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Discharge Readiness after Tricompartment Knee Arthroplasty

Adductor Canal versus Femoral Continuous Nerve Blocks—A Dual-center, Randomized Trial

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ABSTRACT

Background: The authors conducted a randomized, controlled, parallel-arm, superiority study to test the hypothesis that a continuous adductor canal block decreases the time to attain four discharge criteria compared with a continuous femoral nerve block after tricompartment knee arthroplasty.

Methods: Subjects undergoing tricompartment knee arthroplasty were randomized using computer-generated lists to either an adductor canal or femoral perineural catheter (3-day ropivacaine 0.2% infusion) in an unmasked manner. The primary outcome was the time to attain four criteria: (1) adequate analgesia; (2) intravenous opioids independence; (3) ability to stand, walk 3 m, return, and sit down; and (4) ambulate 30 m.

Results: Subjects with an adductor canal catheter ($n = 39$) reached all four criteria in a median of 55 h (interquartile, 42 to 63 h) compared with 61 h (49 to 69 h) for those with a femoral catheter ($n = 41$; 95% CI, -13 to 1 h; $P = 0.12$). The percentage of subjects who reached the two mobilization criteria on postoperative days 1 and 2 were 72 and 95% for those with an adductor canal catheter ($n = 39$), but only 27 and 76% in subjects with a femoral catheter ($n = 41$; both $P < 0.001$). Differences in pain scores at rest and intravenous opioid requirements were minimal, but femoral infusion improved dynamic analgesia ($P = 0.01$ to 0.02).

Conclusion: Compared with a continuous femoral nerve block, a continuous adductor canal block did not appreciably decrease the time to overall discharge readiness even though it did decrease the time until adequate mobilization, primarily because both groups experienced similar analgesia and intravenous opioid requirements that—in most cases—exceeded the time to mobilization. (**ANESTHESIOLOGY 2015; 123:444-56**)

TRICOMPARTMENT knee arthroplasty is among the most common surgical procedures, with over 700,000 procedures performed annually within the United States alone.¹ This surgery results in moderate-to-severe postoperative pain that often requires intravenous analgesics and impairs functional mobility, all of which can prolong hospitalization.² Continuous femoral nerve blocks provide effective postoperative analgesia and are therefore widely used to provide analgesia after knee arthroplasty.³ However, this modality induces quadriceps weakness and is associated with an increased risk of falling,⁴⁻⁶ leading clinicians to question its risk-benefit ratio and consider alternative analgesic approaches.⁷⁻¹¹

A relatively new alternative is an adductor canal block in which local anesthetic is deposited within an aponeurotic tunnel in the middle third of the thigh containing multiple

What We Already Know about This Topic

- Tricompartment knee arthroplasty is a common surgical procedure that results in moderate-to-severe postoperative pain
- Continuous femoral nerve blocks provide effective postoperative analgesia and are widely used but induce quadriceps weakness and possibly increase the risk of falls
- Adductor canal block is a newer alternative, and randomized comparisons of continuous adductor canal and femoral nerve blocks demonstrate the quadriceps-sparing benefit of the adductor canal infusions, yet the overall impact of this new approach remains unexplored

What This Article Tells Us That Is New

- Continuous adductor canal block did not appreciably decrease the time to overall discharge readiness when compared with continuous femoral nerve block even though it did decrease the time until adequate mobilization because both groups often required intravenous opioids beyond the time to mobilization

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afferent sensory nerves—but only a single efferent motor nerve: a branch innervating the vastus medialis of the quadriceps muscle.^{12,13} In both volunteers and surgical patients, a single-injection adductor canal block induces less quadriceps weakness and mobilization disability compared with a single-injection femoral nerve block.^{14–16}

Because pain after knee arthroplasty usually outlasts the duration of a single-injection nerve block, a perineural catheter is often introduced to allow prolonged local anesthetic administration.^{15,17–21} Two randomized comparisons of adductor canal and femoral continuous nerve blocks after knee arthroplasty demonstrated the quadriceps-sparing benefit of the adductor canal infusions, but both limited infusion duration to 24 or fewer hours and evaluated mobilization a maximum of 24 h.^{20,22} Because discharge readiness is rarely achieved within the first 24 h after tricompartiment knee arthroplasty, it remains unknown whether the use of continuous adductor canal blocks will have any appreciable effect on readiness for discharge.²³

We therefore conducted a dual-center, randomized, active-controlled, parallel-arm clinical trial to test the hypothesis that a continuous adductor canal block decreases the time to attain four specific discharge criteria compared with a continuous femoral nerve block after tricompartiment knee arthroplasty: (1) adequate analgesia; (2) independence from intravenous opioids; (3) ability to independently stand; walk 3 m, return, and sit down; and (4) independently ambulate 30 m. Both treatment groups received intraoperative joint infiltration of ropivacaine, ketorolac, epinephrine, and tranexamic acid.

Materials and Methods

Enrollment

This study followed Good Clinical Practice and was conducted within the ethical guidelines outlined in the Declaration of Helsinki. The trial was prospectively registered at ClinicalTrials.gov (NCT01759277). The University of California San Diego Institutional Review Board (San Diego, California) approved all study procedures and provided oversight of the data and safety issues for the duration of the trial. Written, informed consent was obtained from all participating subjects.

Enrollment was conducted exclusively through the orthopedic clinic and was offered to adults (≥ 18 yr old) scheduled for primary, unilateral, tricompartiment knee arthroplasty whose postoperative analgesic plan included a perineural local anesthetic infusion. Exclusion criteria were morbid obesity (body mass index >40 kg/m²), chronic high-dose opioid use (daily oxycodone equivalents >20 mg within 2 weeks before surgery and duration of use >4 weeks), history of opioid abuse, allergy to study medications, known renal insufficiency (creatinine >1.5 mg/dl), pregnancy, incarceration, any known neuromuscular deficit of the ipsilateral femoral nerve, obturator nerve, and quadriceps muscle (including diabetic neuropathy), and inability to ambulate

30 m preoperatively. The study was conducted at Thornton and Hillcrest hospitals, both of which are academic institutions in San Diego, California.

Randomization

Both femoral and adductor canal sites were visualized with ultrasound using a 13–6 MHz 38-mm linear array transducer (M-Turbo; SonoSite, USA). Subjects were randomized to one of the two treatment groups—*adductor canal versus femoral* perineural catheter—only if both locations were considered acceptable for catheter insertion. Randomization lists were created by Investigational Drug Service personnel using a computer-generated randomization table in blocks of four, with a 1:1 ratio, stratified by both treatment center and surgeon. 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.

Catheter Insertion

Blocks were performed preoperatively by regional anesthesia fellows under the guidance of attending anesthesiologists or by attending anesthesiologists. Subjects were positioned supine, given supplemental oxygen *via* nasal cannula, premedicated with intravenous fentanyl and midazolam, and prepped and draped in a sterile manner. The same perineural catheter kits were used for both treatment groups (Flex-Block; Teleflex Medical, Research Triangle Park, USA).

