Adductor Canal Block Provides Noninferior Analgesia and Superior Quadriceps Strength Compared with Femoral Nerve Block in Anterior Cruciate Ligament Reconstruction

Faraj W. Abdallah, M.D., Daniel B. Whelan, M.D., F.R.C.S.C., Vincent W. Chan, M.D., F.R.C.P.C., Govindarajulu A. Prasad, M.D., F.R.C.P.C., Ryan V. Endersby, M.D., F.R.C.P.C., John Theodoropolous, M.D., F.R.C.S.C., Stephanie Oldfield, B.S., Justin Oh, B.A., Richard Brull, M.D., F.R.C.P.C.

ABSTRACT

Background: By targeting the distal branches of the femoral nerve in the mid-thigh, the adductor canal block (ACB) can preserve quadriceps muscle strength while providing analgesia similar to a conventional femoral nerve block (FNB) for inpatients undergoing major knee surgery. In this randomized, double-blind, noninferiority trial, the authors hypothesized that ACB provides postoperative analgesia that is at least as good as FNB while preserving quadriceps strength after outpatient anterior cruciate ligament reconstruction.

Methods: A total of 100 patients were randomized to receive ACB or FNB with 20 ml ropivacaine 0.5% (with epinephrine). The authors sequentially tested the joint hypothesis that ACB is noninferior to FNB for cumulative oral morphine equivalent consumption and area under the curve for pain scores during the first 24 h postoperatively and also superior to FNB for post-block quadriceps maximal voluntary isometric contraction.

Results: The authors analyzed 52 and 48 patients who received ACB and FNB, respectively. Compared with preset noninferiority margins, the ACB–FNB difference (95% CI) in morphine consumption and area under the curve for pain scores were –4.8 mg (–12.3 to 2.7) ($P = 0.03$) and –71 mm h (–148 to 6) ($P < 0.00001$), respectively, indicating noninferiority of ACB for both outcomes. The maximal voluntary isometric contraction for ACB and FNB at 45 min were 26.6 pound-force (24.7–28.6) and 10.6 pound-force (8.3–13.0) ($P < 0.00001$), respectively, indicating superiority of ACB.

Conclusion: Compared with FNB, the study findings suggest that ACB preserves quadriceps strength and provides noninferior postoperative analgesia for outpatients undergoing anterior cruciate ligament reconstruction. (ANESTHESIOLOGY 2016; 124:1053-64)

ANTERIOR cruciate ligament (ACL) reconstruction is one of the most frequently performed orthopedic procedures.[1] The ability to perform ACL reconstruction on outpatient basis is largely dependent on an effective analgesic regimen that minimizes the role of systemic analgesics yet provides adequate postoperative pain control and eliminates the need for overnight stay or readmission.[2] Femoral nerve block (FNB) is an effective analgesic technique for ambulatory ACL reconstruction[3–6]; however, it weakens the quadriceps muscle,[7] an outcome that is preferably avoided. In addition, recent evidence of persistent strength deficits in patients receiving FNB further underscores the need for effective alternatives.[8]

Adductor canal block (ACB), a distal block of the femoral nerve performed in the mid-thigh,[9] is becoming an attractive alternative to FNB as the peripheral nerve block of

What We Already Know about This Topic

- Adductor canal block provides similar analgesia to femoral nerve block after total knee arthroplasty but with less quadriceps weakness
- Rigorous comparison of these blocks after anterior cruciate ligament repair has not been reported

What This Article Tells Us That Is New

- In a randomized trial of 100 subjects undergoing anterior cruciate ligament, analgesia from adductor canal block was not inferior to that from femoral nerve block, but quadriceps muscle strength was superior

choice for total knee arthroplasty.[10] By virtue of the distal anatomical location where it is performed, ACB offers an important advantage, namely preserving the strength of the

---

This article is featured in "This Month in Anesthesiology," page 1A.

<zdoi;10.1097/ALN.0000000000001043>

quadriceps femoris muscle,[9,11] while providing pain relief to the knee that is comparable to FNB.[12] However, generalizing these benefits of ACB to outpatient ACL reconstruction is problematic due to the differences in pain generators between knee arthroplasty[13,14] and ACL reconstruction,[15] as well as the unique requirements of short stay and immediate mobilization[2] for outpatient ACL reconstruction.[16] Importantly, our understanding of the functional anatomy within the adductor canal that is relevant to ACL reconstruction,[17] including the relationship between the saphenous and medial femoral cutaneous nerves,[17] remains limited. Indeed, preliminary evidence from trials of ACB in the setting of ACL reconstruction[18,19] is inconsistent; however, these studies suffer from several important methodological shortcomings. Therefore, the question of potential analgesic and motor-sparing benefits of ACB in the setting of ACL reconstruction remains unanswered.

We believe that ACB would be the preferred technique for ACL reconstruction if it provides postoperative analgesia that is at least as good as that of FNB, while preserving motor strength around the knee. Therefore, this randomized controlled trial aims to test the joint hypothesis that ACB provides noninferior analgesia, as measured by the cumulative opioid consumption and pain scores during the first 24 h postoperatively, and preserves quadriceps femoris muscle motor strength compared with FNB in adult patients undergoing ambulatory ACL reconstruction.

Materials and Methods

This trial received Research Ethics Board approval at Women's College Hospital (2012-0077-B) and was registered on www.ClinicalTrials.gov (NCT01791036; registered on February 12, 2013). The study was conducted at Women's College Hospital, an ambulatory center in Toronto, Ontario, Canada, fully affiliated with the University of Toronto, between May 2013 and March 2015. This study manuscript was compiled in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines[20,21] and the CONSORT extension for noninferiority trials.[22]

Study Participants

We enrolled adult patients aged 18 to 50 yr, with American Society of Anesthesiologists (ASA) physical classification I to II and body mass index 35 kg/m^2 or less, who were scheduled for elective unilateral ACL reconstruction. All subjects provided written informed consent to participate in this prospective, randomized, parallel-arm, patient- and assessor-blinded, placebo-controlled, superiority clinical trial. Patients were excluded in case of pregnancy; significant psychiatric or mental disorders precluding assessment; baseline neuropathy or neurological deficits involving the lower extremities; chronic pain or requirement of 30 mg or greater oxycodone (or equivalent) daily; nerve block contraindications, including coagulopathy

or bleeding diathesis, local skin infections, and allergy to local anesthetics; or any component of multimodal analgesia. Potential study participants were identified from individual surgeons' booking lists in advance of the surgery date. During the preadmission clinic visit before the day of surgery, the research coordinator interviewed eligible patients, introduced the study, and provided an information package describing the study procedures.

