal.	Similar rate of partial or complete sensory block in all nerve territories after 30 minutes. Groups ultrasound versus NS: 95% versus 85%. 55% of group ultrasound and 65% of group NS had complete block of all nerve territories.	No GA: no differences between ultrasound and NS (100 vs. 92%). No supplement: no differences between ultrasound and NS (85 vs. 78%). Similar duration for ultrasound and NS: 846 ± 531 versus 652±473 minutes).	After 1 week: 2 patients from group ultrasound reported paresthesias and 1 patient from group NS reported loss of sensation on the palmar surface of the thumb.	N/A
Dingemans 2007[14]	Infraclavicular block Hand, forearm, and distal arm surgery 36: ultrasound-guided perivascular (ultrasound group); 29 patients required 1 injection for desired spread; 6 patients required2 injections; 1 patient required 3 injections 36: single injection ultrasound-guided with NS (NS group) 0.5 mL/kg (to a max. of 40 mL) of 1:3 0.5% bupivacaine and 2% lidocaine with 1:200,000 epinephrine	Powered to detect difference of 1.6 minutes in performance time between the 2 techniques.	Faster block performance for ultrasound group than for NS group (3.1* ± 1.6 versus 5.2 ± 4.7 minutes). Endpoint for performance: time between skin puncture and final needle withdrawal. Similar lock-related discomfort scores for ultrasound and NS groups (2.8 vs. 2.5).	More complete sensory block after 30 minutes for ultrasound versus NS (86%* vs. 57%). In Group ultrasound, number of injections (single vs. multiple) did not affect rate of complete block (86% for both).	No GA: 100% both groups. No supplement: greater success with ultrasound versus NS (92 vs. 74%*). Similar time intervals from block to first analgesic use for groups ultrasound and NS (7 ± 3 vs. 8 ± 5 hours).	1 patient with paresthesia lasting 7 days in group ultrasound.	N/A

Abbreviations: GA, general anesthesia; N/A, not applicable; ND, nerve stimulator with double injection; NS, nerve stimulator; TA, transarterial; UD, ultrasound with double injection; POD, postoperative day; ISB, interscalene block.

*$P \leq .05$ in statistical assays for significance.

were noted for surgical efficacy. Dingemans et al. examined infraclavicular block with either ultrasound alone, or ultrasound with nerve stimulator-guided single injection.[14] They noted faster block performance (3 minutes difference), more complete early block, and significantly less need for analgesic supplementation with ultrasound alone.

One RCT was identified for pediatric patients undergoing infraclavicular block for arm and forearm surgery[15] (Table 2). Use of ultrasound guidance reduced discomfort during block placement and hastened onset of sensory and motor block. There were no differences in discomfort during surgery, although sensory block duration was greater with ultrasound guidance.

No RCTs were identified for perineural catheters.

Randomized controlled trials for ultrasound-guided lower extremity and lower body anesthesia. Four RCTs in adults that compared ultrasound guidance to an alternative technique were identified (Table 3).[18–21] No RCTs observed a difference between techniques in failed blocks. No RCTs observed any persistent complications. Three RCTs examined femoral nerve blocks.[18,20,21] Casati et al. examined ultrasound versus nerve stimulator-guided femoral nerve blocks in patients undergoing knee arthroscopy with a preexisting sciatic nerve block.[18] The RCT was designed to determine the minimum effective anesthetic volume (MEAV) for the femoral nerve block; as such it was designed to directly measure a 50% effective dose with a planned 50% failure rate in both groups. MEAV was significantly less in the ultrasound group. Marhofer et al. performed 2 RCTs examining femoral nerve block in hip trauma patients.[20,21] Both RCTs observed faster and more complete early onset of sensory block with ultrasound. Both RCTs observed no differences in failed blocks. One RCT examined ultrasound plus nerve stimulator versus nerve stimulator alone for lateral sciatic block for foot and ankle surgery.[19] Addition of ultrasound decreased number of needle passes but did not shorten block performance time. Addition of ultrasound improved tolerance to ankle tourniquet, and increased the number of patients not needing any analgesics. However, incidence of block failure requiring spinal anesthesia was not different between groups.