Femoral Group. A transverse cross-sectional (short axis) view of the femoral nerve was obtained at the inguinal crease with the same ultrasound and transducer used for the initial scan before sterile preparation and draping. A local anesthetic skin wheal was raised lateral to the ultrasound transducer with a 25-gauge needle and lidocaine 1.5%. A 17-gauge Tuohy needle was inserted through the skin wheal in plane with the ultrasound probe toward the femoral nerve. The final needle position for the femoral group was posterior to the femoral nerve and lateral to the femoral artery.

Adductor Canal Group. The midpoint between the anterior superior iliac spine and the cephalad margin of the patella was measured with slight external rotation of the leg at the hip. Using ultrasound at this midpoint, the superficial femoral artery was identified in a short-axis view deep to the sartorius muscle, medial to the rectus femoris muscle and anterior to the adductor longis muscle, with the superficial femoral vein usually posterolateral to the artery (the position of the vein may vary relative to the artery at this level of the thigh). At this position, the ultrasound image of the saphenous nerve or nerve bundle is typically anterolateral to the superficial femoral artery within the adductor canal. The corresponding anatomical positions for each structure are saphenous nerve anterior to the artery, vein lateral to the artery, and sartorius medial to the artery.^{24,25} A local anesthetic skin wheal was raised anterolateral to the ultrasound transducer with a 25-gauge needle and lidocaine 1.5%. A 17-gauge Tuohy

needle 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.²⁶

In both treatment groups, 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 was subsequently inserted 3 to 5 cm past the needle tip. The needle was withdrawn over the catheter, and the catheter hub affixed to the upper lateral thigh with sterile occlusive dressings and an anchoring device. Thirty milliliters of lidocaine 2% was injected *via* the catheter in divided doses after negative aspiration.

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 30 min 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 6 ml/h, a 4-ml bolus, and a lock-out of 30 min using a portable, programmable, electronic infusion pump (ambIT PreSet; Summit Medical, USA).

Intraoperative Management

For surgical anesthesia, subjects received either a single-injection spinal with bupivacaine 0.5% (2 to 3 ml) or a general anesthetic with inhaled volatile anesthetic in nitrous oxide and oxygen. Intravenous 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 ropivacaine (0.5%), ketorolac (30 mg), epinephrine (5 µg/ml), and tranexamic acid (2 g).

Postoperative Analgesics

All subjects received oral acetaminophen (975 mg every 6 h), celecoxib (200 mg every 12 h), and sustained release oxycodone (oxycontin, 10 mg every 12 h). For breakthrough pain, subjects depressed the infusion pump bolus button (4 ml, 30-min lock-out). When necessary, rescue opioid and route of administration were titrated to pain severity using a numeric rating scale (NRS) of 0 to 10: mild pain (NRS <4): oral oxycodone (5 mg); moderate pain (NRS 4 to 7): oral oxycodone (10 mg); and severe pain (NRS >7): intravenous morphine (2 to 4 mg) or hydromorphone (0.5 mg). Within the postanesthesia care unit, a once-only 10 ml lidocaine (2%) bolus was given *via* the perineural catheter for moderate or severe pain.

The basal infusion rate was initiated at 6 ml/h and titrated to subject comfort (increased 2 ml/h for NRS >4) a maximum of twice per day up to a maximum of 12 ml/h. However, muscle strength took precedence to allow for ambulation and minimize the risk of falling. If the physical therapist determined that subject standing and/or ambulation was inhibited by quadriceps weakness, the basal infusion rate was titrated down (decrease 2 ml/h) a maximum of twice per day to a minimum of 2 ml/h. Ropivacaine perineural infusions were continued until the morning of postoperative day (POD) 3.

Outcome Measurements

Failure to meet four criteria determine the majority of hospitalization days at our hospitals: (1) adequate analgesia (defined as NRS <4); (2) independence from intravenous opioids for at least 12 h; (3) ability to independently stand and sit down (evaluated with the Timed Up and Go test)^{27,28}; and (4) unassisted ambulation of at least 30 m (evaluated with the 6-min walk test).²⁹ For both the Timed Up and Go test and general ambulation, a four-legged walker was used by all subjects. The primary endpoint of this study was the time from surgical stop until all four of these criteria were fulfilled without a reversion to unfulfilled status. These criteria were assessed at the end of each 8-h nursing shift: 08:00, 16:00, and midnight. Pain scores were recorded every 4 h and when subjects requested analgesics. Subjects participated in physical therapy sessions twice daily, beginning as early as the afternoon of surgery if they reached the orthopedic wards by 14:00 the day of surgery. Neither study participants nor investigators were masked to treatment group assignment.

Secondary endpoints included each of the four individual discharge criteria of the primary endpoint, supplemental oral opioid consumption, attaining a standing position without assistance, passive knee flexion and extension (measured with a goniometer), catheter site leakage, and the incidence of catheter dislodgement. The time for catheter placement began with the insertion of the Tuohy needle and ended upon final needle withdrawal. Infusion pump memory was interrogated daily and provided the basal infusion rate, self-administered bolus dose attempts and delivery, infused volume, and infusion duration. Subjects were discharged home after meeting all four of the composite primary endpoint criteria, but not before POD 3. Perineural catheters were removed by medical personnel before hospital discharge.

One week after surgery (± 2 days), subjects were called and verbally completed the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire. The WOMAC is an instrument specifically designed to evaluate clinically important, patient-relevant changes in health-related quality-of-life following treatment interventions in patients with osteoarthritis of the knee.⁷ The WOMAC evaluates three dimensions of health-related quality-of-life: pain, stiffness, and physical functional disability with 5, 2, and 17

questions, respectively. An ordinal Likert scale from 0 to 4 is used for each question, with lower scores indicating lower levels of symptoms or physical disability.³⁰ Each subscale is summated to a maximum score of 20, 8, and 68, respectively. The individual dimensions are always analyzed separately, and investigators have often added a “global” score, which is calculated by summating the scores for the three subscales.³¹ The questionnaire may be self-administered or administered *via* a telephone call and takes 5 to 10 min to complete.³² Because it is a proprietary instrument, the questionnaire itself may not be published and is therefore not included in an appendix. Since its inception 2 decades ago, the WOMAC has been translated into 60 languages and used in several hundred published clinical trials.³³ It has been rigorously examined, demonstrating excellent construct validity, responsiveness, and test–retest reliability in patients after total knee replacement,^{30,34–36} and it is therefore recommended in the Osteoarthritis International Research Society’s guidelines for clinical trials.^{33,37}

Statistical Analysis

All analyses were two-tailed tests comparing the randomized (independent) groups and conducted to assess superiority.

