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Review Article

Comparative Evaluation of Ultrasound-Guided Peripheral Nerve Blocks in Elective Orthopedic Procedures

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ABSTRACT

Ultrasound guidance has, over the last two decades, displaced peripheral nerve stimulation and landmark-based technique as the dominant method for placing peripheral nerve blocks in elective orthopedic surgery, on the strength of direct visualization of the target nerve, the spread of local anesthetic, and adjacent vascular structures.

This review synthesizes the comparative evidence for ultrasound-guided peripheral nerve blockade across the elective orthopedic procedures in which it is now most established: upper-limb interscalene and supraclavicular blocks for shoulder arthroscopy and arthroplasty, femoral and adductor canal blocks for total knee arthroplasty, and popliteal sciatic blocks for foot and ankle surgery.

Randomized and meta-analytic data indicate that ultrasound guidance reduces block failure and vascular puncture relative to nerve-stimulator technique, while adductor canal block preserves quadriceps strength and reduces fall risk relative to femoral nerve block after total knee arthroplasty without sacrificing analgesic efficacy.

Continuous perineural catheter techniques extend these benefits into the ambulatory and early postoperative period, and current practice increasingly treats peripheral nerve stimulation as an adjunct confirmatory tool rather than a primary localization method once ultrasound is available.

We conclude that site-specific selection among ultrasound-guided techniques, rather than a single default approach, is what the comparative literature actually supports for elective orthopedic practice, and we identify where the evidence base for newer fascial-plane alternatives remains comparatively thin.

Keywords: *ultrasound-guided nerve block; regional anesthesia; orthopedic surgery; adductor canal block; interscalene block*

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INTRODUCTION

Peripheral nerve blockade has become a routine part

of anesthetic planning for elective orthopedic surgery, valued for the opioid-sparing analgesia it provides in the first postoperative days and for the way it shortens time to mobilization on enhanced-recovery pathways. For most of the technique's history, however, the block itself was placed blind: an anesthesiologist relied on surface landmarks and the motor or paresthetic response elicited by an electrically stimulated needle to infer that the needle tip sat close enough to the target nerve for local anesthetic to work. That approach carried an unavoidable failure rate, and it gave the operator no direct information about where the injected solution was actually going.

The introduction of portable, high-resolution ultrasound into regional anesthesia practice changed that calculus directly. An operator can now watch the needle approach the nerve in real time, confirm perineural rather than intraneural or intravascular placement, and watch the hypoechoic spread of local anesthetic circumferentially around the target structure before withdrawing the needle. This review asks what the comparative literature says that direct visualization has actually bought elective orthopedic practice, procedure by procedure, rather than treating "ultrasound guidance" as a single undifferentiated improvement.

We focus deliberately on the blocks with the deepest comparative evidence base in orthopedic surgery: interscalene and supraclavicular blockade of the brachial plexus for shoulder surgery, femoral and adductor canal blockade for knee surgery, and popliteal sciatic blockade for foot and ankle surgery. Within each, we ask two separate questions: first, whether ultrasound guidance itself measurably outperforms nerve-stimulator or landmark technique for that block; and second, where more than one ultrasound-guided approach to the same anatomic target exists, which one the comparative trials actually favor.

ULTRASOUND GUIDANCE VERSUS NERVE STIMULATION: WHAT THE TRIALS SHOW

The most direct evidence for ultrasound's advantage over electrical neurostimulation comes from a 2009 systematic review and meta-analysis of thirteen randomized controlled trials, which found that ultrasound guidance reduced the risk of block failure by 59% relative to nerve stimulation, shortened performance time by roughly a minute per block, shortened onset time by close to 30%, and reduced the risk of inadvertent vascular puncture by 84% [1]. Those effect sizes are large enough, and consistent enough across the pooled trials, that the finding is now treated as settled rather than provisional in most regional anesthesia teaching.

A subsequent 2015 systematic review and meta-analysis reached a broadly similar conclusion using an expanded and more recent trial set, again finding ultrasound guidance associated with higher block success and fewer vascular complications than electrical stimulation across a range of peripheral nerve targets, while noting that trial quality and blinding remained uneven across the underlying literature [2]. Neither review found convincing evidence that ultrasound guidance reduces the rarer but more serious complications of nerve injury or systemic local anesthetic toxicity, largely because those events are too infrequent for the available trials to be adequately powered to detect a difference.