Two RCTs were identified in pediatric patients (Table 2).[16,17] One study examined ilioinguinal/iliohypogastric nerve block combined with a fixed concentration of sevoflurane for inguinal hernia and urologic surgery.[16] Patients randomized to ultrasound guidance required less local anesthetic for the block, less fentanyl with incision, and less postoperative analgesics. One RCT examined sciatic and femoral blocks for lower extremity surgery.[17] Less local anesthetic was required for the block with ultrasound and a longer duration of postoperative analgesia (~3 hours greater) was reported.

No RCTs were identified for perineural catheters.

Large case series for peripheral nerve blocks. Two prospective case series were identified for infraclavicular[22] and for supraclavicular blocks (Table 4).[23] All case series reported >98% success rate as defined by not needing conversion to general anesthesia and none reported any persistent complications, although no patients were followed up for greater than 24 hours. No large prospective case series was identified for ultrasound-guided lower extremity or lower body blocks. No large prospective case series was identified for ultrasound-guided perineural catheters.

Central Neuraxial Blocks

Randomized controlled trials for ultrasound-guided central neuraxial blockade. Six RCTs[24–29] were identified that compared ultrasound guidance to an alternative technique (Table 5). Five RCTs were from the same authors, had similar study design, and were performed for placement of obstetrical epidurals.[24–28] Of these 5, all but 1 employed prepuncture ultrasound scanning to identify the puncture site, the depth of the epidural space, and the angle for needle passage. In 4 RCTs, all epidurals were placed by the same author with inherent limitations on applicability to other clinicians.[24,26–28] In the initial RCT,[27] preparation time was the same with or without ultrasound prescanning, and prescanning reduced puncture attempts needed for successful combined spinal epidural. The second RCT[26] randomized parturients with presumed difficult epidural puncture to prescanning and similarly found reduced puncture attempts. Additionally, this study found that ultrasound prescanning for epidurals improved parturient satisfaction and reduced visual analog scale pain scores during labor. The next RCT[24] was of larger scale, and found that the scan added 75 seconds to the preparation time. Patients in the ultrasound group needed fewer puncture attempts, fewer intervertebral spaces were punctured, and fewer catheter advancement attempts were made. Patients in the ultrasound group reported lower pain scores during labor or surgery, and had fewer headaches and backaches. The failure rate was the same in both groups. The most recent study from this group[28] randomized 10 parturients per group to combined spinal epidural performed either without ultrasound, with an ultrasound prescan, or with online ultrasound imaging during performance of the block. In both ultrasound groups, fewer puncture attempts were needed compared with control. Patient satisfaction was the same in all groups. No major differences in epidural block were found between prescanning and real time ultrasound use in this study, but a power analysis was not presented.

A final RCT from the same group examined the effect of prepuncture ultrasound scanning on resident performance for epidural placement for obstetrics.[25] In the control group, residents had an initial success rate of 60%, which increased over time to 84%. Success rates for the ultrasound group increased from 86% to 94%. No persistent complications were observed in any RCT from these authors.

One RCT for pediatric patients undergoing epidural catheter placement in addition to general anesthesia for major surgery was identified (Table 5),[29] which compared real time ultrasound-guided epidural placement to a standard loss of resistance technique. No primary outcome was specified. Use of ultrasound guidance reduced the rate of needle to bone contacts (17% vs. 71%), and increased the speed of catheter placement (3 vs. 4 minutes). All epidurals were placed successfully, no major complications occurred in either group, and postoperative analgesia was similar in both groups.

Large case series for ultrasound-guided central neuraxial blockade. One large prospective case series was identified for central neuraxial blockade.[30] Prepuncture ultrasound scanning was performed to identify the distance from the skin to the epidural space for 180 pediatric patients. In 179 patients, the epidural space was located with the first puncture attempt. No postoperative complications were noted.

DISCUSSION

Does Ultrasound Guidance Improve Block Efficacy?

