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ORIGINAL ARTICLE

A randomized comparison of long-axis and short-axis imaging for in-plane ultrasound-guided popliteal-sciatic perineural catheter insertion

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Abstract
Purpose Ultrasound-guided long-axis in-plane sciatic perineural catheter insertion has been described but not validated. For the popliteal-sciatic nerve, we hypothesized that a long-axis in-plane technique, placing the catheter parallel and posterior to the nerve, results in faster onset of sensory anesthesia compared to a short-axis in-plane technique.
Methods Preoperatively, patients receiving a popliteal-sciatic perineural catheter were randomly assigned to either the long-axis or short-axis technique. Mepivacaine 2 % was administered via the catheter following insertion. The primary outcome was time to achieve complete sensory anesthesia. Secondary outcomes included procedural time, onset time of motor block, and pain on postoperative day 1.
Results Fifty patients were enrolled. In the long-axis group ($n = 25$), all patients except 1 (4 %) had successful catheter placement per protocol. Two patients (8 %) in the long-axis group and 1 patient (4 %) in the short-axis group ($n = 25$) did not achieve sensory anesthesia by 30 min and were withdrawn. Seventeen of 24 (71 %) and 17 of 22 (77 %) patients in the short-axis and long-axis groups, respectively, achieved the primary outcome of complete sensory anesthesia ($p = 0.589$). The short-axis group ($n = 17$) required a median (10th–90th ‰) of 18.0 (8.4–30.0) min compared to 18.0 (11.4–27.6) min for the long-axis group ($n = 17$, $p = 0.208$) to achieve complete sensory anesthesia. Procedural time was 6.5 (4.0–12.0) min for the short-axis and 9.5 (7.0–12.7) min for the long-axis ($p < 0.001$) group. There were no statistically significant differences in other secondary outcomes.
Conclusion Long-axis in-plane popliteal-sciatic perineural catheter insertion requires more time to perform compared to a short-axis in-plane technique without demonstrating any advantages.

Keywords Continuous peripheral nerve block · Perineural catheter · Ultrasound-guided regional anesthesia · Sciatic nerve block · Foot and ankle surgery

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Introduction

Continuous popliteal-sciatic nerve blocks provide effective postoperative analgesia for foot and ankle surgery [1–3]. Sciatic nerve localization and perineural catheter insertion techniques in the popliteal fossa have been previously described using electrical stimulation and ultrasound guidance [4, 5]. When employing ultrasonography, the target nerve can be imaged in short- or long-axis view, combined with simultaneous in- or out-of-plane needle guidance [6]. Previous clinical trials have demonstrated advantages in procedural performance time and catheter insertion success in favor of ultrasound using a short-axis

in-plane approach when compared to the validated stimulating catheter technique for lower-extremity catheters [7, 8]; however, for popliteal-sciatic perineural catheters, stimulation-guided catheters may produce greater analgesia [9]. A long-axis in-plane ultrasound-guided technique, while challenging [10], theoretically places the catheter in the same position and orientation as a stimulating catheter technique [6]. For single-injection infragluteal sciatic nerve blocks, this long-axis in-plane technique has been shown to have faster procedural time [11] and faster anesthetic onset [12] compared to other approaches. Similarly, femoral perineural catheters inserted with an ultrasound-guided long-axis in-plane approach demonstrate faster onset of sensory anesthesia but increased procedural time compared to a short-axis in-plane approach [13]. The long-axis in-plane insertion has been reported for sciatic perineural catheters [14] but has not yet been validated; therefore, the benefits of this technique for continuous sciatic nerve block, if any, remain unknown. We designed the present study to test the hypothesis that a long-axis in-plane technique for popliteal-sciatic perineural catheter insertion results in faster onset of sensory anesthesia when compared to a short-axis in-plane technique.

Materials and methods

The Institutional Review Board (Stanford University, Stanford, CA, USA) and Veterans Affairs Research and Development Committee (VA Palo Alto Health Care System, Palo Alto, CA, USA) approved the study, which was prospectively registered at http://www.clinicaltrials.gov (NCT01459523). Patients eligible for study enrollment were 18 years and older and scheduled for unilateral foot or ankle surgery with a continuous popliteal-sciatic nerve block for postoperative analgesia. Patients were excluded for the following conditions: chronic opioid use, active illicit substance abuse, additional surgical sites beyond the extremity intended for catheter placement, inability to understand study protocol, refusal of the infusion pump/catheter system, insulin-dependent diabetes mellitus, neuropathy of any etiology in the affected extremity, pregnancy, known contraindication to study medications or regional anesthesia, hepatic or renal failure, or inability to communicate with the investigators and hospital staff.