Randomization and Blinding

An investigator with no further involvement in the study generated a list of random numbers in varying block sizes by using an online computer randomization service (www. Randomization.com). The unique randomization code was used to randomize consenting study participants on a 1:1 ratio with no restrictions to either of the two study groups: ACB group or FNB group. The results of the allocation were concealed in sealed opaque envelopes and kept with the research coordinator. On the day of surgery, the research coordinator handed an envelope to the attending anesthesiologist or a directly supervised regional anesthesia fellow in the block procedure room immediately before administering the study block to the participant. The staff anesthesiologist or fellow performing the block had no further role in the study.

Preoperative Procedures

Oral acetaminophen 1,000 mg and celecoxib 400 mg were administered to all study participants 1 h before surgery, unless contraindicated. IV access was secured and pulse oximetry, blood pressure cuff, and electrocardiogram were applied upon patient arrival to the block procedure room. Patients received fentanyl 25 μg IV and/or midazolam 1 to 4 mg IV for analgesia and anxiolysis, respectively, as needed, before block performance.

Patient positioning for the block performance was identical regardless of group allocation. While lying supine, the operative limb was externally rotated at the hip and the knee was flexed. Block sites were similarly prepped using chlorhexidine gluconate and isopropyl alcohol swabs in all patients; and all blocks were performed using 20 ml ropivacaine 0.5% with epinephrine 1:200,000.

ACB Group. After sterile skin preparation with chlorhexidine and skin infiltration with 1% lidocaine, a high-frequency linear array transducer (6 to 13 MHz; SonoSite M-Turbo; SonoSite™, USA) probe protected by a 3M Tegaderm® (3M Health Care, USA) dressing was placed in the transverse position on the medial aspect of the mid-thigh. This ACB location has been shown to spare the innervation of the quadriceps muscle.[11,23–25] The femoral artery, vein, and sartorius muscle were identified. The saphenous branch of the femoral nerve is difficult to visualize, but it is usually located within the triangular hyperechoic region bound by the sartorius muscle superiorly, the vastus medialis laterally, and the adductor muscles medially.[9] The ACB was performed using

a 5- or 8-cm 22-gauge insulated needle (B. Braun Medical Inc., USA) inserted in plane with the ultrasound probe and advanced a lateral-to-medial approach until the needle tip was adjacent to the femoral artery, and 20 ml ropivacaine 0.5% with epinephrine 1:200,000 was injected in between the femoral artery and the sartorius muscle in 5-ml aliquots after negative aspiration.[26] A sham subcutaneous injection of 0.5 ml sterile normal saline injection was subsequently performed at the FNB site using ultrasound guidance with transducer pressure intended to simulate a real block procedure.

FNB Group. After sterile skin preparation with chlorhexidine and skin infiltration with 1% lidocaine, a high-frequency linear array transducer (6 to 13 MHz; SonoSite M-Turbo) probe protected by a 3M Tegaderm® dressing was placed parallel and slightly caudad to the inguinal crease and adjusted as necessary to visualize the femoral nerve in short axis. The femoral artery, vein, and iliopsoas muscle were identified. The femoral nerve was sought within a triangular hyperechoic region, deep to the fascia iliaca, lateral to the femoral artery, and superficial to the iliopsoas muscle. The FNB was performed using a 5- or 8-cm 22-gauge insulated needle (B. Braun Medical Inc.) inserted in plane with the ultrasound probe and advanced a lateral-to-medial approach until the needle tip was adjacent to the femoral nerve. Twenty milliliter ropivacaine 0.5% with epinephrine 1:200,000 was injected in 5-ml aliquots after negative aspiration for blood to achieve a spread above the femoral nerve, below the fascia iliaca. A sham subcutaneous injection of 0.5 ml sterile normal saline was subsequently performed at the ACB site using ultrasound guidance with transducer pressure intended to simulate a real block procedure.

Block Assessment. The blinded research coordinator performed baseline and postblock assessment of the sensory and motor blockade. Sensory blockade was assessed up to 30 min by comparing to the nonoperative limb, whereas motor blockade was assessed up to 60 min by comparing the operative limb to its own baseline.

Sensory assessment was performed every 5 min using a pinprick (25-gauge needle) applied to the sensory distribution of the saphenous nerve from medial aspect of the knee to the medial mid-calf in comparison to the nonoperative limb. The degree of sensory blockade was graded on a 3-point scale, where a score of 2 was given for intact sensation, 1 for loss of sensation to pinprick, and 0 for loss of sensation to light touch. A block was considered successful if complete loss of sensation (sensory score = 0) was achieved within 30 min from the end of local anesthetic injection. If block success was not achieved after 30 min, we reported block failure and the corresponding data using an intention-to-treat approach.

Power assessment was performed every 15 min using a handheld isometric force electromechanical dynamometer (MicroFET2; Hoggan Health Industries Inc., USA) that allowed evaluating the variation in quadriceps femoris motor strength (pound-force) in the operative limb during knee extension compared with the baseline. Patients were seated upright at the edge of the stretcher with their thighs horizontal and their legs dangling vertically relative to the floor. The dynamometer was placed on the anterior aspect of their operative leg, on the tibial crest, just above the ankle.[27] Patients were instructed to extend their knee against the dynamometer and to maintain the maximal force for 3 s. The maximal force was documented, and the mean of three consecutive measurements was considered as representative of the maximal voluntary isometric contraction (MVIC). These postblock measurements were repeated every 15 min up to 60 min before surgery, and the preserved percentage of the MVIC when compared with baseline was calculated.