Current evidence suggests that efficacy for ultrasound-guided regional anesthesia and analgesia as defined by failed blocks is similar to most other techniques such as neurostimulation. Importantly, ultrasound guidance was not reported to be inferior in any RCT. In general, RCTs are small and quite diverse

TABLE 2. Pediatric Randomized Controlled Trials with Ultrasound-Guided Peripheral Nerve Blocks

Study	Groups (n: Technique)	Power Analysis	Block Performance	Onset Time	Efficacy	Complications	Patient Satisfaction
Marhofer 2004[15]	Infraclavicular brachial plexus block Arm and forearm surgery 20: ultrasound, median age 6 (range 2–10) 20: NS, median age 6 (range 1–9) Premedication with rectal midazolam 1 mL/kg up to a maximum of 10 mg and intravenous midazolam 0.05 to 0.1 mL/kg Ropivacaine 0.5% 0.5 mL/kg	Not performed	Lower VAS during the performance of the blocks in ultrasound versus NS, mean: 3 (range 1–4) versus 3.75 (range 3–5)*	Shorter sensory block onset times for ultrasound versus NS (median): 9 (range 5–15) versus 15 (range 5–25) minutes* More complete sensory block at 10 minutew with ultrasound* for musculocutaneous, median, and ulnar nerve distributions More complete motor block at 10 minutes with ultrasound* for axillary, musculocutaneous, and ulnar nerves	No difference in VAS observed before blocks, 30 minutes after blocks, or during surgery Longer median (range) sensory block duration for ultrasound versus NS: 384 (280–480) versus 310 (210–420) minutes*	N/A	N/A
Willschke 2005[16]	Ilioinguinal/iliohypogastric nerve block following induction with GA Inguinal hernia repair, orchidopexy, or hydrocele repair 50: ultrasound group 50: FC group GA: 8% sevoflurane via facemask, then 1 MAC halothane in nitrous oxide with O_2 Levobupivacaine 0.25% variable volumes	Powered to detect 50% difference between 2 groups in block sufficiency (or insufficiency as indicated by >10% increase in heart rate or mean arterial pressure following skin incision)	N/A	Lower incidence of increased heart rate at skin incision for ultrasound versus FC: 6% versus 22%* Fewer patients needing additional fentanyl on skin incision for ultrasound versus FC: 4% versus 26%*	Fewer patients requiring postoperative rectal acetaminophen in ultrasound versus FC: 6% versus 40%* Lower amount of LA needed for ultrasound versus FC: 0.19 (0.05) versus 0.3 mL/kg*	No complications occurred in either ultrasound or NS group	N/A
Oberndorfer 2007[17]	Sciatic (all patients) and femoral (14 patients) blocks Surgery of one lower extremity 23: ultrasound 23: NS Premedication with oral midazolam 0.5 mg/kg GA induced with sevoflurane 8% via face mask, 1 MAC halothane in nitrous oxide with O_2 Levobupivacaine 0.5% (NS group: 0.3 mL/kg; ultrasound group: variable dosage)	Powered to detect an increase in block duration from 300 to 450 minutes for NS versus ultrasound guidance	N/A	N/A	Longer duration of analgesia in ultrasound* versus NS: 508 (178) versus 335 (169) minutes Lower volume of LA needed in sciatic and femoral blocks for ultrasound versus NS: 0.2 (0.06) versus 0.3 mL/kg,* and 0.15 (0.04) versus 0.3 mL/kg,* respectively	No complications in either group during block performance	N/A

Abbreviations: FC, fascial click; GA, general anesthesia; LA, local anesthetic; N/A, not applicable; NS, nerve stimulator; VAS, visual analog score.

*$P \leq .05$ in statistical assays for significance.

TABLE 3 . Randomized Controlled Trials with Ultrasound-Guided Lower Extremity Peripheral Nerve Block