Protocol

Following written informed consent, patients were randomly assigned to either the long-axis in-plane (LAX) or short-axis in-plane (SAX) group using a computer-generated randomization sequence (http://www.randomizer.org). Perineural catheters were placed by an experienced attending regional anesthesiologist or by a regional anesthesiology and acute pain medicine fellow directly supervised by the attending. The research assistant performing assessments and the patients were blinded to group assignment.

Before the procedure, a peripheral intravenous (IV) catheter, standard noninvasive monitors, and face mask or nasal cannulae for oxygen delivery were applied to the patients. Patients were placed in prone position with the knee in slight flexion. Intravenous midazolam and fentanyl were titrated as needed to achieve an adequate comfort level for the patient while maintaining verbal responsiveness. The areas for ultrasound scanning and needle/catheter insertion were shaved if needed, sterilely prepared with chlorhexidine gluconate and isopropyl alcohol (ChloraPrep One-Step; CareFusion, Leawood, KS, USA), and covered with a clear fenestrated sterile drape. A 13–6 MHz linear array ultrasound transducer (HFL38; FUJIFILM SonoSite M-Turbo, Bothell, WA, USA) in a sterile sleeve was used for all procedures.

Long-axis in-plane technique

The long-axis popliteal-sciatic perineural catheters were inserted using a previously described technique with minor modifications [14]. The sciatic nerve was initially identified in short axis cephalad to the popliteal crease, before its bifurcation to the tibial and common peroneal nerves in the popliteal fossa. The ultrasound transducer was subsequently rotated 90° to image the sciatic nerve in long-axis view. Lidocaine 1 % was used to anesthetize the skin 1 cm caudad to the transducer and along the expected trajectory of the placement needle. An uninsulated, 8.9-cm, 17 gauge, Tuohy tip needle (Arrow FlexTip Plus; Teleflex Medical, Research Triangle Park, NC, USA) was inserted in-plane, with the transducer positioned parallel to the nerve, and guided toward the target nerve cephalad to the initial needle entry site.

Once the needle tip was visualized directly posterior to the target nerve, 10 ml 5 % dextrose in water was injected. Subsequently, under ultrasound imaging by an assistant, a 19 gauge flexible epidural-type catheter (Arrow FlexTip Plus; Teleflex Medical) was inserted through the needle and advanced 3–5 cm beyond the needle tip posterior to the nerve (Fig. 1). After removal of the placement needle, the final catheter tip position was assessed by injecting 0.5 ml air via the catheter under ultrasound with visualization of hyperechoic air bubbles in proximity to the target nerve (the "air test") [15]. The catheter was secured using a liquid adhesive and clear occlusive dressings and anchored with a stabilization device (StatLock®; Bard Medical,

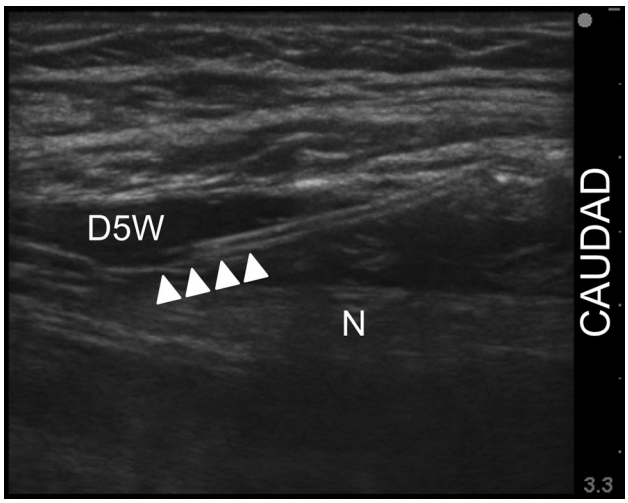

Fig. 1 Long-axis image of the sciatic nerve in the popliteal fossa with in-plane perineural catheter inserted. *N* = sciatic nerve, *D5W* = 5 % dextrose in water injectate, *arrowheads* indicate distal end of catheter