Intraoperative Care

Patients were transferred to the operating room after block assessment, where standard monitoring including pulse oximetry, electrocardiogram, blood pressure cuff, and a skin temperature probe was applied. Patients were then administered a standardized general anesthesia by a blinded anesthesiologist, including propofol 2 to 4 mg/kg IV and fentanyl 1 to 3 µg/kg IV, followed by insertion of a laryngeal mask airway. Patients were allowed to breathe spontaneously using a 40:60 oxygen:air mixture with desflurane 5 to 7%. Supplemental analgesia was provided as needed in the form of fentanyl 1 to 2 µg/kg IV and/or morphine 0.05 to 0.1 mg/kg IV if heart rate and/or mean arterial pressure increased by 20% above the measured baseline. Ondansetron 4 mg IV dose was administered for postoperative nausea and vomiting (PONV) prophylaxis 30 min before the end of the case; dexamethasone use was avoided due to its potential confounding effect on the block characteristics.[28] No further local anesthetics were injected into the knee joint or the site of harvested graft.

Postoperative Management

Postoperatively, patients were transferred to the postanesthesia care unit (PACU) and were subsequently discharged home once they met the hospital discharge criteria.[29] Patient request for additional analgesics or pain in the PACU, defined as visual analog scale (VAS; 10-cm scale, where 0 = no pain and 10 = worst pain) pain severity score 4 or greater, was treated with fentanyl 25 to 50 µg IV every 5 min up to a total of 200 µg, followed by morphine 2 to 4 mg IV to a maximum of 20 mg, or hydromorphone 0.2 to 0.4 mg IV to a maximum of 3 mg, administered by blinded PACU nursing staff. Once oral intake was allowed, patients were able to receive oral analgesics, either Tylenol No. 3® (codeine 30 mg/acetaminophen 300 mg/caffeine 15 mg; Janssen-Ortho, Canada) or Percocet® (oxycodone hydrochloride 5 mg/acetaminophen 325 mg; Bristol-Myers Squibb, Canada) if they were allergic to codeine, as needed. Discharged patients received a prescription for Tylenol No. 3® or Percocet® if intolerant to codeine to use for pain control, as needed. PONV in the PACU was treated sequentially with ondansetron 2 to 4 mg IV, followed by dimenhydrinate 12.5 to 25 mg IV, and then metoclopramide 10 mg IV, as needed.

Discharged patients were provided with a postoperative home diary to document the time when they first experienced pain at the surgical site; pain severity scores; analgesic consumption; opioid-related side effects (nausea, vomiting, itching, or constipation); and satisfaction with pain relief received. The diary was returned to the investigators using a prestamped, self-addressed envelope.

Follow-up

All study participants received a scripted phone call from the research coordinator on postoperative days 1, 2, and 7 to remind them to complete and return their home diary and to inquire about any block-related postoperative neurologic symptoms (persistent numbness or paresthesia, weakness, or nonsurgical pain in the operative extremity). Any complications that were potentially block related were followed until resolution.

Outcome Measures

We sequentially[30] examined three primary outcomes: (1) the cumulative 24-h analgesic consumption (converted to oral morphine equivalent)[31] at home; (2) the area under the curve (AUC) for the postoperative rest pain severity VAS scores measured at PACU admission, at 30, 60, 90, and 120 min, and at 6, 12, and 24 h; and (3) the mean dynamometer reading of MVIC during knee extension of the operative limb at 60 min postblock, as a measure of quadriceps femoris muscle strength. Postblock presurgical assessment of MVIC was the most realistic measure in the outpatient surgical setting as postoperative movement restrictions and discharge preclude postsurgical assessment.

Block-related outcomes included (1) block procedure time, defined as time (minute) between applying the ultrasound probe to the patient's skin and needle withdrawal after local anesthetic injection; (2) block procedural pain, reported by patients as no pain, mild–moderate pain, and moderate–severe pain; (3) the difference in MVIC between the two study groups at 15, 30, 45, and 60 min after nerve block; (4) incidence of falls or near-falls during the first 24 h, as reported by patients; and (5) incidence of postoperative neurologic symptoms (persistent numbness or paresthesia, weakness, or nonsurgical pain in the operative extremity) at 7 days postoperatively.

Analgesic outcomes assessed included (1) intraoperative morphine equivalent requirements (milligram); (2) time (minute) to first analgesic request; (3) time (minute) to PACU discharge[29]; (4) postoperative pain severity (at rest) VAS scores (centimeter) at PACU admission, at 30, 60, 90, and 120 min, and at 6, 12, and 24 h; (5) interval postoperative analgesic consumption during the PACU stay, at 24 and 48 h, and at 7 days (converted to oral morphine equivalent)[31]; (6) incidence of PONV during the PACU stay and the first 24 h postoperatively; and (7) patient satisfaction with analgesia measured on a VAS (10-cm scale, where 0 = least satisfied and 10 = most satisfied) at 24 h postoperatively.

Apart from assessment of block onset, which was performed by the anesthesiologist administering the block, all outcome data were collected by a blinded research coordinator. To assess the success of blinding, all patients were asked which block they think they had received.

Statistical Analysis

We aimed to test the hypothesis[30] that ACB produces postoperative analgesia that is at least as good as FNB while maintaining quadriceps motor strength compared with FNB. The choice of hypotheses and the specific order of their testing were informed by our contemporary clinical and anatomical knowledge of the interventions performed and the outcomes measured. We recognized *a priori* that (1) the ACB was unlikely to produce superior analgesia to FNB in knee surgery[32]; (2) neither opioid consumption nor pain severity scores in isolation were sufficient measures[33] to demonstrate noninferiority of postoperative analgesia; and (3) FNB *per se* may not provide sufficient analgesia in the setting of ACL reconstruction.[34,35] Proving that ACB provides noninferior analgesia was thus a necessary prerequisite before examining the effect on motor strength. We chose the joint hypothesis testing approach with the serial gatekeeping procedure described by Mascha and Turan.[36] We sought to sequentially demonstrate that ACB was noninferior to FNB for postoperative analgesic consumption and then for postoperative pain scores, followed by attempting to prove the superiority of ACB in preserving motor strength. The serial gatekeeping technique allowed us to test several hypotheses while maintaining the level of significance (α) for the one-sided test of noninferiority at 0.025 and at 0.05 for the two-sided test of superiority provided that each hypothesis in the series is proven before proceeding to the next one.[36,37]

