Title

Proximal Versus Distal Continuous Adductor Canal Blocks

Journal

Anesthesia & Analgesia, 127(1)

ISSN

0003-2999

Authors

Sztain, Jacklynn F

Khatibi, Bahareh

Monahan, Amanda M

et al.

Publication Date

2018-07-01

DOI

10.1213/ane.0000000000003422

Peer reviewed

Proximal Versus Distal Continuous Adductor Canal Blocks: Does Varying Perineural Catheter Location Influence Analgesia? A Randomized, Subject-Masked, Controlled Clinical Trial

Jacklynn F. Sztain, MD,* Bahareh Khatibi, MD,* Amanda M. Monahan, MD,† Engy T. Said, MD,* Wendy B. Abramson, MD,* Rodney A. Gabriel, MD, MAS,*‡ John J. Finneran IV, MD,*‡ Richard H. Bellars, MD,* Patrick L. Nguyen, MD,* Scott T. Ball, MD,§ Francis B. Gonzales, MD,§ Sonya S. Ahmed, MD,§ Michael C. Donohue, PhD,‖ Jennifer A. Padwal, BS,¶ and Brian M. Ilfeld, MD, MS (Clinical Investigation)*‡

BACKGROUND: A continuous adductor canal block provides analgesia after surgical procedures of the knee. Recent neuroanatomic descriptions of the thigh and knee led us to speculate that local anesthetic deposited in the distal thigh close to the adductor hiatus would provide superior analgesia compared to a more proximal catheter location. We therefore tested the hypothesis that during a continuous adductor canal nerve block, postoperative analgesia would be improved by placing the perineural catheter tip 2–3 cm cephalad to where the femoral artery descends posteriorly to the adductor hiatus (distal location) compared to a more proximal location at the midpoint between the anterior superior iliac spine and the superior border of the patella (proximal location).

METHODS: Preoperatively, subjects undergoing total knee arthroplasty received an ultrasound-guided perineural catheter inserted either in the proximal or distal location within the adductor canal in a randomized, subject-masked fashion. Subjects received a single injection of lidocaine 2% via the catheter preoperatively, followed by an infusion of ropivacaine 0.2% (8 mL/h basal, 4 mL bolus, 30 minutes lockout) for the study duration. After joint closure, the surgeon infiltrated the entire joint using 30 mL of ropivacaine (0.5%), ketorolac (30 mg), epinephrine (5 μg/mL), and tranexamic acid (2 g). The primary end point was the median level of pain as measured on a numeric rating scale (NRS) during the time period of 8:00 AM to 12:00 PM the day after surgery.

RESULTS: For the primary end point, the NRS of subjects with a catheter inserted at the proximal location (n = 24) was a median (10th, 25th–75th, 90th quartiles) of 0.5 (0.0, 0.0–3.2, 5.0) vs 3.0 (0.0, 2.0–5.4, 7.8) for subjects with a catheter inserted in the distal location (n = 26; P = .011). Median and maximum NRSs were lower in the proximal group at all other time points, but these differences did not reach statistical significance. There were no clinically relevant or statistically significant differences between the treatment groups for any other secondary end point, including opioid consumption and ambulation distance.

CONCLUSIONS: For continuous adductor canal blocks accompanied by intraoperative periarticular local anesthetic infiltration, analgesia the day after knee arthroplasty is improved with a catheter inserted at the level of the midpoint between the anterior superior iliac spine and the superior border of the patella compared with a more distal insertion closer to the adductor hiatus. (Anesth Analg 2018;127:240–6)

KEY POINTS

- **Question:** Neuroanatomy of the thigh and knee has led to speculation that local anesthetic deposited in the distal thigh close to the adductor hiatus would provide superior analgesia compared to a more proximal location, yet this supposition remains unexamined.
- **Findings:** For continuous adductor canal blocks, analgesia the day after knee arthroplasty is improved with a catheter inserted at the level of the midpoint between the anterior superior iliac spine and the superior border of the patella, compared with a more distal insertion closer to the adductor hiatus.
- **Meaning:** For perineural local anesthetic infusion within the adductor canal, a more proximal catheter insertion site improved analgesia the day after knee arthroplasty compared with a more distal insertion point.

From the *Department of Anesthesiology, University of California San Diego, San Diego, California; †Department of Anesthesiology, University of Pittsburgh, Pittsburgh, Pennsylvania; ‡Outcomes Research Consortium, Cleveland, Ohio; §Department of Orthopedics, University of California San Diego, San Diego, California; ‖Division of Biostatistics and Bioinformatics, University of Southern California, Los Angeles, California; and ¶School of Medicine, University of California San Diego, San Diego, California.

DOI: 10.1213/ANE.0000000000003422

Accepted for publication March 27, 2018.