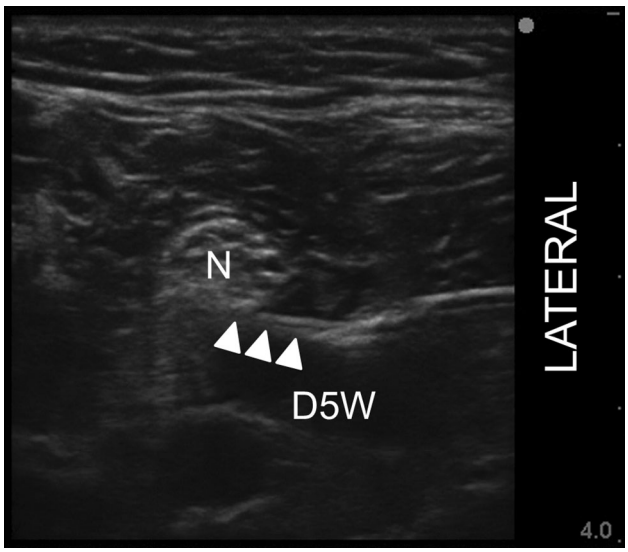

Fig. 2 Short-axis image of the sciatic nerve in the popliteal fossa with in-plane perineural catheter inserted. *N* = sciatic nerve, *D5W* = 5 % dextrose in water injectate, *arrowheads* indicate distal end of catheter

Covington, GA, USA). The catheter insertion site was covered before assessment by the research assistant to maintain blinding. Following negative aspiration for blood, 30 ml mepivacaine 2 % with epinephrine 2.5 μg/ml was injected incrementally via the catheter.

Short-axis in-plane technique

The short-axis popliteal-sciatic perineural catheters were inserted using a previously described technique but with minor modifications [7, 9]. The sciatic nerve was identified in short-axis view within the popliteal fossa before its bifurcation. Lidocaine 1 % was used to anesthetize the skin 1 cm lateral to the transducer and along the expected trajectory of the placement needle. The same type of placement needle used in the LAX group was inserted in-plane, with the transducer perpendicular to the nerve, and guided toward the target nerve.

Once the needle tip was visualized directly anterior to the target nerve, 10 ml 5 % dextrose in water was injected. Subsequently, under ultrasound imaging by an assistant, the same type of catheter used in the LAX group was inserted through the needle and advanced 3–5 cm beyond the needle tip anterior to the nerve (Fig. 2). After confirming final catheter tip position using the "air test," the catheter was dressed and bolused with the same local anesthetic used in the LAX group.

Patients were withdrawn from the study if catheter placement required more than the time allotted in the protocol (30 min); however, patients remained eligible for nerve blockade using a technique preferred by the regional anesthesiologist.

Primary outcome

The primary outcome was onset time (minutes) for complete sensory anesthesia. Time measurements started immediately after the mepivacaine bolus injection was completed. A blinded research assistant performed sensory assessments using pinprick sensation [16, 17] in the dorsal and plantar aspects of the affected foot every 3 min for up to 30 min (0 = no change from baseline; 1 = diminished pinprick sensation; 2 = no pinprick sensation, considered complete sensory anesthesia). If patients did not have complete sensory anesthesia at 30 min, catheter placement was considered unsuccessful, and the patients were withdrawn from the study. However, perineural catheters were maintained and reassessed postoperatively for possible clinical use or replacement.

Secondary outcomes

The following measurements were recorded during the procedure: catheter placement time (minutes) starting from first contact between the ultrasound transducer and patient's skin to removal of the placement needle after catheter insertion, number of needle passes (defined as placement needle withdrawal >1 cm with redirection), total dose of IV fentanyl (μg), and number of vascular punctures (defined as aspiration or presence of blood in the placement needle). Following catheter insertion, procedure-related discomfort was rated using a numeric rating scale of 0–10 (0 = no discomfort; 10 = worst discomfort imaginable). A blinded research assistant performed motor

assessments by asking patients in the supine position to perform active plantar- and dorsiflexion of the foot against resistance every 3 min for up to 30 min (0 = no change from baseline; 1 = diminished active contraction; 2 = no active contraction, considered complete motor block).

All patients received general anesthesia or monitored anesthesia care at the discretion of the anesthesiologists as appropriate for the surgery. Administration of intravenous opioid (e.g., μg fentanyl or mg morphine) during the surgery and in the postanesthesia care unit was not regulated, but the total doses given were recorded. On completion of the surgery, a portable elastomeric infusion device (ON-Q C-bloc with ONDEMAND; I-Flow Corporation, Lake Forest, CA, USA) was connected to each perineural catheter, and an infusion of ropivacaine 0.2 % was started (basal rate of 6 ml/h; patient-controlled bolus of 5 ml; 30 min lockout interval). All patients were prescribed a combination of oral oxycodone and acetaminophen for moderate breakthrough pain, and patients admitted to the hospital were additionally prescribed intravenous morphine or hydromorphone for severe breakthrough pain. Ambulatory surgery patients were provided written and verbal instructions regarding the infusion device and prescription analgesics, as well as the contact information for the on-call Regional Anesthesiologist, before discharge home.