Institutional pilot (R.B., unpublished data, April 2012) data from 12 patients undergoing ACL reconstruction with FNB and using a multimodal analgesic regimen inclusive of FNB with 20 ml ropivacaine 0.5% were used to power this trial. We based our sample size estimate on testing the one-sided ACB noninferiority hypothesis of the mean cumulative oral morphine equivalent consumption at 24 h, our first primary outcome. Our institutional data suggest that the cumulative oral morphine equivalent consumption for the first 24 h postoperatively in patients undergoing ACL reconstruction is 41.5 ± 19.6 mg. Considering a noninferiority margin (Δ) of 25% (*i.e.*, 10 mg morphine), and assuming that the true difference in 24-h oral morphine equivalent consumption between the ACB and FNB treatment groups is 0%, a power analysis using a type I error estimate of 5% ($\alpha = 0.05$), a power (1-β) of 80% indicated that a sample of 45 patients per group would be needed. To account for attrition resulting from incomplete follow-up or dropout of recruited patients, we chose to inflate the sample size by 10%. Consequently, we aimed to enroll a total of 50 patients per group or a total of 100 patients for this study.

Our pilot data suggest that the AUC of postoperative pain VAS scores during the first 24 h for patients who undergo ACL reconstruction with FNB to be 743 ± 312 mm h. Considering that a 30% relative reduction in AUC would be clinically significant,[38,39] we selected a 25% relative reduction as a noninferiority margin (Δ). Assuming the true difference in AUC to be 0%, the above calculated sample size provides 90% power for a one-sided test of noninferiority using $\alpha = 0.05$.

Our pilot data suggest that baseline quadriceps motor strength in patients before receiving FNB is equivalent to 30.3 ± 10.3 pound-force during MVIC. Based on evidence that up to 19% difference in MVIC values between the two lower extremities in the same individual is considered normal,[40–43] we assumed that a 25% reduction in MVIC at 60 min after a nerve block to be clinically significant. Although other studies have considered a 50% reduction to be clinically significant,[44,45] we felt that a much smaller difference would be clinically relevant in the immediate postoperative period after ACL reconstruction. As such, the above calculated sample size provides 84% power at $\alpha = 0.05$ to detect this difference between the ACB and FNB groups.

The SPSS for Windows statistical package (Version 22; IBM, USA) was used in our calculations. We used the Kolmogorov–Smirnov test to confirm the normality of data distribution. All of our analyses were performed using an intention-to-treat approach. Continuous data are presented as mean (SD) or mean (95% CI) and were analyzed by using the Student's t test. Categorical data are presented as numbers or percentages and were analyzed using the chi-square or Fisher exact test, as appropriate. Ordinal data are presented as median (95% CI) and were analyzed by using the Mann–Whitney–Wilcoxon U test. We performed noninferiority testing for a particular outcome by comparing the 95% CI of the difference between groups ACB and FNB to the predetermined noninferiority margin (Δ) for this outcome. The rest pain VAS scores are presented as AUC; the area was calculated using the weighted mean over a fixed time (trapezoid role) and analyzed by using the Mann–Whitney–Wilcoxon U test. We used the Student's paired t test to analyze the preblock and postblock motor strength comparisons within the same study group. We used the Kaplan–Meier survival analysis combined with the log-rank test for time-to-event outcomes. The threshold of statistical significance (P value) was set at 0.05, except if repeated measures of the same outcome were performed, in which case the Bonferroni–Holm correction was used.[46]

Results

We assessed 286 patients for eligibility, of which 115 did not meet the inclusion criteria, 69 declined, 1 had a change of surgical procedure, 1 had a change in the anesthetic plan, and 100 were recruited. Figure 1 depicts the CONSORT[20,21] flow diagram of patient progress through the study. All enrolled patients were randomized (ACB group: n = 52; FNB group: n = 48) and completed the study, and their data were analyzed. Data were complete for the primary outcomes assessed; only minimal secondary outcome data were missing. However, due to time constraints in the block procedure room and/or operating theater, evaluation of the MVIC at 60 min was not feasible, and this measurement was omitted. Enrolled patients had similar demographic characteristics, and no clinically important differences existed between the study groups (table 1). Block success was confirmed in all study participants.

The difference (95% CI) in cumulative 24-h oral morphine equivalent consumption between the study groups (ACB–FNB) was –4.8 mg (–12.3 to 2.7). The upper CI of the difference was significantly smaller ($P = 0.03$) than the predetermined noninferiority margin ($\Delta = 10$ mg) (fig. 2). Consequently, ACB was found to be noninferior to FNB in cumulative 24-h postoperative analgesic consumption after ACL reconstruction. Further testing of potential superiority of ACB for this outcome found no difference between the two study groups ($P = 0.21$) (table 2).

Pain (rest) severity VAS scores for the two groups during the first 24 h postoperatively were plotted over time to examine the AUC (fig. 3). The difference in AUC between the study groups (ACB–FNB) was –71 mm h (–148 to 6). The upper CI of the difference was significantly smaller ($P < 0.00001$) than the predetermined noninferiority margin ($\Delta = 186$ mm h) (fig. 4). Consequently, ACB was found to be noninferior to FNB in postoperative rest pain severity scores during the first 24 h after ACL reconstruction. Further testing of potential superiority of ACB for this outcome found no difference between the two study groups ($P = 0.07$) (table 2).

Starting from similar quadriceps femoris baseline strength in both groups (table 2), patients in ACB group were found to have significantly greater motor strength at 45 min postblock, with an MVIC of 26.6 pound-force (24.7–28.6) when compared with 10.6 pound-force (8.3–13.0) ($P < 0.00001$) for the FNB group (fig. 5). The decrease in quadriceps strength from baseline was statistically significant (paired t test) for both groups, with a 21.8 and 67.5% relative reduction in the ACB and FNB groups, respectively (table 2). In fact, patients in the ACB group had superior motor strength, as measured by the MVIC, at all of the time points examined, up to 45 min postblock. These findings of our joint hypothesis testing indicate that ACB provides noninferior analgesia up to 24 h postoperatively and preserves quadriceps muscle strength when compared with FNB in patients undergoing ACL reconstruction.