Primary Analysis. Balance between the adductor canal and femoral randomized groups on postrandomization catheter insertion and perioperative characteristics was assessed using standard summary statistics. The effect of perineural catheter location (adductor canal *vs.* femoral) on time to reach all four discharge criteria was assessed using the two-tailed Wilcoxon rank sum test, with difference in medians estimated using the method of Hodges–Lehmann. In addition, Kaplan–Meier analysis on these time-to-event outcomes was conducted, and groups compared with the log-rank test. Finally, hazard ratios were estimated using a Cox proportional hazards regression model, and the proportional hazards assumption was tested by assessing the group-by-time interaction.

Secondary Analyses. Each of the four individual discharge criteria of the primary endpoint, including (1) adequate analgesia, (2) independence from intravenous opioids, (3) independent ambulation 30 m or greater, and (4) the ability to independently stand, walk 3 m, return, and sit down was compared between the two randomized groups using the same statistical methods as outlined in the previous paragraph for the primary endpoint. The treatment effects on (5) time to attaining a standing position without assistance and (6) time to physical therapy unlimited by quadriceps weakness were assessed by log-rank test as well. The treatment effects on (7) passive knee flexion and (8) extension (after logarithm transformation) and (9) average and (10) worst pain score over time were assessed by repeated-measures general linear model with an autoregressive covariance structure. The treatment-by-time interaction was assessed for each outcome.

A Student *t* test or Wilcoxon rank sum test was used to compare adductor canal and femoral groups on continuous

or ordinal outcomes, including (11) total supplemental oral opioid consumption, (12) total local anesthetic administered, (13) basal rate, and (14) hours from surgical stop to discharge, as appropriate. Pearson chi-square test or the Fisher exact test was used for (15) catheter site leakage, (16) catheter dislodgement, (17) hospital discharge rate, and additional categorical data, as appropriate. For each secondary outcome, we used an overall significance criterion of 0.003 (*i.e.*, 0.05/17, a total of 17 secondary outcomes, Bonferroni correction) to control the type I error at 0.05 for this set of outcomes. Throughout we refer to them as “95% CIs” to indicate that the significance level was controlled at 5% for each hypothesis. Last, the chi-square test was used for comparisons of categorical data. SAS software version 9.3 for Windows (SAS Institute, USA) was used for all statistical analyses.

Sample Size Considerations. This superiority study was powered for the composite primary endpoint. Based on previously published data for tricompartment knee arthroplasty, the estimated distribution of time-to-discharge readiness for the adductor canal (femoral) catheter groups was 30 h: 60% (25%); 45 h: 20% (25%); 54 h: 10% (25%); and 69+h: 10% (25%).² The given distributions are consistent with mean time-to-discharge readiness of 39 h *versus* 49 h (assuming the last category equals 70 h). To ensure 90% power at the 0.05 significance level for the Wilcoxon rank sum test to detect differences in the distribution of time-to-discharge category at least as large as specified in the two preceding sentences, 38 subjects were required in each treatment group. Sample size calculations were made using the POWER procedure (twosamplewilcoxon statement) in SAS statistical software. Therefore, we planned to enroll a total of 80 subjects having tricompartment knee arthroplasty who reached all four discharge criteria and therefore had an evaluable primary endpoint.

Results

From January 2013 to September 2014, 84 subjects signed an informed consent form. We discovered that one individual had an exclusion criteria (body mass index >40 kg/m²) before randomization and the subject was excluded from further study. The remaining 83 subjects were randomized to either an adductor canal (*n* = 40) or femoral (*n* = 43) catheter, and all perineural catheters were inserted per protocol. However, one subject with a femoral catheter did not develop a sensory block within 30 min as required per protocol and was therefore withdrawn from study before perineural infusion initiation and further data collection. Two subjects began their infusions but withdrew from the study on PODs 1 (femoral) and 2 (adductor canal) before meeting all four discharge criteria, leaving 80 subjects with an evaluable primary endpoint (table 1). Of postrandomization catheter insertion and perioperative characteristics, only catheter insertion time differed to a statistically significant degree between treatment groups, with adductor canal catheters requiring 50% more time than their femoral counterparts (table 2).

Table 1. Anthropomorphic and Prerandomization Surgical Characteristics of the Study Subjects

	Adductor Canal (n = 39)	Femoral (n = 41)
Age (yr)	67 ± 8	66 ± 7
Sex (female)	23 (59%)	27 (66%)
Height (cm)	169 ± 11	168 ± 10
Weight (kg)	87 ± 16	84 ± 16
Body mass index (kg/m ²)	30 ± 5	29 ± 5
Surgeon (A)	26 (67%)	25 (61%)
Hospital (Thornton)	30 (77%)	33 (80%)

Values are reported as mean ± SD or number of subjects (percentage of treatment group).

Primary Endpoint

Subjects assigned to an adductor canal catheter (n = 39) met the four discharge readiness criteria in a median of 55 h (interquartile range, 42 to 63 h) compared with 61 h (49 to 69 h) for subjects who received a femoral catheter (n = 41; $P = 0.12$; fig. 1). The median was an estimated 6 h less (95% CI, 13 h less, 1 h more) for adductor canal than femoral. The estimated hazard ratio of meeting all four discharge criteria was 1.26 (95% CI, 0.80 to 1.96) for adductor canal *versus* femoral (proportional hazards assumption was not violated, $P = 0.08$). In other words, subjects with an adductor canal catheter were 26% more likely to meet all four discharge criteria at any one time than subjects with a femoral catheter. In terms of discrete days after surgery, on POD 1, seven (18%) of the subjects with an adductor canal catheter met the four discharge readiness criteria *versus* only two subjects (5%) with a femoral catheter ($P = 0.004$). However, by POD 2, there was no statistically significant difference between the treatment groups (51 *vs.* 44%, $P = 0.157$; fig. 1). Therefore, use of a continuous adductor canal catheter possibly hastened overall discharge readiness for 5 of 39 subjects (13%), who would have been discharged the following day if they had instead received a femoral perineural infusion.

Secondary Endpoints

On POD 1, 72% of subjects in the adductor canal group were able to fulfill both the Timed Up and Go test (fig. 2) and ambulation (fig. 3) criteria compared with 27% in the femoral catheter group ($P < 0.001$; table 3). In contrast, there were minimal differences between treatment groups in both pain scores at rest (fig. 4) and supplemental opioid requirements (fig. 5).