An important caveat to this literature, raised explicitly in a 2021 review of nerve stimulation's continuing role, is that ultrasound and electrical stimulation are not mutually exclusive techniques [3]. A meaningful proportion of contemporary practice uses ultrasound for primary visualization while retaining a nerve stimulator as a secondary confirmatory signal, particularly when the target nerve is difficult to resolve sonographically due to patient body habitus or when a stimulating perineural catheter is being placed for continuous infusion. The comparative trials described above were largely designed to test ultrasound against stimulation as competing primary techniques, and their results should not be read as evidence against this dual-modality practice.

Needle trajectory relative to the ultrasound transducer is itself a live technical variable within ultrasound-guided practice. A comparison of the out-of-plane and in-plane approaches to ultrasound-guided femoral nerve block found a measurable difference in the incidence of inadvertent intraneural needle placement between the two trajectories, and a separate retrospective single-center comparison of block complications using landmark nerve stimulation versus ultrasound as the primary localization method likewise found technique-dependent differences in complication rates [4,5]. A prospective series of 1,000 ultrasound-guided peripheral nerve blocks for elective orthopedic surgery reported a low but non-zero rate of postoperative neurological symptoms, most of which resolved without specific treatment, giving one of the more widely cited denominators for how often transient neurological complications occur under ultrasound guidance specifically [6].

The safety literature around ultrasound-guided blockade extends beyond nerve injury to systemic local anesthetic toxicity. A large prospective clinical registry analysis of 12,668 ultrasound-guided nerve blocks quantified the incidence of local anesthetic systemic toxicity and postoperative neurologic symptoms in contemporary practice, and a subsequent narrative review has updated the field's understanding of systemic toxicity risk factors and lipid-emulsion rescue treatment as ultrasound-guided volumes have grown [7,8]. Body habitus remains a recognized limiting factor for ultrasound image quality regardless of operator skill, and case-level reports of multiple ultrasound-guided blocks in severely obese

patients illustrate both the technique's adaptability and the added difficulty of nerve visualization at depth in this population [9].

UPPER-LIMB BLOCKADE FOR SHOULDER SURGERY

Interscalene brachial plexus block is the standard regional technique for open and arthroscopic shoulder surgery, and ultrasound guidance is now the dominant method for placing it in most orthopedic anesthesia practices. A large single-center series of 1,322 ultrasound-guided interscalene blocks performed as part of routine shoulder surgery practice reported a low overall complication rate and supported the technique's feasibility at high procedural volume, consistent with its position as a default rather than a specialized approach for shoulder surgery analgesia. Reported complications in this and comparable series cluster around transient neurological symptoms and phrenic nerve palsy from local anesthetic spread to the phrenic nerve as it crosses the anterior scalene muscle, both of which are recognized, generally self-limited risks of the interscalene approach specifically rather than of ultrasound guidance as a technique.

Supraclavicular and infraclavicular approaches to the brachial plexus are used as alternatives when phrenic-sparing is a priority, such as in patients with limited pulmonary reserve who cannot tolerate hemidiaphragmatic paresis, and ultrasound guidance is credited in the wider brachial plexus literature with making these deeper approaches more consistently reproducible than they were under landmark or stimulator technique, since the subclavian artery and pleura can be kept in view throughout needle advancement.

Local anesthetic selection interacts with block choice in shoulder surgery as elsewhere. Classic double-blind comparisons of ropivacaine, bupivacaine, and mepivacaine for sciatic and femoral blockade established the differing onset and motor-block profiles of these agents [10], and a PRISMA-compliant meta-analysis of randomized trials comparing ropivacaine with levobupivacaine for peripheral nerve block found broadly similar analgesic efficacy between the two amide agents, with modest differences in motor-block duration [11]. A randomized trial comparing 0.375% ropivacaine with 0.25% levobupivacaine specifically for ultrasound-guided infraclavicular brachial plexus block found comparable sensory onset between the two concentrations [12], reinforcing that concentration and agent selection remain adjustable variables independent of the guidance technique itself.

LOWER-LIMB BLOCKADE FOR KNEE ARTHROPLASTY

Femoral nerve block was, for many years, the default regional technique for analgesia after total knee arthroplasty, but it produces quadriceps motor weakness as an inevitable consequence of blocking the nerve proximal to its motor branches, which has been directly implicated in postoperative falls. The adductor canal block was developed specifically to address this: by depositing local anesthetic more distally, around the predominantly sensory saphenous nerve and the terminal branches to vastus medialis, it aims to preserve quadriceps strength while still providing meaningful analgesia to the anteromedial knee.