Both study groups had similar intraoperative opioid requirements as well as time-to-first postoperative analgesic request; but the patients in the ACB group were discharged from PACU 18 min earlier than those in the FNB group ($P = 0.02$) because they met the ambulation requirements of the discharge criteria earlier (table 2).
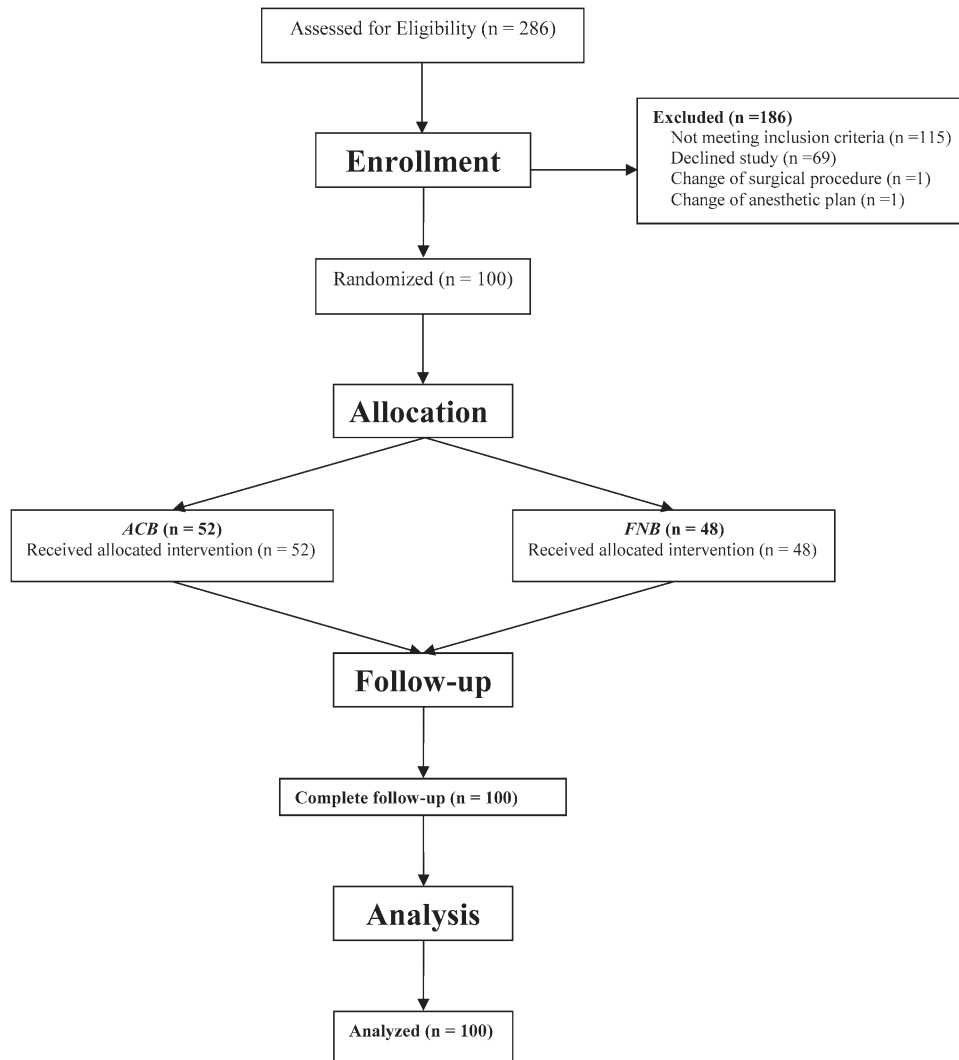
Fig. 1. Consolidated Standards of Reporting Trials flow diagram showing patient progress through the study phases. ACB = adductor canal block; FNB = femoral nerve block.

The postoperative rest pain severity VAS scores were similar for both groups at all of the time points examined (fig. 3) The postoperative interval oral morphine equivalent consumption was also similar between the two groups at all of the time points examined (fig. 6). There was no difference between the two groups in the incidence of PONV during PACU stay or at 24 h after ACL reconstruction (table 2). The degree of satisfaction with postoperative analgesia received was also similar between the two groups. The proportion of patients providing the correct answer to the question "which block do you think you received" was similar between the two groups (table 2), suggesting that the measures taken to maintain patient blinding throughout the trial interventions were successful. Three patients reported falls or near-falls after hospital discharge in the FNB group when compared with none in the ACB group; but the difference did not reach statistical significance. None of the patients reported postoperative neurologic symptoms when contacted at 7 days after ACL reconstruction.

Discussion

This study demonstrates that ACB is a superior analgesic modality to FNB in patients undergoing ACL reconstruction as it provides postoperative analgesia that is as effective as that of FNB while producing less weakness of the quadriceps femoris muscle than FNB. Both the analgesic consumption and pain control associated with ACB were noninferior to those associated with FNB during the first 24 h postoperatively, whereas the quadriceps weakness produced by ACB was significantly less compared with FNB.

In contrast to earlier work,[18,19,47] our findings favor the ACB in the setting of ACL reconstruction. Three studies[18,19,47] have previously attempted to explore the potential role of ACB in this population; however, each had important design and methodological limitations. Two

Table 1. Patient Characteristics

Parameters	Adductor Canal Block (N = 52)	Femoral Nerve Block (N = 48)	P Value
Age (yr)	31.6 (28.9–34.3)	33.3 (30.7–35.9)	0.36
Sex (female/male)	14/38	22/26	0.05
Height (cm)	171.8 (169.9–174.0)	172.4 (169.9–174.9)	0.16
Weight (kg)	81.3 (76.7–85.9)	79.4 (74.6–84.2)	0.56
American Society of Anesthesiologists physical status (I/II)	43/9	35/13	0.24
Surgical side (left/right)	26/26	21/27	0.53
Duration of surgery (min)	153 (144.7–161.4)	146 (137.6–154.4)	0.24
Surgical procedure			
Anterior cruciate ligament (ACL) reconstruction: hamstring	34	37	0.2
ACL reconstruction: bone-tendon-bone	18	11	0.2