Study	Groups (n: Technique)	Power Analysis	Block Performance	Onset Time	Efficacy	Complications	Patient Satisfaction
Casati 2007[18]	Femoral NB with preceding sciatic NB Knee arthroscopy 30: Femoral NB using NS 30: Femoral NB using ultrasound Sciatic: 12 mL 2% mepivicaine, double injection with NS using subgluteal approach Femoral: variable volumes of 0.5% ropivacaine	Powered to detect 3 mL difference $MEAV_{50}$	N/A	No difference in percent of patients showing incomplete block (requiring intra-articular infiltration with intravenous fentanyl supplement) after 30 minutes: 50% of group ultrasound and 56% of group NS	Lower $MEAV_{50}$, and (SD) for group ultrasound versus group NS: 15 (4) versus 26(4)mL*	At 24 hours, all patients showed complete recovery of sensory and motor functions. No neurological complications reported	N/A
Domingo-Triado 2007[19]	Sciatic NB at midfemoral level Foot and ankle surgery 30: ultrasound with NS (group ultrasound) 31: NS alone 35 mL 0.5% ropivacaine	Powered to detect 25% difference in the number of attempts to perform the technique	Higher level of success in sciatic nerve location on first attempt for group ultrasound versus NS: 76.7% versus 41.9%* No difference in time to perform the block Endpoint for block perfirmance: time from first needle insertion to successful nerve location or from begginning of ultrasound technique to successful nerve location	No difference in onset time, or in duration of sensory and motor block Quality of sensory block and tolerance to tourniquet better in group ultrasound: 96.7% versus 71% achieved complete sensory block,* 93.3% versus 48.4% tolerated the tourniquet without sedation.*	No difference in failed block requiring spinal anesthesia with ultrasound (3%) versus NS (6.6%)	One patient had neuropathic pain in the innervation area of the sciatic 1 week after puncture. Re solved in 10 days	N/A
Marhofer 1998[20]	3-in-1 block Hip surgery after trauma 20: ultrasound (group A), 20 mL 0.5% bupivacaine 20: ultrasound (group B), 20 mL 0.5% bupivacaine 20: ultrasound (group C), 30 mL 0.5% bupivacaine	Not performed	N/A	Shorter onset (sensation at <30% of initial value) Ultrasound versus NS: 13 ± 16 (group A) versus 27 ± 12 (group B) versus 26 ± 13 (group C) minutes* No difference in complete 3-in-1 blocks (sensation at <30% initial value) observed in ultrasound (95%) versus NS (both 80%). No motor evaluation Quality of block better in group A than groups B and C during first hour: final sensation at 4 ± 5% of initial value versus 21 ± 11% and 22 ± 19%, respectively*	No difference in failed blocks; group A (5%), group B (10%), group C (5%)	No complications lasted longer than 24 hours in any patients	N/A

Marhofer 1997[21]	3-in-1 block Hip surgery after trauma 20: ultrasound 20: NS 20 mL 0.5% bupivacaine	Not Performed	N/A	Shorter onset for ultrasound versus NS: 16 ± 14 versus 27 ± 16 minutes* No difference in complete 3-in-1 block (sensation at <30 initial value) observed in ultrasound (95%) versus NS (85%). No motor evaluation Better quality of block for period after 30 to 60 minutes in ultrasound 10 % versus 27 ± 14% of initial value*	No difference in failed block: ultrasound (5%) versus NS (10%)	No recorded complications after 24 hours	N/A

Abbreviations: $MEAV_{50}$, minimum effective anesthetic volume of ropivacaine 0.5% providing adequate surgical block of the femoral nerve within 30 minutes in 50% of patients; N/A, not applicable; NB, nerve block; NS, nerve stimulator.

*$P \leq .05$ in statistical assays for significance.

in terms of type of block, anesthetic and analgesic agents, and comparative control techniques. Most RCTs compared ultrasound with nerve stimulator but other techniques included fascial pops, transarterial, surface landmarks, and ultrasound combined with nerve stimulator. The use of the combined technique may be especially difficult to evaluate, as it may be confusing which endpoint (visual vs. stimulating current threshold) to accept if there is discrepancy.[31] A further confounding factor for review was diversity in number of injections used for both ultrasound and control techniques. Previous studies with nerve stimulator-guided peripheral nerve blocks have demonstrated increased efficacy with either multiple injections[32,33] or specific multinerve motor responses,[34] 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.[13,14,19] Finally, many RCTs were performed in a limited number of institutions with access to and expertise with ultrasound guidance, thus generalization of results to other environments may be limited.

All included RCTs and the 3 included prospective case series reported success rates for upper extremity peripheral nerve blocks of 95% to 100% for ultrasound guidance. These success rates were similar (95%–100%) to use of nerve stimulator-guided upper extremity blocks in the included RCTs for review, and from previously published much larger prospective case series (300–700 patients) using nerve stimulator for upper extremity peripheral nerve blocks.[35,36] Other techniques, such as transarterial and surface landmarks, were not consistently compared in more than 1 RCT. Only 1 RCT was performed in pediatric patients with similar lack of difference in anesthetic efficacy but with a prolonged duration of postoperative analgesia (~70 extra minutes).[15] As mentioned, only 2 small (≤200 patients) prospective case series were identified for ultrasound-guided supra-clavicular and infraclavicular blocks. No RCTs or large, prospective case series were identified for ultrasound-guided perineural catheters.