On postoperative day 1, a blinded research assistant either evaluated patients in-person if hospitalized or by phone if ambulatory and collected the following information: average and worst postsurgical pain (Numeric Rating Scale 0–10), opioids consumed (mg oxycodone and/or IV morphine), number of awakenings caused by pain, satisfaction with pain control using a Likert scale (0 = not at all satisfied; 10 = extremely satisfied), catheter site leakage, and subjective rating of numbness (0 = normal sensation; 10 = completely insensate). After data collection, the Acute Pain Medicine and Regional Anesthesiology team continued to clinically evaluate all inpatients daily until removal of perineural catheters or discharge from the hospital; ambulatory surgery patients were followed by telephone. Outpatient perineural catheters were removed by the patients themselves following exhaustion of the infusion device reservoir or sooner if requested by the patient or referring surgeon.

Sample size estimate

The primary outcome of the study was onset time of complete sensory anesthesia. To achieve two-sided type 1 error protection of 0.05, power = 80 %, and clinical relevance determined as a mean difference of 10 min between the study groups, 21 patients were required in each group based on previously reported onset time for ultrasound-guided popliteal-sciatic nerve blocks with mepivacaine [16]. In anticipation of potential dropouts or protocol violations, 25 patients were enrolled in each group.

Statistical analysis

An investigator blinded to patient group assignment performed all statistical analyses (NCSS-PASS Statistical Software, Kaysville, UT, USA). Normality of distribution was determined for all scale variables. Single comparisons were performed using Student's t test for normally distributed data; the Mann–Whitney U test was applied for continuous data in distributions other than normal. For comparisons of survival distributions, the log-rank test was used in the case of progressive censoring or Gehan–Wilcoxon test in the case of no censoring. The Z test or Barnard exact test ($n < 5$ in any field) was used for comparisons of categorical data. A two-sided $p < 0.05$ was considered statistically significant for the primary outcome.

Results

Assessment of 67 patients was needed to enroll and randomly assign 50 patients the two study groups (11 patients did not meet the criteria for enrollment, 3 patients were not enrolled because of time constraints, and 3 patients declined to participate). The two groups shared similar demographic and morphometric characteristics (Table 1). In the LAX group ($n = 25$), all patients except 1 (4 %) had successful catheter placement per protocol, and 2 patients (8 %) did not achieve sensory anesthesia by 30 min and were withdrawn. In the SAX group ($n = 25$), all patients' catheters were placed per protocol but 1 patient (4 %) did not achieve complete sensory anesthesia by 30 min and was withdrawn. All patients, including those who did not remain in the study, were assessed postoperatively and determined to have successful block characteristics. Subsequently, their perineural catheters were continued for postoperative analgesia. Four patients in the SAX group and 7 patients in the LAX group were planned inpatient admissions. On postoperative day 1, 21 of 22 patients in the LAX group and 19 of 24 patients in the SAX group were successfully contacted to provide follow-up data. There were no adverse events related to study procedures.

Primary outcome

Seventeen of 24 (71 %) and 17 of 22 (77 %) in the SAX and LAX groups, respectively, achieved complete sensory anesthesia ($p = 0.589$). The SAX perineural catheter insertion technique ($n = 17$) required a median (10th–90th ‰) of 18.0 (8.4–30.0) min compared to 18.0

Table 1 Morphometric data and procedural information

	SAX ($n = 24$)	LAX ($n = 22$)
Age (years)	54 (30–70)	58 (29–77)
Female/male (n)	2/24	3/19
ASA physical status	2 (1–3)	3 (2–3)
Height (cm)	175 (170–184)	174 (163–189)
Weight (kg)	91 (78–120)	90 (67–125)
BMI (kg/m^2)	30 (25–38)	32 (24–42)
Attending/fellow placement (n)	1/23	1/21
Surgical procedure		
Digit amputation/neuroma excision (n)	2	0
Foot fusion/ORIF/osteotomy/ arthroplasty (n)	14	10
Achilles tendon repair (n)	3	3
Ankle fusion/ORIF/ arthrotomy (n)	5	8
Ankle arthroscopic stabilization (n)	0	1

Values are reported as median (10th–90th ‰) or number of patients (n), as indicated

LAX long-axis in-plane group, *SAX* short-axis in-plane group, *ASA* American Society of Anesthesiologists. There were no statistically significant differences between groups

(11.4–27.6) min for the LAX technique ($n = 17$, $p = 0.208$) to achieve complete sensory anesthesia.