Funding: This work was supported by the Department of Anesthesiology, University of California San Diego (San Diego, CA).

The authors declare no conflicts of interest.

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the funding entity.

Institutional review board: University California San Diego Human Research Protections Program at (858) 657–5100, 9500 Gilman Dr, La Jolla, CA 92093-0052. E-mail: tnelson@ucsd.edu.

Continuous adductor canal nerve blocks provide postoperative analgesia after surgical procedures of the knee.[1,2] Inserting the perineural catheter distal to the location of a traditional inguinal femoral nerve block decreases induced quadriceps femoris weakness while retaining similar analgesic potential.[3–5] Remaining undetermined is the optimal location for catheter insertion within the thigh.

The most commonly reported level of insertion is the midpoint between the anterior superior iliac spine and the cephalad border of the patella (commonly referred to as the "midthigh" approach),[1–14] although a more cephalad placement has been reported.[15–18] Recent investigation and description of the relevant neuroanatomy of the thigh and knee had led us to speculate that superior postoperative analgesia might be produced with deposition of local anesthetic further caudad in "the distal thigh within the AC [adductor canal] where the femoral artery is sonographically seen to descend posteriorly toward the adductor hiatus, as described by Manickam et al in 2009."[19–21] In contrast, other investigators have provided anatomically based reasons for why the more proximal insertion site might provide optimal analgesia after knee surgery.[12]

Unfortunately, no published data exist comparing the midthigh and a more distal perineural catheter location. Considering >700,000 knee arthroplasty procedures are performed within the United States annually, and continuous adductor canal blocks are frequently used to provide analgesia after these procedures, there is value in identifying the optimal perineural catheter location.[22]

We therefore conducted this randomized, subject-masked, controlled, parallel-arm clinical trial to test the hypothesis that during a continuous adductor canal nerve block, postoperative analgesia after knee arthroplasty will be improved with the perineural catheter tip inserted in a distal location 2–3 cm cephalad to where the femoral artery descends posteriorly to the adductor hiatus compared to a more proximal location at the midpoint between the anterior superior iliac spine and the superior border of the patella. The primary end point was the median pain between 8:00 AM and 12:00 PM the day after surgery as measured on a numeric rating scale (NRS).

METHODS

Enrollment

This study adhered to good clinical practice quality standards and ethical guidelines defined by the Declaration of Helsinki. Study protocol approval as well as data and safety oversight were conducted by the University of California San Diego institutional review board (#151094; San Diego, CA). Written informed consent was obtained from all subjects participating in the trial. The trial was prospectively registered at clinicaltrials.gov (NCT02523235, Principal Investigator: B.M.I., date of registration: August 14, 2015) before initiation of enrollment.

Enrollment was offered preoperatively to adults (age 18 years or older) undergoing primary tricompartment knee arthroplasty with a preplanned adductor canal catheter and local anesthetic infusion for postoperative analgesia. Exclusion criteria included neuropathy of the operative extremity, chronic opioid use (daily use for >4 weeks before surgery of at least the equivalent of 20 mg oxycodone), body mass index >40 kg/m^2; allergy to lidocaine or ropivacaine, renal insufficiency, inability to communicate with the investigators, pregnancy, and incarceration. The study was conducted at Hillcrest Hospital (San Diego, CA) as well as Thornton and Jacobs Medical Center (La Jolla, CA), both academic institutions associated with the University of California San Diego Medical Center.

Perineural Catheter Insertion

Subjects were positioned supine with slight external rotation of the leg at the hip. Standard monitors were applied, and oxygen was administered by facemask at 8 L/min. Intravenous (IV) midazolam (1–2 mg) and fentanyl (50–100 μg) were administered, titrating for anxiolysis and analgesia, with verbal responsiveness maintained at all times. Procedures were completed by regional anesthesia fellows under the direct supervision of an attending regional anesthesiologist.

Using a 13–6 MHz 38-mm linear array ultrasound transducer (M-Turbo; SonoSite, Bothell, WA) in the short-axis view, the 2 possible catheter insertion locations were identified. The proximal location was defined as, "… halfway between the superior anterior iliac spine and the [superior border of the] patella."[23] The sartorius muscle was located anteromedially to the femoral artery. The distal location was then identified by moving the transducer "… caudally along the long axis of the thigh until the femoral artery was seen diving deep and moving away from the anterior muscle plane (sartorius and vastus medialis muscles), toward the posterior aspect of the thigh, where it becomes the popliteal artery. This area was identified as the adductor hiatus, and the block location was selected 2 to 3 cm proximally to this area, in the distal adductor canal."[21]

Randomization was performed only if both sites were determined to be acceptable for catheter insertion. Allocation to one of the 2 locations was achieved using computer-generated lists in blocks of 8 with a 1:1 ratio, stratified for 2 treating hospitals. Treatment allocation was concealed using consecutively numbered, sealed, opaque envelopes that were opened only after confirmation by ultrasound that either insertion site would be acceptable. Treatment group assignment was masked to subjects, but not investigators.