There were even fewer data for lower extremity peripheral nerve blocks. Only 3 RCTs and 1 MEAV study in adults were identified. Success rates were 90% to 97% with use of ultrasound or nerve stimulator. This is consistent with a previous large prospective case series for nerve stimulator-guided sciatic blocks that reported 97% success rate in 500 patients.[37] Two RCTs with pediatric patients were identified; they reported improved postoperative analgesia with use of ultrasound for lower extremity and inguinal hernia and urologic surgery. No large prospective case series was identified for ultrasound-guided lower extremity peripheral nerve blocks. No RCTs or large prospective case series were identified for ultrasound-guided perineural catheters.

None of the epidural RCTs showed reduced failure rates from addition of ultrasound guidance. Use of ultrasound prescanning in parturients consistently reduced the number of punctures, and number of vertebral interspaces attempted. However, almost all of these RCTs were performed entirely by a single operator and may have limited applicability to other clinicians. The largest (150/group) of these RCTs did report a probably clinically insignificant reduction in pain scores (0.8 vs. 1.3) during labor or Cesarean delivery (both were analyzed together) with ultrasound prescanning.[24] One small RCT with 10 subjects per group did not report an advantage for real time scanning versus prescanning with ultrasound for obstetrical combined spinal epidural analgesia.[28] Another RCT reported faster learning curves for residents with prepuncture ultrasound scanning, but the control learning curve lagged behind previously reported learning curves for residents learning

TABLE 4. Large (n > 100) Case Series of Ultrasound-Guided Peripheral Nerve Block

Study	Type of Block and Specifics	Block Performance	Efficacy (Not Requiring General Anesthesia)	Efficacy (Not Requiring Supplemental Analgesics)	Complications
Sainz Lopez 2006[23]	n = 200 (all by author) Supraclavicular block 3 injection Hand and elbow surgery 10 mL 2% mepivacaine	Not applicable	98% (95% CI of 96–99%)	97% (95% CI of 95–99%)	No persistent complications but unspecified observation period
Sandhu 2002[22]	n = 126 Infraclavicular block 3 injection Hand, forearm, and AV fistula surgery 33 mL 2% lidocaine with epinephrine 1: 200,000 and $NaHCO_3$ (0.9 mEq/ 10 mL)	10 ± 4.4 minutes (time from imaging to end of injection) Complete sensory and motor block 6.7 ± 3.2 minutes	98% (95% CI of 95–99%)	93% (95% CI of 88–97%)	No complications within 24 hours

Abbreviation: CI, confidence interval; AV, arterio-venous.

traditional loss of resistance epidural placement.[38] The pediatric epidural study also reported no differences in failed blocks.[29] No large prospective case series was identified for adults. One case series was identified for pediatrics. Prepuncture scanning resulted in a 99% success rate of locating the epidural space with first puncture attempt. This success rate is better than a 91% success rate reported for epidural localization with a 17-gauge needle loss of resistance technique (number of attempts not specified)[39] and a 94.3% first attempt success rate observed with staff anesthesiologists locating the epidural space with the "drip and tube method."[40]

Does Ultrasound Guidance Offer Other Potential Benefits?

Faster block performance or fewer needle passes. Consistently, RCTs for ultrasound-guided peripheral nerve blocks report that blocks can be performed more quickly than with nerve stimulator (approximately 3 minutes),[9–11,13,14] with fewer needle passes,[8,19] and less discomfort.[14,15] All RCTs for epidural blocks also reported fewer attempts, fewer needle passes, or faster performance with prepuncture scanning or real time scanning and analysis (Table 5). Although these findings would seem inherently advantageous, only 2 of the 5 RCTs that measured satisfaction noted a statistically significant difference between groups.[8,12,24,26,28] We note that none of these studies considered satisfaction to be a primary outcome, and were not powered to determine a difference in this outcome.