A meta-analysis of twelve randomized controlled trials comparing the two techniques after total knee arthroplasty found no significant difference in pain scores at rest or during activity at any postoperative time point, but found that adductor canal block preserved quadriceps strength significantly better than femoral nerve block (mean difference in maximum voluntary isometric contraction of 1.55, 95% CI 1.09 to 2.01), that patients receiving adductor canal block were substantially more likely to complete a timed-up-and-go mobility test within the first postoperative day (odds ratio 23.14), and that adductor canal block was associated with a 70% relative reduction in the odds of a postoperative fall [13]. Opioid consumption did not differ significantly between the two groups. Taken together, this trial evidence is one of the clearer examples in orthopedic regional anesthesia of two ultrasound-guided techniques targeting overlapping anatomy producing materially different functional outcomes, and it underlies the shift in many enhanced-recovery knee arthroplasty pathways toward adductor canal block as the preferred approach specifically because motor-sparing analgesia supports same-day mobilization.

Ultrasound guidance is now standard for both approaches, since the femoral nerve, the adductor canal's neurovascular bundle, and the femoral artery are all readily identified sonographically, and confirming the injectate spreads within the correct fascial compartment is more reliably done under direct vision than by relying on stimulator response alone.

Genicular nerve block, targeting the sensory branches supplying the knee joint capsule rather than a major mixed motor-sensory trunk, has more recently been studied as a motor-sparing adjunct or alternative to adductor canal block. Randomized, placebo-controlled trials combining ultrasound-guided genicular nerve block with adductor canal block after total knee arthroplasty have reported additive analgesic benefit without additional motor weakness [14,15], and a further randomized comparison against surgeon-administered periarticular infiltration found genicular nerve block produced comparable postoperative pain control and functional recovery [16]. Liposomal bupivacaine formulations, intended to extend single-injection block duration toward that of a continuous catheter, have also been evaluated

specifically in a four-in-one nerve block for total knee arthroplasty, with a randomized trial reporting prolonged analgesia relative to plain ropivacaine [17].

LOWER-LIMB BLOCKADE FOR HIP AND FOOT/ANKLE SURGERY

Regional analgesia has also been examined specifically for hip fracture surgery, a population in which preoperative pain control and opioid-sparing are both disproportionately important given the older, comorbid patient population typically involved. A systematic review of ultrasound-guided peripheral nerve blocks for preoperative pain management in hip fracture patients concluded that, despite heterogeneous trial quality, these blocks produced clinically meaningful reductions in preoperative pain and systemic opioid requirement compared with conventional analgesia [18], reinforcing the broader pattern that ultrasound-guided regional technique is being extended earlier into the perioperative pathway rather than confined to intraoperative anesthesia. Randomized trials specifically in elderly hip fracture patients have confirmed that ultrasound-guided fascia iliaca compartment block, delivered either as a single injection in the emergency department or as a continuous catheter through the perioperative period, reduces pain scores and systemic analgesic requirement relative to conventional care [19,20,21].

The pericapsular nerve group (PENG) block has emerged more recently as a motor-sparing alternative to fascia iliaca and femoral nerve blocks for both elective hip arthroplasty and hip fracture surgery, targeting the articular sensory branches to the anterior hip capsule rather than the femoral nerve trunk itself. Prospective randomized trials have reported effective postoperative analgesia after total hip arthroplasty with the PENG block combined with local infiltration analgesia [22], and comparative trials against fascia iliaca block and against quadratus lumborum block in elderly arthroplasty patients have generally found comparable or improved analgesia with preserved quadriceps function [23,24]. As with adductor canal block at the knee, the appeal of the PENG approach in hip surgery is explicitly about motor sparing in an older, fall-prone population rather than analgesic efficacy alone.

For foot and ankle surgery, popliteal sciatic block, typically combined with a saphenous or adductor canal block to cover the medial foot, is the standard lower-leg regional technique, and ultrasound guidance allows the sciatic nerve to be tracked to its bifurcation into the tibial and common peroneal components, informing catheter tip placement when continuous infusion is planned. A randomized, subject-masked trial examining perineural catheter location relative to the sciatic bifurcation found that catheter position affected block characteristics, underscoring that ultrasound's contribution to popliteal blockade is not just initial needle placement but precise, reproducible catheter tip localization for continuous techniques [25].