The designated site was cleaned with chlorhexidine gluconate/isopropyl alcohol solution and a sterile fenestrated drape applied. A local anesthetic skin wheal was raised anterolateral to the ultrasound transducer with the target location visualized in short axis. A 17-gauge Tuohy needle

This report describes human research and a prospective randomized clinical trial. The authors state that the report includes every item in the Consolidated Standards of Reporting Trials (CONSORT) checklist for a prospective randomized clinical trial. This study was conducted with written informed consent from the study subjects.

The study was registered before patient enrollment.

This was not an observational clinical study.

Registry URL: clinicaltrials.gov NCT02523235.

Reprints will not be available from the authors.

Address correspondence to Brian M. Ilfeld, MD, MS (Clinical Investigation), Department of Anesthesiology, University California San Diego, 9500 Gilman Dr, La Jolla, CA 92093-0898. Address e-mail to bilfeld@ucsd.edu.

(FlexTip Plus; Teleflex Medical, Research Triangle Park, NC) was inserted in-plane from the anterolateral side of the transducer, through the sartorius muscle with the final needle tip positioning between the artery and the saphenous nerve. If the saphenous nerve could not be well visualized, the needle tip was placed at 5 o'clock relative to the femoral artery within the adductor canal .[6] Normal saline was injected via the needle for hydrodissection in the minimal amount necessary to open a space for catheter insertion.

A 19-gauge perineural catheter (FlexTip Plus; Teleflex Medical) was subsequently inserted 3–5 cm past the needle tip. The needle was then withdrawn over the stationary catheter at least 3 cm, held stationary, and subsequently 2–3 cm of catheter was inserted to create "slack" between the adductor canal and skin exit point. Finally, the needle was withdrawn over the remaining catheter. Distal catheters were tunneled cephalad as described previously, resulting in a catheter exit from the skin at approximately the same location as for proximally inserted catheters and keeping the subject masked to treatment group.[16] The catheter was secured with sterile liquid adhesive, an occlusive dressing, and an anchoring device. The time for catheter insertion was measured from the time the Tuohy needle first touched the subject until it was completely withdrawn without reinsertion. For the distal group, the time to tunnel the catheter was excluded from this measurement.

Thirty milliliters of lidocaine 2% with epinephrine, 5 μg/mL, was injected via the catheter in divided doses. Catheter insertion success was defined as a change in cutaneous sensation to touch with an alcohol pad in the saphenous nerve distribution over the medial leg within 15 minutes after injection. Subjects with successful catheter placement per protocol and nerve block onset were retained in the study. Subjects with a failed catheter insertion or misplaced catheter indicated by a lack of sensory changes had their catheter replaced or were withdrawn from the study. A ropivacaine 0.2% infusion was initiated via the perineural catheter with a basal rate of 8 mL/h, a 4 mL bolus, and a lock-out of 30 minutes using a portable, programmable, electronic infusion pump (ambIT PreSet; Summit Medical Products, Inc Salt Lake City, UT).

Intraoperative Management

For surgical anesthesia, subjects received either a single injection spinal with bupivacaine 0.5% (2–3 mL) or a general anesthetic with inhaled volatile anesthetic in nitrous oxide and oxygen. IV fentanyl, hydromorphone, and/or morphine were administered intraoperatively, as needed. Implants were fixed with methyl methacrylate bone cement via a parapatellar approach (a tourniquet was used for all cases). After joint closure, the surgeon infiltrated the entire joint using 30 mL of ropivacaine (0.5%), ketorolac (30 mg), epinephrine (5 μg/mL), and tranexamic acid (2 g).

Postoperative Protocol

All subjects received oral acetaminophen (975 mg every 6 hours), celecoxib (200 mg every 12 hours), and sustained release oxycodone (oxycontin, 10 mg every 12 hours). For breakthrough pain, subjects depressed the infusion pump bolus button (4 mL, 30 minutes lockout). When necessary, rescue opioid and route of administration were titrated to pain severity using an NRS of 0–10: mild pain (NRS <4): oral oxycodone 5 mg; moderate pain (NRS 4–7): oral oxycodone 10 mg; and severe pain (NRS >7): IV morphine (2–4 mg) or hydromorphone (0.5 mg). Pain scores were recorded every 4 hours and when a subject requested supplemental analgesics, and the median pain score for each subject in each category was calculated. The ropivacaine perineural infusion was continued at least through midnight the day after surgery.