Values are expressed as the mean (95% CI) or absolute numbers.
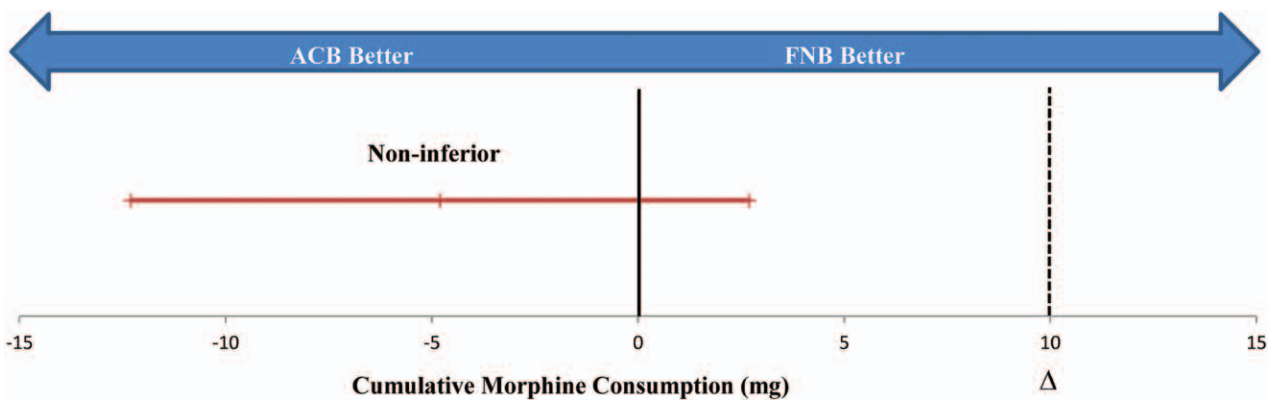

Fig. 2. Noninferiority diagram with the observed difference between the adductor canal block (ACB) group and the femoral nerve block (FNB) group in cumulative 24-h oral morphine equivalent consumption. The *dashed line* designates the noninferiority margin (Δ). The *error bars* designate the 95% CI of the (ACB–FNB) difference. The diagram indicates noninferiority of ACB for the outcome examined.

trials performed blocks postsurgically[18,19] while patients were still under general anesthesia and did not ascertain block success and not performed an objective assessment of quadriceps motor strength. In the first study, Espelund *et al.*[18] found no analgesic benefits when ACB was compared with placebo. Another major limitation of this trial is that it was designed to detect large changes (50%) in pain scores at a single time point (2 h postoperatively) while standing, in non–weight-bearing patients. Although opioid consumption and AUC of rest pain scores were examined, the trial lacked sufficient power to detect differences in these important outcomes. It is also noteworthy that the pain severity scores reported at 2 h in this study were unusually low and not commensurate with the findings of numerous other trials.[6,48–52] In the second trial, El Ahl[19] compared ACB to FNB and observed similar pain scores up to 12 h postoperatively, yet he concluded that ACB provided inferior analgesia based on differences in pain scores and analgesic consumption that can be attributed to the 12- to 24-h interval when both blocks would have already worn off. Finally, a third trial involving a variety of

arthroscopic knee surgeries resorted to *post hoc* subgroup analysis to tease out the analgesic benefits of postoperative ACB during the first 90 min specifically after ACL reconstruction and found ACB to be not better than placebo for rest pain.[47] Notably, patients undergoing ACL reconstruction with a hamstring graft were excluded from this study.

Our understanding of adductor canal anatomy, particularly nerves relevant to ACL reconstruction, remains limited and precludes an anatomically based theoretical assumption of analgesic effectiveness of the ACB.[17] For example, descriptions of the anatomical communication between the saphenous and medial femoral cutaneous nerves in the adductor canal have been inconsistent.[17,53] Furthermore, the posterior branch of the medial femoral cutaneous nerve, which provides cutaneous innervation to the medial thigh and leg, may not pass in the adductor canal in up to 40% of cases, whereas its anterior branch, which provides cutaneous innervation to the medial and lateral knee, is never part of the adductor canal.[14,17,53] As such, our trial provides much needed clinical evidence regarding the functional anatomy of the adductor canal relevant to ACL reconstruction.

Table 2. Analgesic and Other Outcomes Results

Outcomes	Adductor Canal Block (N = 52)	Femoral Nerve Block (N = 48)	P Value
Postoperative cumulative 24-h oral morphine equivalent consumption (mg)*	39.6 (34.6 to 44.6)	44.4 (38.6 to 50.2)	0.21
Area under the curve for postoperative visual analog scale (VAS) scores during the first 24 h (mm h)*	657 (606 to 708)	728 (673 to 783)	0.07
Quadriceps motor strength			
Baseline maximal voluntary isometric contraction (MVIC) (pound-force)	34.0 (32.1 to 35.9)	32.6 (30.3 to 34.9)	0.34
MVIC at 1 h (pound-force)*	26.5 (24.5 to 28.5)	9.5 (7.4 to 11.6)	< 0.00001
Percentage reduction at 1 h, %	22.1	70.8	< 0.00001
Paired *t* test (*t* critical)	10.3 (2.0)	15.8 (2.0)	Not applicable
Block procedure time (min)	6.0 (5.2 to 6.8)	7.0 (6.1 to 7.9)	0.1
Mild–moderate discomfort during block	4 (7.7)	0 (0)	0.14
Intraoperative IV morphine equivalent consumption (mg)	19.9 (17.7 to 22.2)	19.7 (17.5 to 21.9)	0.9
Time to first analgesic request (min)	100.0 (12.6 to 187.4)	83.0 (−6.1 to 172.3)	0.78
Time to postanesthesia care unit (PACU) discharge (min)	168.0 (158.0 to 178.0)	186.0 (174.4 to 197.6)	0.02
Incidence of postoperative nausea and vomiting			
In PACU	8 (15.4)	14 (29.2)	0.1
At 24 h	19 (36.5)	26 (54.2)	0.08
Incidence of falls and near-falls during the first 24 h	0 (0)	3 (6.3)†	0.17
Patient satisfaction with pain relief at 24 h (VAS)	6.8 (6.1 to 7.5)	6.2 (5.4 to 7.0)	0.27
Incidence of postoperative neurologic symptoms at 1 week (n/N) (numbness, paresthesia, weakness, or pain)	0 (0)	0 (0)	1.0
Correct answer to the question "which block do you think you received?"	26 (50)	24 (50)	1.0