The femoral catheter group reported superior analgesia during physical therapy sessions compared with the adductor canal catheter group (table 4), and this group demonstrated a higher mean/median passive knee flexion with a femoral catheter although this difference did not reach statistical significance (7 to 15 degrees; $P = 0.15$; table 3). There were no statistically significant differences detected between the two groups regarding passive knee extension (table 3), catheter site leakage during the first 2 days of infusion, day of actual hospital discharge (table 5), or health-related quality-of-life 1 week after surgery (fig. 6). However, a larger percentage of subjects with a femoral catheter had their basal infusion rate decreased by POD 3 ($P < 0.001$), whereas a larger percentage of subjects with an adductor canal catheter had their basal infusion rate increased during the same period of time ($P < 0.001$; table 5). This resulted in subjects with an adductor canal catheter consuming more local anesthetic relative to those with a femoral catheter ($P = 0.004$; table 5).

Major Protocol Violations and Adverse Events

One adductor canal catheter broke external to the subject in the late evening of POD 1 for an unknown reason. For purposes of analysis, this subject was retained in her treatment group per the intention-to-treat principle.³⁸ There were seven subjects erroneously discharged a day early on POD 2 after meeting all discharge criteria: four (10%) and three (7%) with adductor canal and femoral catheters, respectively. There were five (6%) falls total, two subjects (5%) with adductor canal

Table 2. Postrandomization Catheter Insertion and Perioperative Characteristics

	Adductor Canal (n = 39)	Femoral (n = 41)	P Value
Catheter insertion time (min)	3.9 (3.1–5.7)	2.6 (1.9–3.7)	<0.001
Difficulty placing catheter (no.)	4 (10%)	1 (3%) ¹	0.20
Worst pain during placement (NRS)	1 (0–3)	1 (0–1)	0.21
Fentanyl for catheter insertion (μg)	50 (50–100)	75 (50–100)	0.93
Midazolam for catheter insertion (mg)	2 (1–2)	2 (1–2)	0.96
General anesthetic (no.)	27 (69%)	29 (71%)	0.88
Time of incision (hour of day)	10:00 (8:00–13:00)	11:00 (8:00–13:00)	0.22
Tourniquet duration (min)	100 ± 21	106 ± 19	0.25
Surgical start to stop (min)	113 ± 32	115 ± 21	0.78
OR morphine equivalents (mg)	13 (5–17)	13 (8–16)	0.50

Values are reported as mean ± SD, median (interquartile), or number of subjects (percentage of treatment group), as appropriate. P values were derived from t test or Wilcoxon rank sum test for continuous variables and Pearson chi-square test or Fisher exact test for categorical variables. All tests were two sided. Superscript number represents missing value.

NRS = numeric rating scale for pain (0–10; 0: no pain, 10: worst pain imaginable); OR = operating room.

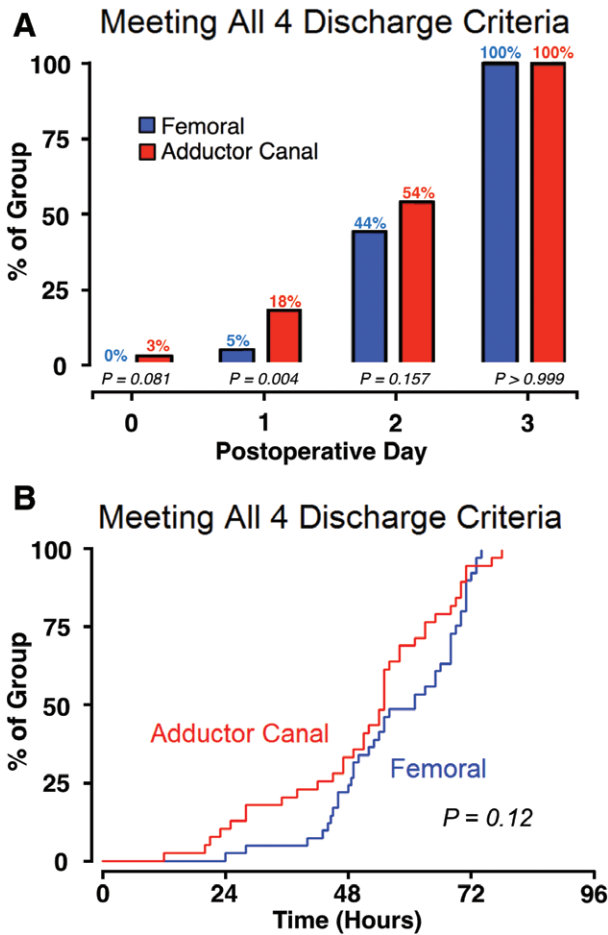


Fig. 1. Effects of perineural catheter location—adductor canal versus femoral—on the time to reach four important discharge criteria (adequate analgesia, independence from intravenous opioids, independent ambulation ≥ 30 m, and the ability to independently stand, walk 3 m, return, and sit down) after tricompartment knee arthroplasty. Data presented are the percentage of each treatment group to achieve all four criteria at each time point (A). Kaplan–Meier estimates of the cumulative percentages of subjects meeting all four discharge criteria at each time point and subsequent time points (B). Subjects with an adductor canal catheter reached all four criteria in a median of 55 h (interquartile range, 42 to 63 h) compared with 61 h (49 to 69 h) for those with a femoral catheter (95% CI for difference in medians: -13 to 1 h; $P = 0.12$). For each secondary outcome, we used an overall significance criterion of 0.003 (i.e., 0.05/17, a total of 17 secondary outcomes, Bonferroni correction) to control the type I error at 0.05 for this set of outcomes.

catheters on PODs 1 and 3 and three subjects (7%) with femoral catheters on PODs 1, 2, and 3. There were no injuries or complications as a result of these falls. No catheter-related infections or nerve injuries were identified.

Discussion

This dual-center, randomized, controlled, parallel-arm clinical trial provides strong evidence that a continuous