Faster initial onset of block. Overall, ultrasound resulted in faster onset of block and more complete block during early measurement periods (≤30 minutes) after upper and lower extremity peripheral nerve blocks.[8–10,12,14,15,19–21] This finding may be explained by closer approximation of the needle and local anesthetic solution to the nerves with use of ultrasound. As noted above, this enhanced onset of block with ultrasound did not ultimately reduce incidence of failed blocks requiring conversion to general anesthesia. This apparent discrepancy may be due to the additional onset time allowed to all block techniques with patient transport, positioning, and surgical preparation.

Reduced dose of local anesthetic. Four included RCTs reported reduced need for dose of local anesthetic.[16–18,20] None of the studies was a rigorous dose response comparison so interpretation is difficult. It is tempting to speculate that ability of ultrasound to closely approximate the needle to the target nerve would allow a reduction in dose of required local anesthetic. If proven, this may be a safety advantage for reduced risk of toxic systemic reactions to local anesthetics. However, this may be a theoretical advantage as a recent large scale prospective surveillance study of 158,000 regional anesthetics reported no cardiac arrest and 7 seizures (0.004% incidence) due to local anesthetic toxicity.[41]

Does Ultrasound Guidance Reduce Risk of Nerve Injury From Regional Anesthesia and Analgesia?

A potential advantage is that direct visualization of a needle with ultrasound should help prevent intraneural puncture and injection of local anesthetic with resultant reduction in risk of neural injury. This may be especially relevant for peripheral nerve blocks, as recent studies suggest that intraneural injections may frequently occur with a fascial pop technique,[42] and that reliance on a minimum stimulating current of 0.3 mA to 0.5 mA with a nerve stimulator may not identify intraneural or very close perineural needle placement.[31,41,43,44] However, current evidence is insufficient to answer this question. Virtually no RCTs or prospective case series observed any persistent complications, but the subject numbers for each study are too small for meaningful extrapolation to various block locations. Similarly, in the epidural studies, permanent injury was not identified in any patients, with or without ultrasound. However, only 1 small epidural study used real time scanning to identify position of the needle during block performance. Current estimates of permanent nerve injury after peripheral nerve blocks range from 0.03%[41] to 3%[45] depending on location of block, and would require 3,068 patients in a randomized trial to determine a 50% reduction from 3% to 1.5%, and >1,200 patients in a case series to determine a 95% confidence interval of 1% for the true incidence of a studies technique. Estimates for permanent

TABLE 5. Randomized Controlled Trials and Case Series with Ultrasound-Guided Epidural Anesthesia/Analgesia in Adults and Children

Study	Groups (n: Technique)	Power Analysis	Block Performance	Onset Time	Efficacy	Complications	Patient Satisfaction
Grau 2004[28]	Obstetric epidural anesthesia 10: CSE (control) 10: CSE with offline prepuncture ultrasound scan (offline) 10: CSE with online ultrasound imaging during epidural puncture (online) Spinal: 1.5 mL bupivacaine 0.5% Epidural: 7.5 mL bupivacaine 0.5% plus 10 μg sufentanil	Not performed	Greater level of success in reaching the epidural space on the first attempt in online ultrasound groups versus control: 100% versus 40%* Overall, fewer puncture attempts in both ultrasound groups versus control: 10 (online) and 13 (offline) versus 18* Fewer interspaces punctured before successful location of the epidural space in online versus control: 0 versus 5 patients requiring a change of puncture site* All blocks were performed by the author, T.G.	Elapsed time between injection and first effects or complete block showed no differences across the 3 groups	Incidence of failed blocks not reported No difference in average VAS during the operation across the 3 groups: 0.7 ± 0.94 (control) versus 0.3 ± 0.94 (offline) versus 0.3 ± 1.63 (online)	No difference in the incidence of headache or backache after CSE across the 3 groups	No difference in patient satisfaction with the epidural anesthesia across the 3 groups: 1.65 ± 0.74 (control) versus 1.35 ± 0.57 (offline) versus 1.2 ± 0.42 (online) on a satisfaction scale of 1 (very good) to 6 (insufficient)
Grau 2003[25]	Obstetric epidural anesthesia 10 residents (5/group) were assigned to perform their first 60 obstetric epidurals either with or without prepuncture ultrasound imaging 300: LOR technique (CG) 300: LOR technique with prepuncture ultrasound imaging of puncture area (UG)	Not Performed	Improvement in success rate of epidural anesthetic in CG versus UG after 60 cases: 60 ± 15% up to 84 ± 25% versus 86 ± 15% up to 94 ± 9%* Success: adequate obstetric epidural anesthesia within 3 attempts; VAS <1 during entire procedure; no intervention from a supervisor	N/A	N/A	N/A	N/A
Grau 2002[24]	Obstetric epidural anesthesia 150: LOR technique with prepuncture ultrasound imaging of puncture area (UG)	Not performed	Lower average number of puncture attempts needed for successful epidural space cannulation in UG versus CG: 1.3 ± 0.6 versus 2.2 ± 1.1 attempts* Fewer intervertebral spaces punctured before successful identification of the epidural space in UG versus CG: 1.1 ± 0.4 versus 1.3 ± 0.6*	No difference between UG and CG in onset from injection to complete block	No difference in failed blocks 0% UG versus 1% CG More cases of complete analgesia in UG versus CG: 147 versus 138 patients*	Less frequent postpartum headache and backache in UG versus CG: 33 (22%) versus 54 (36%) patients*	Higher level of satisfaction in anesthesia procedure in UG versus CG: 1.3 ± 0.5 versus 1.8 ± 0.9 on a satisfaction scale of 1 (very good) to 6 (insufficient)*