Outcome Measurements

The primary end point was the median pain as measured on an NRS (0–10; 0: no pain, 10: worst imaginable pain) during the time period of 8:00 AM to 12:00 PM the day after surgery. Secondary end points included the median pain at other time points, maximum NRS, opioid consumption (measured in morphine IV equivalents), ambulation distance, median NRS during physical therapy sessions, fluid leakage at the catheter insertion site, and local anesthetic consumption.

Statistical Analysis

To calculate a sample size, we focused on our primary hypothesis that postoperative analgesia is improved with the perineural catheter tip within the adductor canal 2–3 cm proximal to where the femoral artery descends posteriorly to the adductor hiatus (distal location) compared to within the canal at the midpoint between the anterior superior iliac spine and the superior border of the patella (proximal location) from 8:00 AM to 12:00 PM the day after knee arthroplasty. We estimated the density of pain scores after a proximal insertion (mean, 4.12; standard deviation, 1.74) based on published data.[4] To simulate power, we used the truncated Gaussian distribution with range 0–10; standard deviation = 1.74; proximal group mean = 4.12. Under these assumptions and 2-sided $\alpha = 5\%$, we simulated 10,000 trials with sample size of 25 per group. With an overall sample size of 50 subjects, we have 80% power to detect group differences in pain as small as approximately 1.6.

The prespecified analysis for the primary hypothesis was the Mann-Whitney *U* test. Secondary end points were also tested using the Mann-Whitney *U* test and presented along with median (interquartile range). No covariate-adjusted analyses were prespecified. Nominal variables were analyzed using the Pearson χ^2 test. $P < .05$ was considered significant. Significant findings in secondary outcomes should be viewed as suggestive, requiring confirmation in a future trial before considering them as definitive.[24] R version 3.4.2 (https://www.r-project.org/) was used for all analyses.

RESULTS

Of 53 subjects enrolled, 2 (3.8%) were found to have inferior visualization of the distal location and therefore excluded before randomization per protocol. The remaining 51 subjects were randomized to one of the 2 treatment groups (Table 1) with no clinically relevant differences noted between groups; and all subjects had a catheter inserted successfully per protocol. One subject (2.0%) randomized to the proximal location experienced a medical complication

intraoperatively unrelated to the study protocol and was withdrawn from the investigation. Therefore, a total of 50 subjects with a recorded primary end point were included in the final analysis (Figure 1).

Primary End Point

The NRS of subjects with a catheter inserted at the proximal location (n = 24) was a median (10th, 25th–75th, 90th quartiles) of 0.5 (0.0, 0.0–3.2, 5.0) vs 3.0 (0.0, 2.0–5.4, 7.8) for subjects with a catheter inserted in the distal location (n = 26; P = .011).

Secondary End Points

Median and maximum NRSs were lower in the proximal group at all other time points, but these differences did not reach statistical significance (Figure 2). There were no clinically relevant or statistically significant differences between the treatment groups for any other secondary end point with the exception of intraoperative opioid requirements (Table 2).

Table 1. Subject Characteristics

	Proximal (n = 25)	Distal (n = 26)
Age (y)	69 (10)	69 (9)
Sex (female)	8 (32%)	14 (54%)
Height (cm)	166 (10)	170 (11)
Weight (kg)	79 (19)	86 (18)
Body mass index (kg/m^2)	28.4 (6.0)	29.9 (6.9)
Distance between proximal and distal insertion points (cm)	9.1 (2.3)	9.5 (2.2)

Values are reported as mean (SD) or number (percentage) of subjects.
Abbreviation: SD, standard deviation.

DISCUSSION

This randomized, subject-masked, controlled, parallel-arm clinical trial demonstrates that for continuous adductor canal nerve blocks, postoperative analgesia after knee arthroplasty is improved with the perineural catheter tip inserted at the midpoint between the anterior superior iliac spine and the superior border of the patella when compared with a more distal location closer to the adductor hiatus.

This finding is the inverse of our original hypothesis that the more distal location would offer improved analgesia compared to the proximal insertion point, which was based on recent anatomic descriptions of knee and thigh neuroanatomy[19–21]: local anesthetic deposited closer to the adductor hiatus "can be speculated to spread into the popliteal fossa and anesthetize the posterior branch of the obturator nerve and the popliteal plexus, which provide intra-articular innervation of the knee."[25] Others have opined, "it could be speculated that a true adductor canal block [the "distal" location of our study] may not produce the same effective analgesia after total knee arthroplasty if the medial vastus nerve is an important contributor to knee innervation," because this nerve travels within the femoral triangle but branches separately from the more distal adductor canal.[25] Nevertheless, from a patients' perspective, the neuroanatomy discussion is of little consequence relative to the analgesia derived from their postoperative perineural local anesthetic infusion. In this regard, the present study provides actionable information for clinicians on the relative benefits of a proximal versus distal catheter insertion site, as defined by this study.