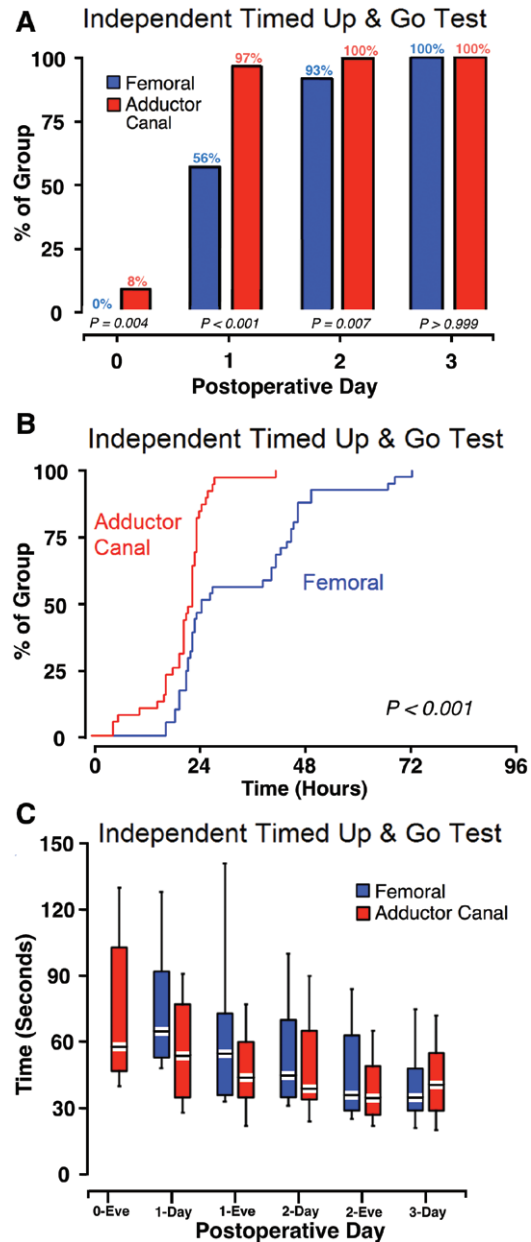


Fig. 2. Effects of perineural catheter location—adductor canal versus femoral—on the Timed Up and Go test (independently stand, walk 3 m, return, and sit down) after tricompartment knee arthroplasty, using a four-legged walker. Data presented are the percentage of each treatment group to achieve the specified criteria at each time point (A); Kaplan–Meier estimates of the cumulative percentages of subjects meeting the specified criteria at each time point and subsequent time points (B); and time to perform the specified criteria as median (horizontal bar) with 25th to 75th (box) and 10th to 90th (whiskers) percentiles (C). Subjects with a continuous adductor canal block attained the ability to independently stand, walk 3 m, return, and sit down in a median of 23 h (interquartile range, 19 to 24 h) compared with 25 h (22 to 46 h) for those with a continuous femoral nerve block ($P < 0.001$). For each secondary outcome, we used an overall significance criterion of 0.003 (i.e., 0.05/17, a total of 17 secondary outcomes, Bonferroni correction) to control the type I error at 0.05 for this set of outcomes.

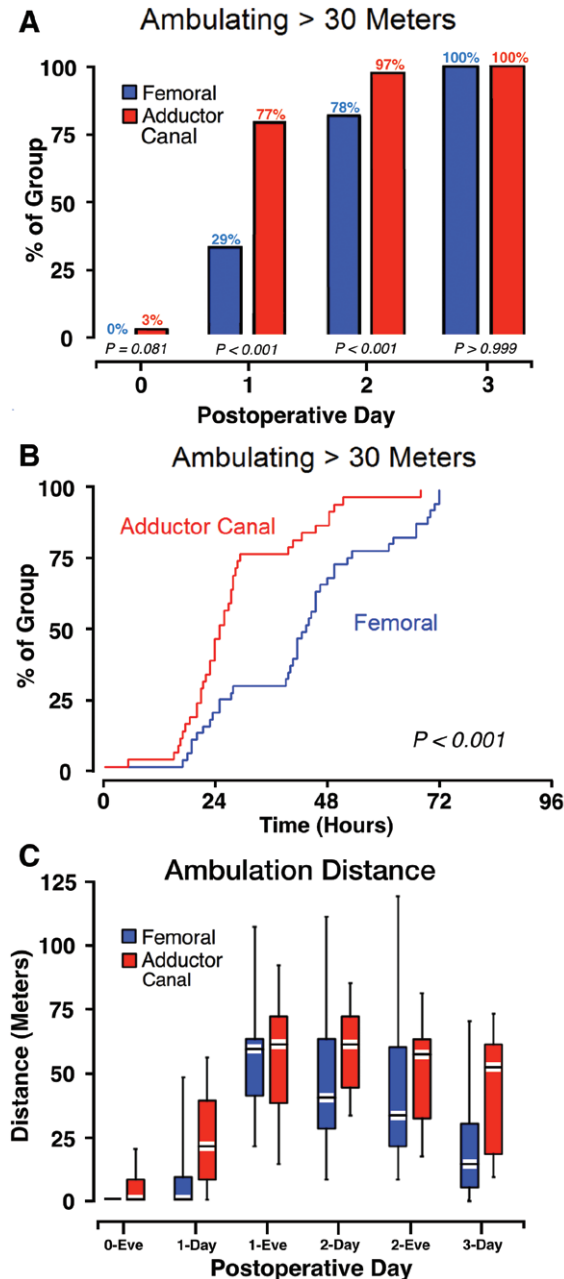


Fig. 3. Effects of perineural catheter location—adductor canal *versus* femoral—on ambulation after tricompartment knee arthroplasty, using a four-legged walker. Data presented are the percentage of each treatment group to ambulate at least 30 m at each time point (A); Kaplan-Meier estimates of the cumulative percentages of subjects ambulating at least 30 m at each time point and subsequent time points (B); and distance of ambulation as median (horizontal bar) with 25th to 75th (box) and 10th to 90th (whiskers) percentiles (C). Subjects with a continuous adductor canal block attained the ability to ambulate at least 30 m in a median of 25 h (interquartile range, 21 to 29 h) compared with 44 h (28 to 53 h) for those with a continuous femoral nerve block ($P < 0.001$). For each secondary outcome, we used an overall significance criterion of 0.003 (i.e., 0.05/17, a total of 17 secondary outcomes, Bonferroni correction) to control the type I error at 0.05 for this set of outcomes.

adductor canal block does not appreciably decrease the time to overall discharge readiness compared with a continuous femoral nerve block after tricompartment knee arthroplasty. Although an adductor canal infusion did decrease the time to achieve adequate mobilization, this had minimal effects on overall discharge readiness because both groups experienced similar analgesia and intravenous opioid requirements that—in most cases—exceeded the time required for adequate mobilization. Because the adductor canal infusions provided similar analgesia at rest compared with their femoral counterparts, these findings suggest that continuous adductor canal blocks may be preferable due to their greatly decreased inhibition of mobilization and ambulation—both important components of recovery after knee arthroplasty.³⁹ Conversely, femoral catheters provided superior dynamic analgesia during physical therapy ($P = 0.01$ and 0.02), and this group had a higher mean/median passive knee flexion although this difference did not reach statistical significance ($P = 0.15$).

Although previously published randomized studies have reported similar findings for some of the outcome measurements of the current trial, this is the first study—to our knowledge—to determine the relative effects of using an adductor canal *versus* femoral perineural infusion of multiple days on discharge readiness after knee arthroplasty using objective, prospectively determined discharge criteria.