Secondary outcomes

Time required to perform SAX procedures was 6.5 (4.0–12.0) min compared to 9.5 (7.0–12.7) min for LAX procedures ($p < 0.001$). There was one vascular puncture in the LAX group and none in the SAX group. There were no differences in number of needle passes, fentanyl administered during catheter insertion, or procedure-related pain (Table 2).

SAX ($n = 24$) achieved onset of sensory anesthesia in 6.0 (3.0–15.0) min compared to 6.0 (3.0–14.1) for LAX ($n = 22$; $p = 0.783$). SAX ($n = 22$) achieved onset of motor block in 15.0 (6.0–24.0) min compared to 15.0 (3.0–27.0) for LAX ($n = 19$; $p = 0.929$). In the SAX group, 9/24 (37.5 %) achieved complete motor block within the testing period compared to 8/22 (36.4 %) for LAX ($p > 0.999$); SAX required 18.0 (12.0–30.0) min, and LAX required 27.0 (6.0–30.0) min ($p = 0.351$). Total dose of opioid administration during the surgery and in the PACU was similar: 100 (0–250) and 150 (55–290) μg IV fentanyl for SAX and LAX, respectively ($p = 0.165$); and 0.0 (0.0–2.5) and 0.0 (0.0–3.6) mg IV morphine for SAX and LAX, respectively ($p = 0.355$). Total opioid consumption in the first 24 h after surgery was similar: 15.0 (0.0–35.0) and 15.0 (0.0–40.0) mg oral oxycodone for SAX and LAX, respectively ($p = 0.382$); and 0.0 (0.0–30.0) and 0.0 (0.0–40.0) mg IV morphine for SAX ($n = 4$) and LAX ($n = 7$), respectively ($p = 0.730$). No statistically significant differences were found in leakage, dislodgement, numbness, pain scores, awakenings from pain, or patient satisfaction on postoperative day 1 (Table 3).

Table 2 Secondary outcomes related to perineural catheter placement

	SAX ($n = 24$)	LAX ($n = 22$)	P value
Number of needle passes	1 (1–2)	1 (1–2)	0.852
Fentanyl (μg)	100 (50–150)	62 (32–150)	0.106
Procedural pain (NRS 0–10)	1 (0–4)	1 (0–4)	0.918

Values are reported as median (10th−90th ‰)

NRS Numeric Rating Scale

Table 3 Secondary outcomes on postoperative day 1

	SAX ($n = 21$)	LAX ($n = 19$)	P value
Fluid leakage at site (n)	3	7	0.108
Dislodged (n)	1	3	0.284
Numbness (Likert 0–10)	5 (0–10)	5 (0–10)	0.843
Average pain (NRS 0–10)	2.0 (0.0–9.0)	3.0 (0.0–7.8)	0.331
Worst pain (NRS 0–10)	8.0 (0.0–10.0)	8.0 (1.2–10.0)	0.230
Awakenings from pain (n)	0 (0–8)	3 (0–10)	0.222
Satisfaction (Likert 0–10)	10 (3–10)	8 (0–10)	0.133

Values are reported as median (10th–90th ‰) or number of patients (n), as indicated

NRS Numeric Rating Scale

Discussion

For ultrasound-guided popliteal-sciatic perineural catheter placement, a long-axis in-plane technique does not result in a statistically significant difference in onset time to complete sensory anesthesia and needs more time to perform compared to the short-axis in-plane technique. The present study is the first randomized clinical trial to evaluate popliteal-sciatic catheters placed using the long-axis in-plane technique versus a previously validated ultrasound-guided technique.