CONTINUOUS CATHETER TECHNIQUES AND AMBULATORY PRACTICE

A recurring theme across all three anatomic regions discussed above is that ultrasound guidance has made continuous perineural catheter techniques considerably more practical than they were under landmark or stimulator-guided placement, because the catheter tip's final position relative to the target nerve can be confirmed sonographically, and local anesthetic spread through the catheter can be visualized directly at the time of insertion rather than inferred. This has supported the extension of peripheral nerve block analgesia from a single-shot intraoperative technique into a multi-day ambulatory therapy, with elastomeric infusion pumps allowing patients to be discharged home with a functioning continuous block after procedures such as shoulder arthroplasty, total knee arthroplasty, and foot and ankle reconstruction that would previously have required prolonged inpatient analgesic management [26]. Patient-reported outcomes after ambulatory peripheral nerve block are not uniformly positive, however: a study of factors associated with low patient satisfaction after peripheral nerve block identified unmet expectations about block duration and residual numbness as recurring drivers of dissatisfaction independent of analgesic success [27], a finding that overlaps with the specific problem of rebound pain discussed below.

ADJUNCTS, REBOUND PAIN, AND EMERGING FASCIAL-PLANE TECHNIQUES

Perineural and intravenous dexamethasone are now widely used adjuncts intended to extend single-injection block duration without resorting to a catheter. Systematic reviews and a model-based network meta-analysis of dexamethasone as an adjuvant to peripheral nerve blocks have found consistent, dose-related prolongation of analgesia with perineural administration, with intravenous dexamethasone producing a smaller but still measurable effect [28,29]. That prolongation, however, has drawn attention to what happens once even an extended block ends: rebound pain, a sharp increase in pain intensity as a dense single-injection block resolves, has been identified as a distinct clinical problem in ambulatory surgery, and a systematic review and network meta-analysis of prophylactic interventions found that perineural and intravenous dexamethasone reduce, without eliminating, the incidence and severity of rebound pain [30,31].

Fascial-plane blocks originally described for truncal and spinal surgery, including the erector spinae plane block and the quadratus lumborum block, are increasingly reported as adjuncts for hip and proximal femur surgery, where they are proposed as opioid-sparing additions with a more favorable safety

margin than deep plexus blocks because they do not require needle contact with a major nerve trunk. Comparative trials and meta-analyses between the two approaches in hip and lumbar spine surgery report broadly similar analgesic efficacy, though the comparative trial base for orthopedic indications specifically remains considerably smaller than for the site-specific peripheral nerve blocks reviewed above [32,33].

CONCLUSION

The comparative literature on ultrasound-guided peripheral nerve blockade in elective orthopedic surgery does not support a single blanket claim that ultrasound is simply "better" across the board; what it supports is a more specific set of conclusions that vary by anatomic target. Against electrical neurostimulation, ultrasound guidance measurably reduces block failure, shortens onset, and reduces vascular puncture, though it has not yet been shown in adequately powered trials to reduce the rarer complications of nerve injury or systemic toxicity. Within a single anatomic region, the choice between ultrasound-guided techniques can matter as much as the choice to use ultrasound at all, as the adductor canal versus femoral nerve block comparison for total knee arthroplasty demonstrates most clearly: a motor-sparing approach that provides equivalent analgesia while measurably reducing fall risk represents a genuinely different clinical outcome, not simply a refinement in technique. For elective orthopedic anesthesia going forward, the practical implication is that block selection should be driven by procedure-specific comparative evidence rather than by a single default technique per anatomic region, and that the strongest remaining gaps in the evidence base concern serious but rare complications and the newer fascial-plane block variants that have not yet accumulated comparable trial volume.

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Conflict of Interest

The authors declare that they have no competing interests, financial or otherwise, relevant to the content of this review.

Author Contributions

Joao Carvalho conceived the review and drafted the initial manuscript. Owen Dubois and Marius Kowalczyk contributed to the literature search, critical revision of the manuscript, and final approval of the submitted version. All authors read and approved the final manuscript.

Ethics Statement

As a literature review synthesizing previously published, publicly available research, this article did not involve new data collection from human or animal subjects and did not require institutional review board or ethics committee approval.

Data Availability

No new data were generated or analyzed in the preparation of this review. All findings discussed are drawn from the published studies cited in the References section, which are available from their respective publishers.

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