Previous studies examining the adductor canal block support its efficacy of perioperative analgesia for total knee arthroplasty relative to placebo.^{19,21} A single-injection adductor canal block has also been shown to exhibit improved quadriceps strength and noninferior analgesia when compared with a single-injection femoral nerve block for total knee arthroplasty.¹⁵

Two previous randomized studies examined *continuous* adductor canal blockade *versus* *continuous* femoral nerve blockade for total knee arthroplasty. Jaeger *et al.* compared quadriceps muscle strength using a hand-held dynamometer the day after surgery, whereas Shah and Jain²⁰ compared mobilization ability using the Timed Up and Go, 10-m walk, and 30-s chair stand/sit tests.²² Unlike the current study, both previous investigations included a large bolus of long-acting local anesthetic (30 ml of 0.5% or 0.75% ropivacaine) during postoperative catheter insertion. Furthermore, they provided perineural local anesthetic for 24 or fewer hours, leaving a relatively short period of time between the initial block resolution and perineural catheter removal. In addition, the primary endpoints for both investigations were measured at a maximum of 24 h postoperatively. Our study, in contrast, extended previous work by providing a 3-day perineural infusion and measuring the primary endpoint for 72 h or until discharge readiness was attained, whichever occurred later.

Discharge Criteria

Among the four required discharge criteria, we did not detect a statistically significant difference in two: time until

Table 3. Physical Therapy *Functional* Endpoints

	Adductor Canal (n = 39)	Femoral (n = 41)	P Value
Subjects participating on POD 0	21%	15%	
Independently <i>stand and sit</i> (% of treatment group)			<0.001
POD 0 afternoon	63	0	
POD 1 morning	89	38	
POD 1 afternoon	100	68	
POD 2 morning	100	93	
POD 2 afternoon	100	91	
POD 3 morning	100	100	
Independent <i>Timed Up and Go test</i> (% of treatment group)			<0.001
POD 0 afternoon	38	0	
POD 1 morning	79	31	
POD 1 afternoon	100	65	
POD 2 morning	100	88	
POD 2 afternoon	100	86	
POD 3 morning	100	100	
<i>Quadriceps weakness</i> limiting physical therapy (% of treatment group)			0.07
POD 0 afternoon	13	50	
POD 1 morning	0	39	
POD 1 afternoon	0	24	
POD 2 morning	0	5	
POD 2 afternoon	0	3	
POD 3 morning	4	3	
Passive knee <i>flexion</i> (degrees)			0.15
POD 0 afternoon	79 (74–89)	94 (90–96)	
POD 1 morning	85 (70–92)	92 (77–98)	
POD 1 afternoon	88 (76–95)	96 (80–105)	
POD 2 morning	85 ± 14	91 ± 14	
POD 2 afternoon	88 ± 10	94 ± 13	
POD 3 morning	86 ± 12	94 ± 10	
Passive knee <i>extension</i> (degrees)			0.97
POD 0 afternoon	5 (4–7)	9 (5–10)	
POD 1 morning	4 (3–6)	7 (3–8)	
POD 1 afternoon	5 (3–7)	5 (2–8)	
POD 2 morning	4 (2–7)	5 (2–6)	
POD 2 afternoon	4 (2–6)	3 (1–5)	
POD 3 morning	4 (2–6)	5 (2–6)	

Values are reported as mean ± SD, median (interquartile), or percentage of treatment group, as appropriate. *P* values were derived from log-rank test for time-to-event outcomes or repeated-measures general linear model with an autoregressive covariance structure for passive knee flexion and extension (after logarithmic transformation). All tests were two sided. We used a significance criterion of 0.003. No treatment-by-time interaction: *P* = 0.78 and *P* = 0.36 for passive knee flexion and extension, respectively. For both the stand/sit and Timed Up and Go tests, a four-legged walker was used by all subjects.

POD = postoperative day.

adequate analgesia and independence from intravenous opioids. However, there were remarkable differences for the remaining two criteria: time until able to independently ambulate 30 m and independently stand, walk 3 m, return, and then sit down. These findings are consistent with data from one of the two previously published studies comparing adductor canal and femoral continuous nerve blocks, by Shah and Jain,²⁰ and considerably extends the observation period. The second related study, by Jaeger *et al.*, found improved quadriceps strength for subjects with adductor canal catheters (retaining 52 *vs.* 18% of baseline; *P* = 0.004), a difference that did not translate into improved ambulation or mobilization—in contrast with our current results.²²

Differences may be attributable to lower power in the previous study due to a smaller sample size (48 *vs.* 80 subjects), a large (30 ml) initial bolus of 0.5% ropivacaine combined with outcomes measured only 24 h later, or a fixed basal infusion (8 ml/h) without patient-controlled bolus doses.

One notable difference previously unreported in similar studies is that the subjects with adductor canal catheters reported greater degrees of pain during their physical therapy sessions compared with the group with femoral catheters (although a study involving single-injection blocks did detect a similar difference at 24 h).⁴⁰ This association may be due to subjects with adductor canal catheters ambulating further, inducing a greater degree of dynamic pain; or,

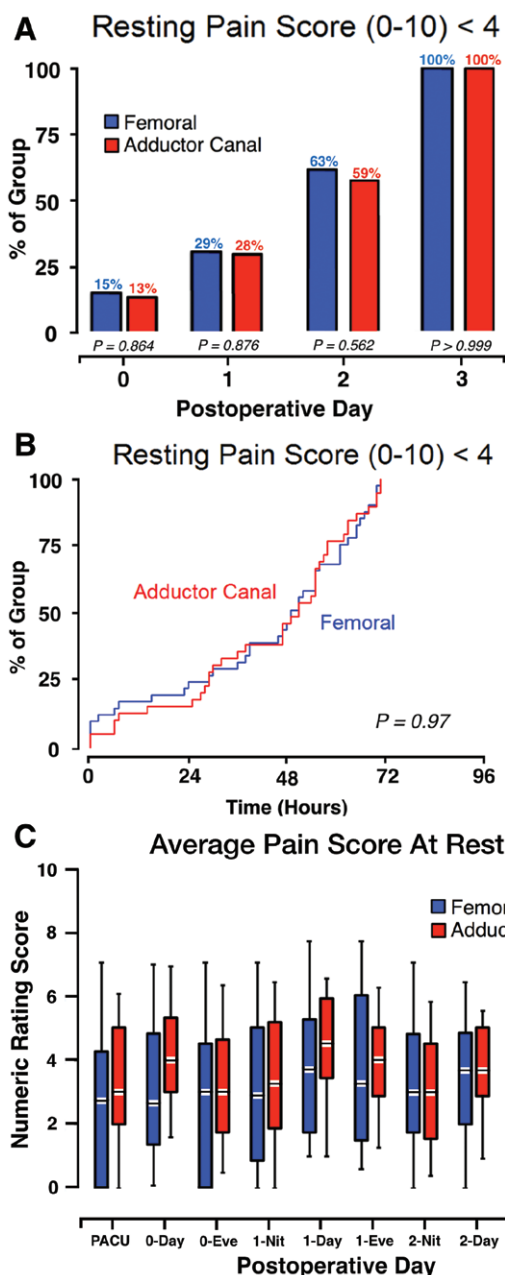


Fig. 4. Effects of perineural catheter location—adductor canal *versus* femoral—on analgesia after tricompartment knee arthroplasty. Data presented are the percentage of each treatment group to have a mean numeric rating scale (NRS) for pain less than 4 at each time point (A); Kaplan-Meier estimates of the cumulative percentages of subjects with a mean NRS less than 4 at each time point and subsequent time points (B); and mean NRS presented as median (*horizontal bar*) with 25th to 75th (*box*) and 10th to 90th (*whiskers*) percentiles (C). Subjects with a continuous adductor canal block attained a mean NRS less than 4 in a median of 51 h (interquartile range, 29 to 58 h) compared with 49 h (29 to 61 h) for those with a continuous femoral nerve block ($P = 0.97$).