Of importance, this clinical trial defined the midpoint between the anterior superior iliac spine and superior border of the patella—frequently termed midthigh—as the "proximal" location. However, 2 previously published

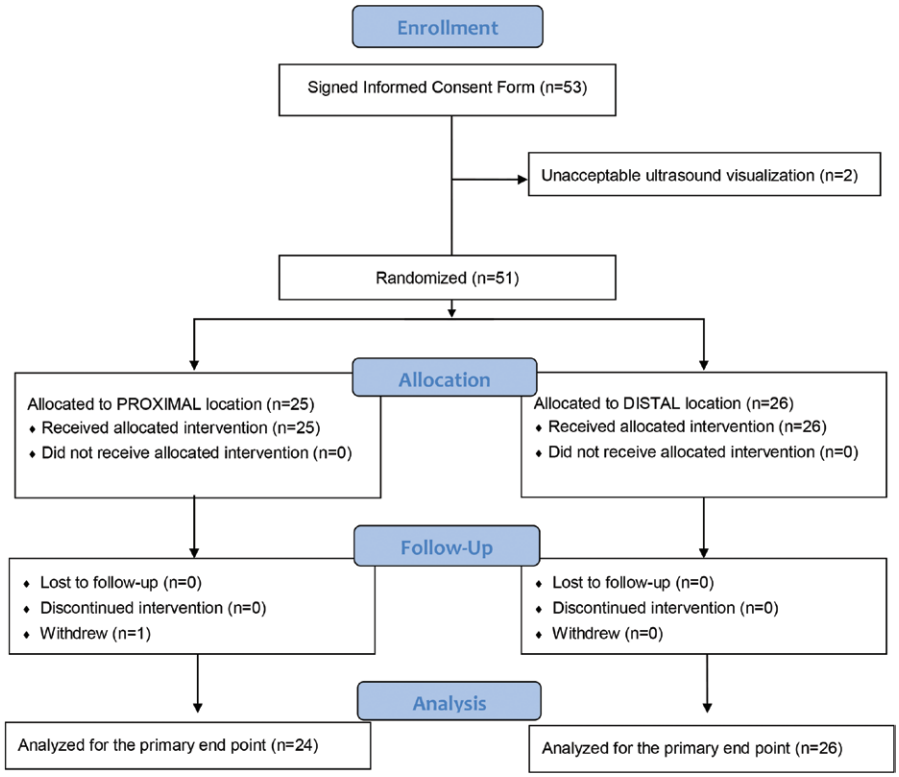

Figure 1. CONSORT flow diagram. CONSORT indicates Consolidated Standards of Reporting Trials.

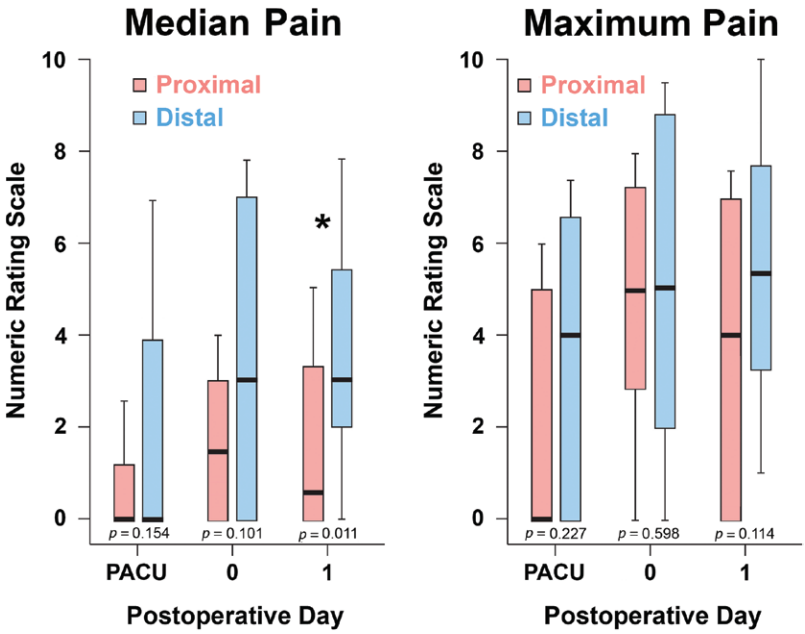

Figure 2. Perineural catheter location effects on postoperative pain after total knee arthroplasty with a ropivacaine 0.2% perineural infusion with either a distal insertion point 2–3 cm cephalad to where the femoral artery descends posteriorly to the adductor hiatus or a more proximal insertion at the midpoint between the anterior superior iliac spine and the superior border of the patella. Pain severity indicated using a numeric rating scale of 0–10, with 0 equal to no pain and 10 being the worst imaginable pain. Data include the median and maximum pain reported for 3 time points: within the recovery room ("PACU"); postrecovery room through 8:00 AM on postoperative day 1 ("postoperative day 0"); and 8:00 AM to 12:00 PM on postoperative day 1 ("postoperative day 1"). Data are expressed as median (horizontal bars) with 25th–75th (box) and 10th–90th (whiskers). * denotes statistical significance ($P < .05$). PACU indicates postanesthesia care unit.