(Continued on next page)

TABLE 5. *(continued)*

Study	Groups (n: Technique)	Power Analysis	Block Performance	Onset Time	Efficacy	Complications	Patients Satisfaction
	150: LOR, (CG) Both groups: 85 labor analgesia, 65 cesarean section Labor analgesia: 11 to 15 mL of bupivacaine 2.5 mg/mL plus 10 μg sufentanil Cesarean section: 14 to 16 mL of bupivacaine 5.0 mg/mL plus 20 μg sufentanil		Fewer catheter advancement attempts on average in UG versus CG: 1.3 ± 0.6 versus 2.1 ± 1.1 times All blocks were performed by the author, T.G.		Lower maximum VAS in UG versus CG: 0.8 ± 1.5 versus 1.3 ± 2.2* Complete motor block in 100% of patients in both groups		
Grau 2001[26]	Obstetric epidural anesthesia 36: LOR technique with prepuncture ultrasound scan (ultrasound group) 36: LOR technique alone (CG group) 10 to 13 mL bupivacaine 0.25 mg/mL plus 10 μg sufentanil	Not performed	Fewer puncture attempts made in ultrasound versus CG: 1.15 ± 0.9 versus 2.6 ± 1.4* Fewer intervertebral spaces punctured before successfully reaching the epidural space in ultrasound versus CG (1.3 ± 0.5 vs. 1.5 ± 0.7)* Fewer catheter advancement attempts in ultrasound versus CG: 1.1 ± 0.4 versus 1.3 ± 0.6* All blocks were performed by the author, T.G.	N/A	No difference in failed blocks: 0% ultrasound versus 5% CG Maximum VAS during labor with epidural anesthesia lower in ultrasound versus CG: 0.8 ± 1.4 versus 1.8 ± 2.7*	N/A	Higher level of satisfaction in anesthesia procedure in ultrasound versus CG: 1.3 ± 0.5 versus 2.1 ± 1.3 on a satisfaction scale of 1 (very good) to 6 (insufficient)*
Grau 2001[27]	Obstetric epidural anesthesia for Cesarean section 40: CSE 40: CSE with prepuncture ultrasound imaging (ultrasound-CSE) Spinal: 1.5 mL bupivacaine 0.5% Epidural: 7.5 mL bupivacaine 0.5% plus 10 μg sufentanil	Not performed	Higher success rate in locating the epidural space on the first try in ultrasound-CSE versus CSE: 75% versus 20%.* A third attempt was needed in 1 patient for ultrasound-CSE versus 8 patients for CSE alone (3% vs. 20%)* Fewer interspaces punctured before successful location of the epidural space in ultrasound-CSE versus CSE: versus 6 patients requiring a change of puncture site* All blocks were performed by the author, T.G.	N/A	N/A	N/A	N/A