it might be because femoral catheters provided superior analgesia, regardless of ambulation distance. The fact that subjects with a femoral catheter had a greater mean/median

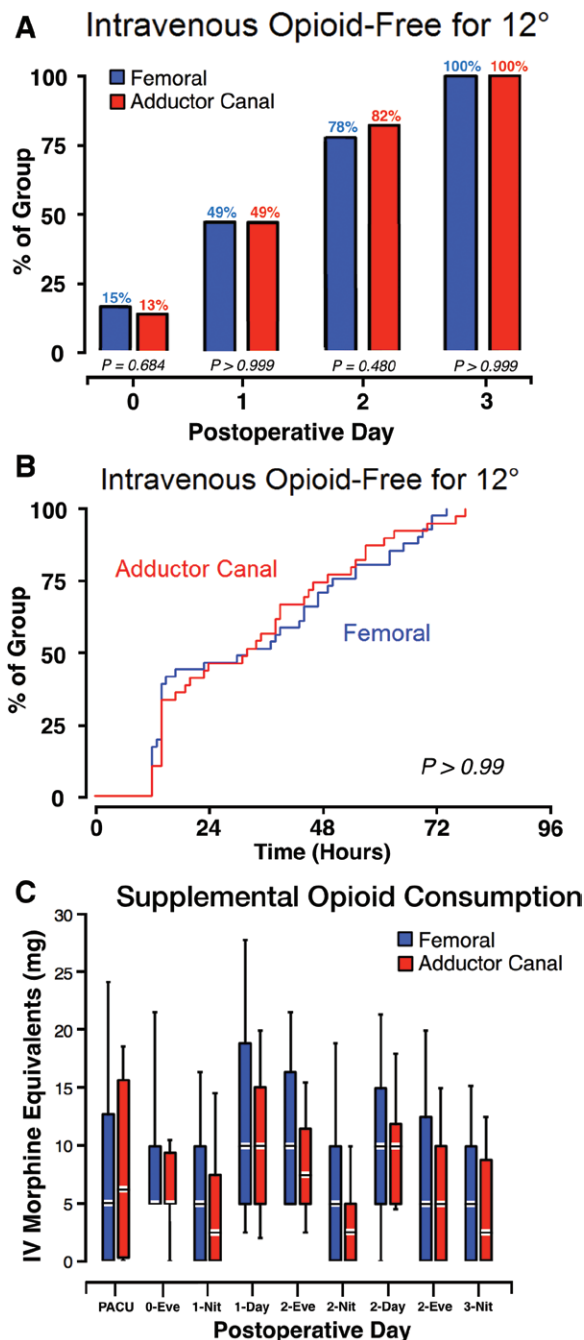


Fig. 5. Effects of perineural catheter location—adductor canal *versus* femoral—on supplemental opioid requirements after tricompartment knee arthroplasty. Data presented are the percentage of each treatment group free of intravenous opioids for the previous 12 h at each time point (A); Kaplan-Meier estimates of the cumulative percentages of subjects free of intravenous opioids for the previous 12 h at each time point and subsequent time points (B); and mean oral and intravenous supplemental opioid requirements (morphine equivalents) as median (*horizontal bar*) with 25th to 75th (*box*) and 10th to 90th (*whiskers*) percentiles (C). Subjects with a continuous adductor canal block were free from intravenous opioids for the previous 12 h in a median of 32 h (interquartile range, 14 to 48 h) compared with 32 h (14 to 50 h) for those with a continuous femoral nerve block ($P > 0.99$).

Table 4. Physical Therapy Analgesia Endpoints

	Adductor Canal (n = 39)	Femoral (n = 41)	P Value
Subjects participating POD 0	21%	15%	
Average pain during session (NRS)	4 (1–6)	2 (2–3)	0.02
POD 0 afternoon	4 ± 2	4 ± 2	
POD 1 morning	4 ± 2	3 ± 2	
POD 1 afternoon	4 ± 2	3 ± 2	
POD 2 morning	3 ± 2	3 ± 2	
POD 2 afternoon	4 ± 2	3 ± 2	
POD 3 morning			
Worst pain during session (NRS)			0.01
POD 0 afternoon	6 (2–8)	3 (2–4)	
POD 1 morning	5 ± 2	5 ± 3	
POD 1 afternoon	5 ± 3	4 ± 3	
POD 2 morning	5 ± 2	4 ± 2	
POD 2 afternoon	4 ± 2	4 ± 3	
POD 3 morning	6 ± 2	4 ± 2	

Values are reported as mean ± SD or median (interquartile range), as appropriate. *P* values were derived from repeated-measures general linear model with an autoregressive covariance structure. All tests were two sided. We used a significance criterion of 0.003. No treatment-by-time interaction: *P* = 0.21 and *P* = 0.41 for average and worst pain scores, respectively.

NRS = numeric rating scale for pain (0–10; 0: no pain, 10: worst pain imaginable); POD = postoperative day.

passive knee flexion (7 to 15 degrees; *P* = 0.15) suggests the latter. Although the causative relationship among these variables requires further study, the clinical association remains: the desire for dynamic analgesia (favoring femoral catheters) and improved mobility (favoring adductor canal catheters) appears to be at odds; and, practitioners will need to determine the relative importance of each before choosing a catheter insertion site.

Perineural Infusion

We gave 30 ml lidocaine 2% for the initial bolus and ropivacaine 0.2% at 6 ml/h for the initial basal infusion. The basal infusion rate was adjusted in 2 ml/h increments up to twice per day according to pain needs and quadriceps strength. It is noteworthy that by the second POD, nearly a third of subjects with adductor canal catheters had been increased to 8 ml/h *versus* only 5% with femoral catheters. Conversely, nearly 50% of subjects with a femoral catheter had been decreased to 4 ml/h due to quadriceps weakness compared with not a single subject with an adductor canal catheter.