Table 2. Postrandomization End Points

	Proximal (n = 24)[a]	Distal (n = 26)	*P* Value
Time for catheter insertion (min)	5.5 (4.8–8.2)	5.0 (5.0–8.0)	.945
Spinal anesthetic (#)	15 (63%)	13 (50%)	.374
Surgical start to stop (min)	135 (115–148)	127 (111–144)	.657
Self-administered bolus doses (#)	8 (4–14)	10 (5–16)	.573
Fluid leakage at catheter site (#)	3 (13%)	1 (4%)	.317
Ambulation distance POD 1			
Morning (m)	120 (66–200)	110 (75–200)	.967
Afternoon (m)	150 (92–200)	170 (129–200)	.548
Pain scores during physical therapy POD 1			
Morning (NRS)	3.0 (0.8–4.2)	3.0 (2.0–5.0)	.385
Afternoon (NRS)	3.0 (0–5.0)	3.0 (2.0–5.0)	.247
Opioid consumption (morphine equivalents)			
Intraoperative (mg)	0.5 (0–2.5)	1.2 (0.6–2.5)	.024
Recovery room (mg)	2.2 (0–5.8)	2.0 (0–4.2)	.857
After recovery room through POD 1 8:00 AM (mg)	6.7 (2.5–8.8)	6.7 (3.3–11.4)	.739
POD 1 8:00 AM through 12:00 PM (mg)	6.7 (3.3–10.4)	6.7 (3.3–15.0)	.553

Values are reported as number (percentage) of subjects or median (interquartile).
Abbreviations: NRS, numeric rating scale; POD, postoperative day.
[a]One subject withdrew before any data collection and is not included in totals.

randomized, controlled studies comparing adductor canal catheter insertion sites designated this point as the "distal" location, with the alternative proximal treatment further cephalad.[16,18] In other words, the previous studies compared the midthigh with a more proximal insertion point, while the present study compared the midthigh with a more distal insertion point.

There are no demonstrated differences among these 3 insertion levels other than the finding of the present study that a midthigh catheter provides superior analgesia the day after surgery compared with a more distal location after knee arthroplasty.[16,18] However, a "theoretical" benefit of a more proximal insertion is decreasing possible overlap of catheter and surgical dressings—and therefore possible infection risk[26]—by permitting more distance between the catheter and surgical site.[27] Indeed, to avoid having our catheter site encroach on the intraoperative surgical drapes and postoperative surgical dressing, we tunneled the distal catheters cephalad 5–8 cm, as have others.[28] In contrast, the midthigh catheters did not require tunneling, also reported by others,[18] although requirements will vary depending on each surgeon's dressing preference and patient anatomy.[16] We chose to exclude the tunneling time in our catheter insertion time measurements to allow a better comparison of insertion duration between the 2 treatment locations. It is self-evident that tunneling a catheter requires additional time, and so with this protocol, our results are applicable to practices that both do and do not choose to tunnel. Compared to proximal catheter locations, tunneling for distal catheter placement requires longer total insertion time, increases physical tunneling risk, and creates more difficulty in postoperative insertion with any applied surgical dressings.[27]

Relatedly, because the point between the anterior superior iliac spine and superior patellar border may indeed

be located at the femoral triangle in a subset of patients, there is theoretical risk of proximal local anesthetic spread to the motor components of the femoral nerve, which may increase quadriceps femoris weakness and suboptimal physical therapy.[25] While we did not directly measure quadriceps strength, the distance of ambulation was higher for the proximal group in both the morning and afternoon physical therapy sessions (although not to a statistically significant degree). However, the effect of catheter location on quadriceps strength and incidence of falls deserves further investigation because the present study was not powered to detect differences in this outcome.

Sixty-three percent of the proximal group versus 50% of the distal group had a spinal anesthetic, although this difference did not reach statistical significance (P = .374). However, we speculate that even this small difference in anesthetic type explains the statistically significant difference in intraoperative opioid consumptions between the 2 groups.