Willschke 2006[29]	Pediatric epidural catheter placement Children from neonate to 6 years 32: ultrasound-guided catheter placement 32: LOR catheter placement Major abdominal or thoracic surgery Levobupivacaine 0.25% 0.2 mL/kg	Not performed	Epidural catheters placed more swiftly in the ultrasound group than in the LOR group: 162 ± 75 versus 234 ± 138 seconds* Bone contact occurred in fewer children for ultrasound vs. LOR: 17% versus 71%*	N/A	N/A	No dural puncture occurred in either group	N/A
Kil 2007[30]	Pediatric epidural anesthesia n = 180, aged 2 to 84 months Urologic surgery	Not performed	Epidural space located upon first puncture attempt in 179 of 180 cases (99.4%)	N/A	N/A	No incidences of dural puncture, bloody tap, or postoperative complications related to epidural cannulation occurred	N/A

Abbreviations: CG, control group; CSE, combined spinal-epidural; LOR, loss-of-resistance; N/A, not applicable; UG, ultrasound group; VAS, visual analog score.
*$P \leq .05$ in statistical assays for significance.

neurologic injury after central neuraxial block range from 0.02% to 0.0009%[45] and would require even more subjects for a definitive RCT or case series.

CONCLUSIONS AND FUTURE DIRECTIONS

Current evidence is sparse and suggests that use of ultrasound for peripheral nerve blocks hastens block performance and onset of block, however onset of surgical anesthesia, and need for conversion to general anesthesia is not significantly affected. There are several limitations inherent to this systematic qualitative review. New technologies, such as ultrasound, must be mastered through practice and shared experience. Adoption therefore often precedes the best evidence of benefit, as many years of trial (and sometimes error) are required before "best" use of a technology is determined. Rapid improvement of the techniques using the new technology over time makes comparisons using older literature difficult. Also, practitioner experience with the new technology will initially be less than with established ones, further confounding many attempts at comparison. Thus, additional well designed RCTs or appropriately performed meta-analyses would be welcome to confirm our impressions.

As block or epidural success rates are high (>90%) with conventional techniques, future RCTs would need to be appropriately large and sufficiently powered in order to examine a potential difference in efficacy as a primary outcome. RCTs for perineural catheters are completely lacking and should be performed with primary outcomes of time required to place the catheter, and success of catheter in terms of need to convert to alternative analgesic technique. Central neuraxial RCTs outside of the obstetric or pediatric population are entirely lacking. Additional epidural studies are needed in all patient populations with meaningful primary outcomes, such as improved analgesia, or fewer failures. Ideally, future epidural studies would blind the subjects and the data collector to group assignment. Large (hundreds to thousands of patients) prospective case series are lacking and would be useful for all techniques to define population rates of efficacy, and complications from use of ultrasound. Generation of such evidence is an ambitious task and may or may not ultimately affect acceptance and popularity of ultrasound. We note that there are no previously published data to show conclusive superiority of neurostimulation in terms of block success or safety, yet this has become a common standard of regional anesthesia practice today. The same analogy may extend to ultrasound. It is conceivable that a difference in block outcome cannot be demonstrated for ultrasound in the hands of the regional anesthesia experts, yet popular preference may ultimately launch ultrasound as the preferred technique.

Finally, several potential patient-oriented benefits may be associated with ultrasound, such as faster block performance, fewer needle passes, and less discomfort and minor side effects from block performance. Additional potential yet poorly defined benefits from ultrasound guidance may include: (1) an increase in the practice of peripheral nerve blocks, even in the hands of the trainees and occasional regional anesthesia practitioners; (2) understanding of why blocks fail as judged by local anesthetic spread; (3) avoidance of an unintentional intravascular injection; (4) avoidance of an unintentional pleural and vascular puncture; (5) early detection of an early intraneural injection; (6) recognition or avoidance of an unintentional intramuscular and intraperitoneal injection; and (7) an understanding of inconsistent motor response associated with electrical stimulation. We encourage future studies which examine and quantify these important patient-oriented and more qualitative outcomes. Although

potentially fruitful, it is important to note that validated instruments to measure patient-oriented outcomes are lacking, and should also be developed in concert.[46]

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