Values are expressed as the mean (95% CI) or absolute numbers (%). n/N is the percentage.
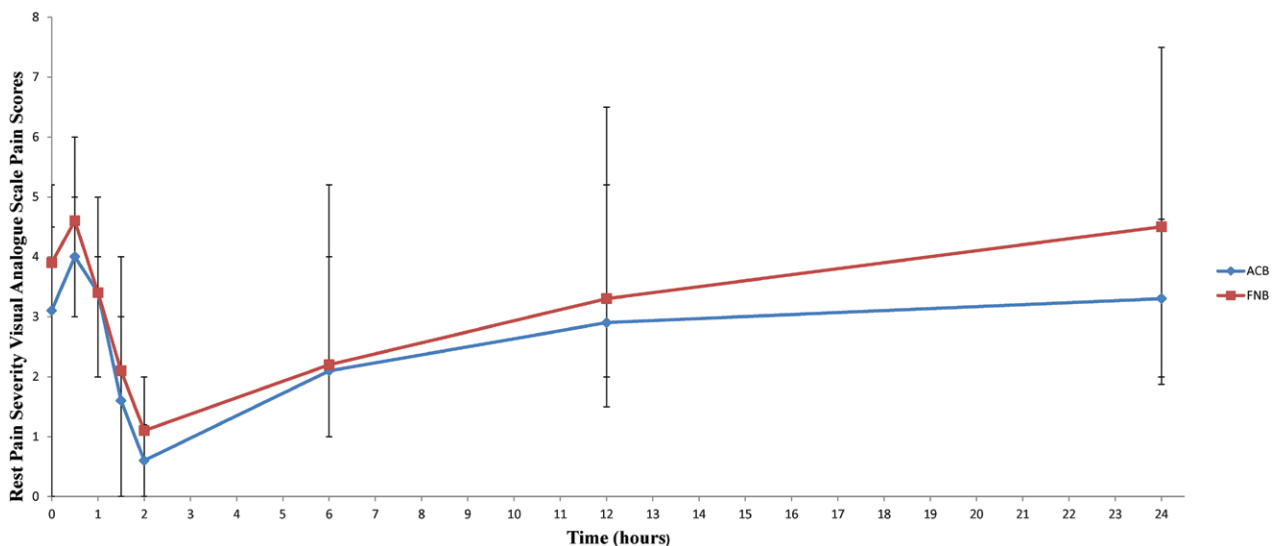*Primary outcome. †Two falls and one near-fall.

Fig. 3. Plot of the mean and interquartile range of postoperative rest pain severity visual analog scale scores during the first 24 h used for computing area under the curve. ACB = adductor canal block; FNB = femoral nerve block.

Our study is subject to several limitations. First, in terms of outcome selection, we did not include an assessment of posterior pain originating from the back of knee or the graft site[15]; neither FNB nor ACB may provide sufficient relief to this component of pain.[54] In fact, clinical evidence suggests that pain may occasionally arise in anatomical areas innervated by the sciatic[55] and obturator[56] nerves after ACL reconstruction. Accurate assessment of such pain requires thoughtful study designs that involve catheters and staged treatment of each pain component, according to its source, to permit isolation of the various contributors to pain.[57] However, in an attempt to explore the role of posterior knee pain in our results, we performed *post hoc* analysis according to the type of graft received; the results suggested no difference in pain severity between ACB and FNB (*P* = 0.06). In addition, our evaluation of overall the analgesic efficacy of
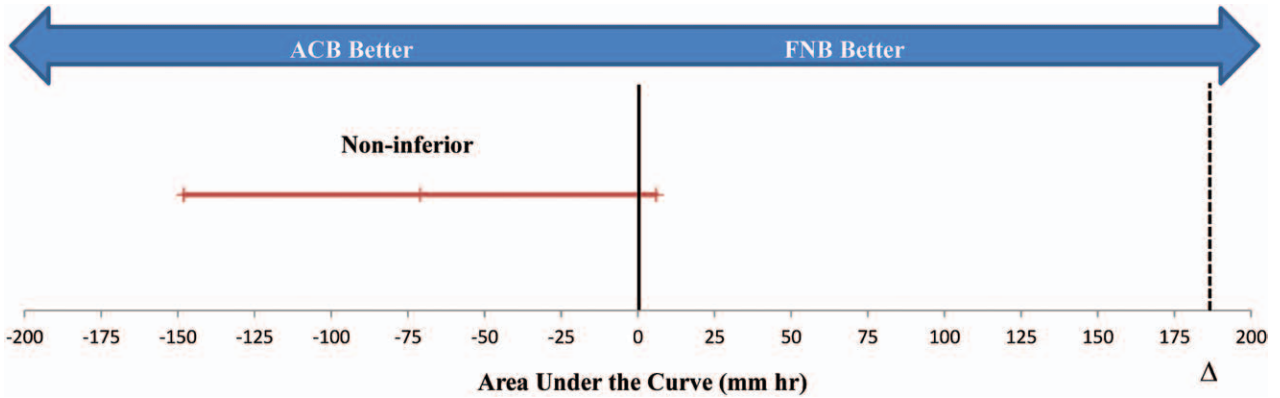
Fig. 4. Noninferiority diagram with the observed difference between the adductor canal block (ACB) group and the femoral nerve block (FNB) group in area under the curve for the postoperative rest pain severity visual analog scale scores for the first 24 h postoperatively. The *dashed line* designates the noninferiority margin (Δ). The *error bars* designate the 95% CI of the (ACB–FNB) difference. The diagram indicates noninferiority of ACB for the outcome examined.
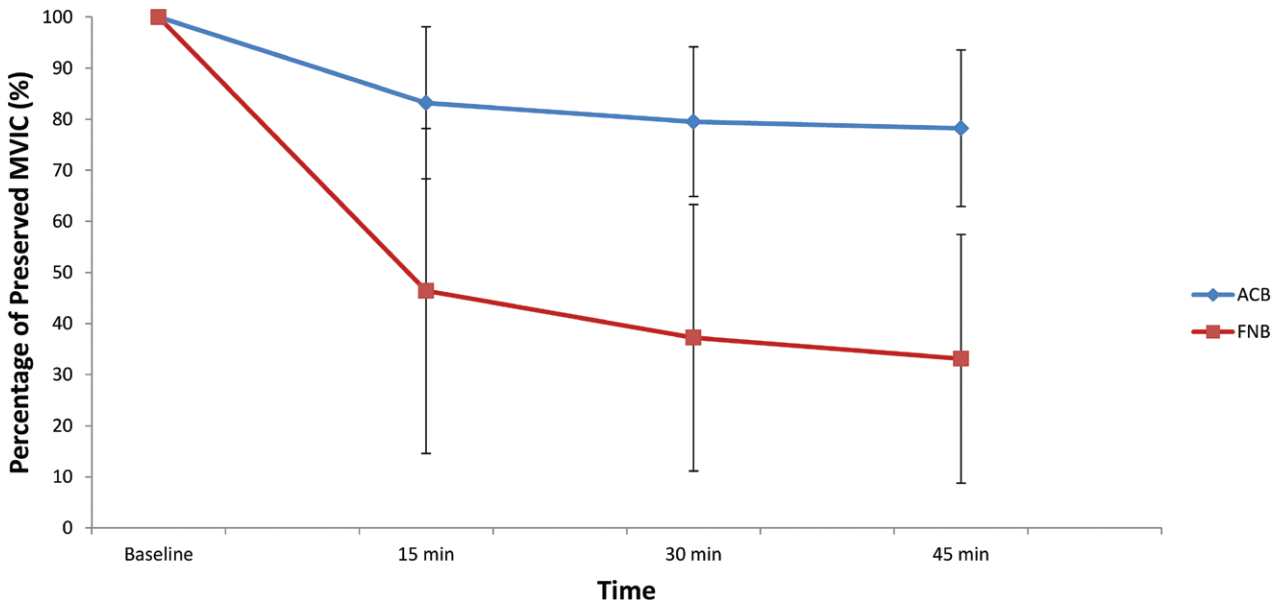