Catheter tip location and onset time

The ultrasound-guided long-axis in-plane technique should replicate the catheter tip placement location and orientation of the stimulating catheter technique with its potential advantages of cephalad spread of local anesthetic, catheter

position parallel to the nerve, and superior analgesia [9] combined with high placement success rates and short procedural times associated with ultrasound-guided techniques [7]. However, the present study did not result in a statistically significant decrease in onset time. This finding differs from the Tammam [12] study of single-injection infragluteal sciatic nerve blocks and may have been influenced by a couple of factors. First, the injection of dextrose in water solution, which is not typically part of a single-injection technique and is used for catheter placement only, may have affected catheter tip location and subsequent local anesthetic spread. Second, the volume of the local anesthetic bolus injected via the catheter after placement may have negated any difference in catheter tip location. Third, sciatic nerve histology and selected injection sites along the nerve may affect block characteristics, with distal nerve sites offering potential advantages in onset time for single-injection block [16, 18]. Further studies comparing perineural catheter placement at different sites along the sciatic nerve are needed to delineate the potential effects of nerve anatomy and catheter position on perineural infusion characteristics.

Catheter placement time

For single-injection ultrasound-guided infragluteal sciatic nerve block, the long-axis in-plane technique was found to have the fastest procedural time [11]. In contrast, the LAX group in the present study required 3 min more for procedure completion compared to the SAX group. In contrast to the single-injection technique, the challenge of keeping the nerve, needle, and catheter in the same plane may be potentially magnified during the long-axis in-plane catheter insertion technique [6], especially at greater target depths. The 3 min median difference in procedural time is arguably not clinically relevant, and there may be a role for both ultrasound-guided perineural catheter insertion techniques in clinical practice. In certain circumstances, the long-axis in-plane approach may provide select advantages (e.g., decreasing the distance traveled from skin to target nerve in patients at higher risk for bleeding).

Through-the-needle versus through-the-catheter bolus

For the purposes of studying anesthetic onset and catheter placement accuracy, we elected to deliver the local anesthetic bolus via the catheter rather than through the needle [7, 9]. In the present study, the two study groups had similar numbers of patients who did not achieve the primary outcome. The lack of complete sensory anesthesia in these patients within the fixed study assessment interval may be explained by sciatic nerve anatomy and not necessarily catheter tip position. Since the initiation of the present study, a "common paraneural sheath" has been described for the sciatic nerve [19–21]. Injection of local anesthetic into this sheath results in decreased onset time for single injection; however, this technique has not been studied for perineural catheter placement. In the present study, both the LAX and SAX perineural catheters were deliberately placed *outside* the paraneural sheath. The presence of the paraneural sheath may delay absorption of local anesthetic and potentially prolong onset time by creating a "barrier" between the injectate and the nerves. Further studies examining the effects of continuous infusions within and outside the paraneural sheath are needed to delineate block characteristics and optimal catheter tip positioning.

Catheter placement "success"

Catheters in both groups were placed per protocol with the exception of one catheter in the long-axis group. Although two patients in the LAX group and one patient in the SAX group were withdrawn for not achieving sensory anesthesia within 30 min, all four of these catheter placements produced a clinical sciatic nerve block postoperatively and were continued for analgesic purposes. Five patients in the LAX group and seven patients in the SAX group did not achieve complete sensory anesthesia (the primary outcome) despite initial onset of local anesthetic effects. Onset time for sciatic nerve blocks can be variable, and deliberate placement of catheters outside the paraneural sheath [20] combined with our defined time limit of 30 min per protocol may have resulted in a higher "failure" rate. These findings provide further argument against extrapolating the results of one perineural catheter insertion study to other target nerve locations [22, 23].

Study limitations

The main limitation of this study is the potential for type 2 error. Because the number of patients who did not achieve the primary outcome of complete sensory anesthesia was higher than expected, the study was not sufficiently powered to detect a potential difference in onset time of 10 min between the LAX and SAX groups. The 10-min difference between the study groups was chosen because we assumed that a clinically superior catheter placement technique would demonstrate a clear advantage in onset time. Because this study was designed to demonstrate superiority, the lack of statistically significant difference between the LAX and SAX groups should not be interpreted as equivalence. With ultrasound guidance, the visualization of conventional perineural catheters remains challenging, and techniques to infer catheter tip position are often employed [24]. In the present study, all catheter placements were performed by either regional anesthesia and acute pain

medicine fellows or trained attending staff. Therefore, the results of the present study may not be generalizable to every practice. Finally, this study was not truly double blinded. The study patients and the outcome assessor were blinded, and the statistical analysis was performed before unmasking group identity; however, the practitioners performing study procedures were not blinded.

In summary, popliteal-sciatic catheter placement using an ultrasound-guided long-axis in-plane technique requires a longer procedure time but does not result in a faster onset time nor demonstrate additional clinical advantages compared to a previously validated short-axis in-plane technique.

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