Study Limitations

Although the subjects of this investigation were masked to treatment group assignment, investigators were aware of the randomization results. In addition, the results apply only to the specific local anesthetic type, concentration, bolus volume, and basal rate of the present study. Similarly, results for single injection adductor canal blocks may differ from this investigation involving a perineural ropivacaine infusion (after the initial bolus of intermediate-acting local anesthetic). Furthermore, we evaluated subjects only through midnight the evening after surgery. Median pain level the day after surgery was prospectively designated as the primary end point because in our experience, pain from the sciatic nerve distribution frequently greatly decreases by this period, allowing for a better differentiation between adductor canal catheter locations. Last, the results of this study apply to patients receiving intraoperative periarticular local anesthetic infiltration which provides some degree of posterior analgesia—our results may have been different without this intervention.

In conclusion, for continuous adductor canal blocks accompanied by intraoperative periarticular local anesthetic infiltration, analgesia the day after knee arthroplasty is improved with a catheter inserted at the level of the midpoint between the anterior superior iliac spine and the superior border of the patella, compared with a more distal insertion closer to the adductor hiatus.

ACKNOWLEDGMENTS

The authors appreciate the invaluable assistance of Thomas Bendtsen, MD, PhD (Aarhus University Hospital, Copenhagen, Denmark), and Pia Jaeger, MD, PhD (Rigshospitalet, Copenhagen University Hospital, Copenhagen, Denmark), for their review of the manuscript.

DISCLOSURES

Name: Jacklynn F. Sztain, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Bahareh Khatibi, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Amanda M. Monahan, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Engy T. Said, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Wendy B. Abramson, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Rodney A. Gabriel, MD, MAS.
Contribution: This author helped conduct the study, provide the data analysis, and write the manuscript.
Name: John J. Finneran IV, MD.
Contribution: This author helped conduct the study and write the manuscript.
Name: Richard H. Bellars, MD.
Contribution: This author helped develop the protocol, conduct the study, and write the manuscript.
Name: Patrick L. Nguyen, MD.
Contribution: This author helped develop the protocol, conduct the study, and write the manuscript.
Name: Scott T. Ball, MD.
Contribution: This author helped develop the protocol, conduct the study, and write the manuscript.
Name: Francis B. Gonzales, MD.
Contribution: This author helped develop the protocol, conduct the study, and write the manuscript.
Name: Sonya S. Ahmed, MD.
Contribution: This author helped develop the protocol and write the manuscript.
Name: Michael C. Donohue, PhD.
Contribution: This author helped provide the data analysis and write the manuscript.
Name: Jennifer A. Padwal, BS.
Contribution: This author helped write the manuscript.
Name: Brian M. Ilfeld, MD, MS (Clinical Investigation).
Contribution: This author helped design the original study, secure appropriate funding, see the original study data, review the analysis of the data, approve the final manuscript, and archive the study files.
This manuscript was handled by: Richard Brull, MD, FRCPC.

REFERENCES

1. Jenstrup MT, Jæger P, Lund J, et al. Effects of adductor-canal-blockade on pain and ambulation after total knee arthroplasty: a randomized study. *Acta Anaesthesiol Scand*. 2012;56:357–364.
2. Hanson NA, Allen CJ, Hostetter LS, et al. Continuous ultrasound-guided adductor canal block for total knee arthroplasty: a randomized, double-blind trial. *Anesth Analg*. 2014;118:1370–1377.
3. Jæger P, Zaric D, Fomsgaard JS, et al. Adductor canal block versus femoral nerve block for analgesia after total knee arthroplasty: a randomized, double-blind study. *Reg Anesth Pain Med*. 2013;38:526–532.
4. Machi AT, Sztain JF, Kormylo NJ, et al. Discharge readiness after tricompartment knee arthroplasty: adductor canal versus femoral continuous nerve blocks-a dual-center, randomized trial. *Anesthesiology*. 2015;123:444–456.
5. Sztain JF, Machi AT, Kormylo NJ, et al. Continuous adductor canal versus continuous femoral nerve blocks: relative effects on discharge readiness following unicompartment knee arthroplasty. *Reg Anesth Pain Med*. 2015;40:559–567.
6. Lund J, Jenstrup MT, Jaeger P, Sørensen AM, Dahl JB. Continuous adductor-canal-blockade for adjuvant post-operative analgesia after major knee surgery: preliminary results. *Acta Anaesthesiol Scand*. 2011;55:14–19.
7. Jaeger P, Grevstad U, Henningsen MH, Gottschau B, Mathiesen O, Dahl JB. Effect of adductor-canal-blockade on established, severe post-operative pain after total knee arthroplasty: a randomised study. *Acta Anaesthesiol Scand*. 2012;56:1013–1019.
8. Veal C, Auyong DB, Hanson NA, Allen CJ, Strodtbeck W. Delayed quadriceps weakness after continuous adductor canal