These results not only demonstrate the quadriceps sparing of adductor canal relative to femoral infusions but also suggest that adductor canal basal infusions of ropivacaine 0.2% should be initially set at a higher rate than their femoral counterparts. Consequently, the average infusion rate for the femoral catheters was less than the average infusion rate for the adductor canal block, 5 *versus* 8 ml/h. The optimal local anesthetic and concentration, basal infusion rate, bolus volume, and infusion regimen (basal-only, basal/bolus

combination, and repeated bolus doses) remain unknown and require further study.

Falls

Although single-injection femoral nerve blocks may not be associated with an increased risk of falls,^{9,41} continuous peripheral nerve blocks involving the femoral nerve *have* been associated with an increased risk of falling.^{4–6} It remains unknown to what degree each induced deficit—motor, sensory, and proprioception—contributes to increased risk.⁴² The greatly reduced motor block induced by both single-injection and continuous adductor canal blocks relative to their femoral counterparts has raised hopes of decreasing the risk of falls.^{14,21} Our current study, with only two (5%) adductor canal and three (7%) femoral block subjects falling is underpowered for this important outcome and should not be taken as supporting or refuting the potential benefits of adductor canal blocks on falls.

Limitations

The anatomic location of catheter insertion used in this study mirrors that used by the majority of recent investigations involving the adductor canal block. The technique used was selected for its benefit shown by Lund *et al.*²⁶ and Jaeger *et al.*²¹ as well as the authors' examination of the underlying neuroanatomy and clinical observations. This technique has demonstrated analgesic benefit and preserved quadriceps strength for patients after knee arthroplasty. It also minimizes interference with the surgical field, thus decreasing the potential for catheter dislodgement and possibly reducing the theoretical impact of bacterial colonization or potential localized infection affecting the new implant.⁴³ However, the optimal catheter insertion site has not yet been determined.^{44–46} Therefore, our results may be applicable exclusively to catheters inserted midway on the line between the anterior superior iliac spine and the cephalad margin of the patella.

Similarly, the optimal perineural local anesthetic infusion regimen has yet to be elucidated. For continuous blocks involving the femoral nerve, dose appears to be the predominant determinant of infusion effects relative to local anesthetic concentration or basal rate; therefore, we do not believe that a change in ropivacaine concentration would produce differing results.^{47–49} However, it remains unknown whether local anesthetic introduced into the adductor canal as regularly scheduled bolus doses—as opposed to a basal infusion and added patient-controlled bolus doses—would change the pharmacodynamics of the infusion.⁵⁰ In addition, both treatment groups received intraoperative joint infiltration of ropivacaine, ketorolac, epinephrine, and tranexamic acid. It thus remains unknown whether the results of our study would be different if this infiltration was not included or modified. Furthermore, practitioners were more experienced placing femoral compared with adductor canal catheters, at least during the first half of enrollment; thus, our finding

Table 5. Infusion-related Endpoints

	Adductor Canal (n = 39)	Femoral (n = 41)	P Value
Total local anesthetic administered, ml	514 ± 80 ⁹	447 ± 97 ⁸	0.004
Basal rate on morning of POD 1 (no.), ml/h			0.08
4	0%	2%	
6	85%	93%	
8	15%	5%	
Basal rate on morning of POD 2 (no.), ml/h			<0.001
4	0% ¹	46%	
6	71%	49%	
8	29%	5%	
Basal rate on morning of POD 3 (no.), ml/h			<0.001
2	0% ⁹	6% ⁸	
4	3%	45%	
6	63%	39%	
8	30%	9%	
Fluid leakage at catheter site (no.)			
By morning of POD 1	5%	5%	0.99
By morning of POD 2	21% ¹	20%	0.86
By morning of POD 3	10% ⁹	33% ⁸	0.03
Inadvertent catheter dislodgement			
By morning of POD 1	3%	0%	0.49
By morning of POD 2	5% ¹	12%	0.43
By morning of POD 3	6% ⁸	15% ⁸	0.43
Actual discharge*			
Hours from surgical stop	74 (69–76)	73 (70–77)	0.97
POD 2	10%	7%	
POD 3	79%	78%	
POD 4	10%	15%	

Values are reported as median (interquartile) or percentage of treatment group, as appropriate. *P* values were derived from *t* test or Wilcoxon rank sum test for continuous or ordinal variables and Pearson chi-square test or Fisher exact test for categorical variables. All tests were two sided. We used a significance criterion of 0.003. Superscript numbers represent missing values.

* Adductor canal group percentages do not add to 100% due to rounding of values at individual time points.

POD = postoperative day.

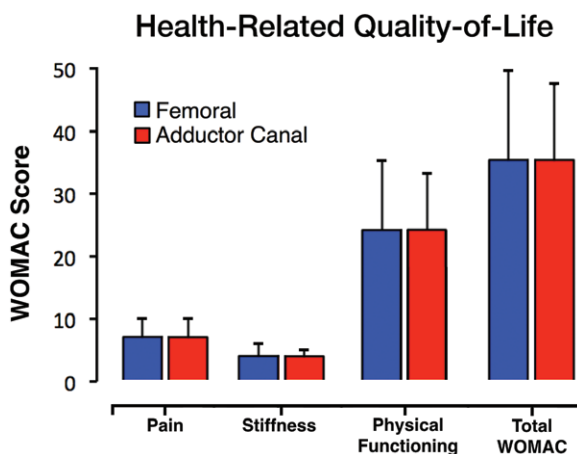


Fig. 6. Effects of perineural catheter location—adductor canal *versus* femoral—on the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) quality-of-life questionnaire 1 week after tricompartment knee arthroplasty. Data are presented as mean (SD) for each treatment group. There are no statistically significant differences between the treatment groups (*P* = 0.92).

that adductor canal catheters required 50% more time for insertion than their femoral counterparts may have been strongly influenced by this difference in familiarity.

Last, subjects and investigators were not masked to treatment group. Although it is unlikely that subjects had a predisposition toward one insertion site *versus* another, outcome assessors (nursing staff, physical therapists, and investigators) may have had preconceived bias toward one of the two treatments. In addition, caretaker bias may have been subconsciously transferred to patients, and therefore biased the results.

Conclusions

Compared with a continuous femoral nerve block, a continuous adductor canal block decreased the time to achieve adequate mobilization for discharge after tricompartment knee arthroplasty. This resulted in minimal overall earlier discharge readiness because both groups experienced similar analgesia and intravenous opioid requirements that—in most cases—exceeded the time to attain adequate mobilization. Adductor

canal blocks may nonetheless be preferable to femoral nerve blocks because they better preserve quadriceps strength and shorten time until adequate mobilization is achieved while providing comparable analgesia at rest. Conversely, femoral catheters provide superior dynamic analgesia, and practitioners thus must decide the relative importance of this factor *versus* the relative benefits of adductor canal catheters on quadriceps strength and mobilization. These results may have been influenced by the unmasked design of this study.

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Competing Interests

The authors declare no competing interests.

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