block for total knee arthroplasty: a case report. *Acta Anaesthesiol Scand*. 2014;58:362–364.
9. Yuan SC, Hanson NA, Auyong DB, Choi DS, Coy D, Strodtbeck WM. Fluoroscopic evaluation of contrast distribution within the adductor canal. *Reg Anesth Pain Med*. 2015;40:154–157.
10. Jæger P, Koscielniak-Nielsen ZJ, Schrøder HM, et al. Adductor canal block for postoperative pain treatment after revision knee arthroplasty: a blinded, randomized, placebo-controlled study. *PLoS One*. 2014;9:e111951.
11. Monahan AM, Sztain JF, Khatibi B, et al. Continuous adductor canal blocks: does varying local anesthetic delivery method (automatic repeated bolus doses versus continuous basal infusion) influence cutaneous analgesia and quadriceps femoris strength? a randomized, double-masked, controlled, split-body volunteer study. *Anesth Analg*. 2016;122:1681–1688.
12. Egeler C, Jayakumar A, Ford S. Adductor canal block is useful but does not achieve a complete block of the knee. *Reg Anesth Pain Med*. 2014;39:81–82.
13. Mudumbai SC, Kim TE, Howard SK, et al. Continuous adductor canal blocks are superior to continuous femoral nerve blocks in promoting early ambulation after TKA. *Clin Orthop Relat Res*. 2013;473:1377–1383.
14. Andersen HL, Gyrn J, Møller L, Christensen B, Zaric D. Continuous saphenous nerve block as supplement to single-dose local infiltration analgesia for postoperative pain management after total knee arthroplasty. *Reg Anesth Pain Med*. 2013;38:106–111.
15. Elkassabany NM, Antosh S, Ahmed M, et al. The risk of falls after total knee arthroplasty with the use of a femoral nerve block versus an adductor canal block: a double-blinded randomized controlled study. *Anesth Analg*. 2016;122:1696–1703.
16. Mariano ER, Kim TE, Wagner MJ, et al. A randomized comparison of proximal and distal ultrasound-guided adductor canal catheter insertion sites for knee arthroplasty. *J Ultrasound Med*. 2014;33:1653–1662.
17. Zhang W, Hu Y, Tao Y, Liu X, Wang G. Ultrasound-guided continuous adductor canal block for analgesia after total knee replacement. *Chin Med J (Engl)*. 2014;127:4077–4081.
18. Meier AW, Auyong DB, Yuan SC, Lin SE, Flaherty JM, Hanson NA. Comparison of continuous proximal versus distal adductor canal blocks for total knee arthroplasty: a randomized, double-blind, noninferiority trial. *Reg Anesth Pain Med*. 2018;43:36–42.
19. Bendtsen TF, Moriggl B, Chan V, Pedersen EM, Børglum J. Defining adductor canal block. *Reg Anesth Pain Med*. 2014;39:253–254.
20. Bendtsen TF, Moriggl B, Chan V, Børglum J. The optimal analgesic block for total knee arthroplasty. *Reg Anesth Pain Med*. 2016;41:711–719.
21. Manickam B, Perlas A, Duggan E, Brull R, Chan VW, Ramlogan R. Feasibility and efficacy of ultrasound-guided block of the saphenous nerve in the adductor canal. *Reg Anesth Pain Med*. 2009;34:578–580.
22. Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States - an alternative projection model. *Osteoarthritis Cartilage*. 2017;25:1797–1803.
23. Jaeger P, Nielsen ZJ, Henningsen MH, Hilsted KL, Mathiesen O, Dahl JB. Adductor canal block versus femoral nerve block and quadriceps strength: a randomized, double-blind, placebo-controlled, crossover study in healthy volunteers. *Anesthesiology*. 2013;118:409–415.
24. Mariano ER, Ilfeld BM, Neal JM. "Going fishing"–the practice of reporting secondary outcomes as separate studies. *Reg Anesth Pain Med*. 2007;32:183–185.
25. Wong WY, Bjørn S, Strid JM, Børglum J, Bendtsen TF. Defining the location of the adductor canal using ultrasound. *Reg Anesth Pain Med*. 2017;42:241–245.
26. Chelly JE. Is the continuous saphenous block the right technique for postoperative pain management after total knee replacement? *Reg Anesth Pain Med*. 2013;38:461.
27. Kwofie MK, Shastri UD, Gadsden JC. Reply to Drs Egeler, Jayakumar, and Ford. *Reg Anesth Pain Med*. 2014;39:82.
28. Moore DM, O'Gara A, Duggan M. Continuous saphenous nerve block for total knee arthroplasty: when and how? *Reg Anesth Pain Med*. 2013;38:370–371.