Fig. 5. Effect of nerve block on quadriceps muscle strength, as measured by isometric dynamometer during maximal isometric contraction. The mean and SD of the percentage of maximal voluntary isometric contraction (MVIC) preserved is examined up to 1 h postblock. Apart from baseline, the difference is statistically significant ($P < 0.00001$) at all time points (Bonferroni–Holm correction). ACB = adductor canal block; FNB = femoral nerve block.

both blocks may have been limited by the lack of a control group. We also did not evaluate the effect of either block on the occurrence of rebound pain.[50] Furthermore, our assessment of quadriceps strength was limited to 45 min presurgery, and postsurgical assessment was not possible because of immobilization and discharge. This precluded investigating any delayed-onset motor weakness after ACB as well as the duration of motor blockade or persistent weakness[8] in either group. Nonetheless, recent evidence suggests that quadriceps weakness is caused by postsurgical pain as the analgesic effect of the blocks subsides.[45] We also excluded assessment of hip adduction as both ACB and FNB have been shown to similarly affect hip adduction.[11,12] In the absence of any formal postoperative strength testing, the

clinical importance of our postblock strength data remains to be elucidated. However, we have recently demonstrated that despite superior analgesia compared with placebo, FNB causes an increased risk of falls in similarly young healthy outpatients discharged using crutches after hip arthroscopy.[58] Finally, our results are applicable to the specific settings described in this trial and may not necessarily be generalizable to different surgical procedures (*e.g.*, revisions, medial or posterior cruciate reconstruction, and meniscectomy), ACB injection locations (*e.g.*, more distal),[59] local anesthetic volumes,[60] or other analgesic modalities (*e.g.*, infrapatellar saphenous block,[61] intra- and periarticular local anesthetic infiltration,[62,63] hamstring block,[15] and fascia iliaca block[51]).
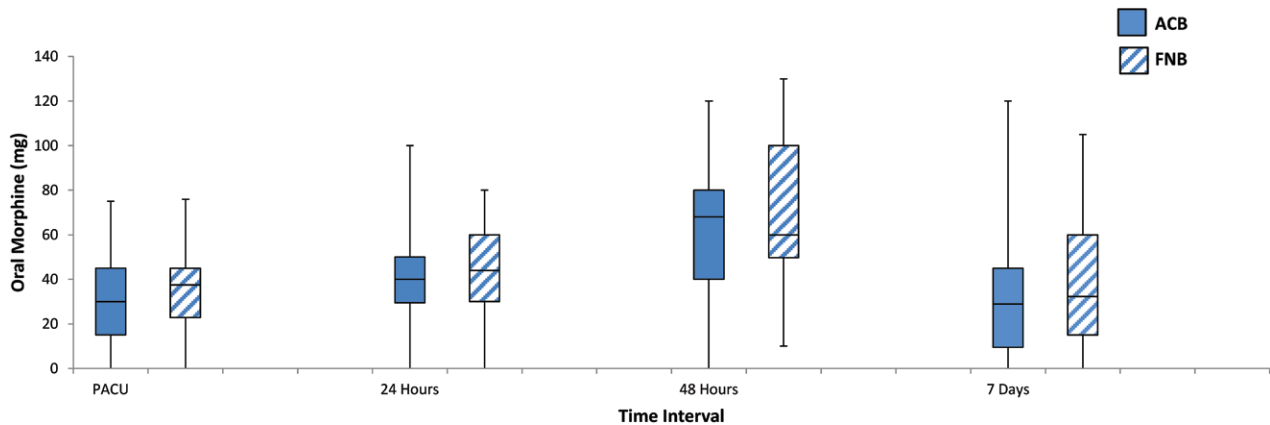
Fig. 6. Box plots (median and interquartile range) of the interval postoperative oral morphine equivalent consumption for the two study groups. No statistically significant differences were detected (Bonferroni–Holm correction). ACB = adductor canal block; FNB = femoral nerve block; PACU = postanesthesia care unit.

In summary, our trial suggests that ACB is a better option compared with FNB in patients undergoing outpatient ACL reconstruction as it provides noninferior postoperative analgesia while preserving quadriceps motor strength.

Acknowledgments

Competing Interests

Dr. Chan is a member of the medical advisory board of Philips Medical Systems (Andover, Massachusetts) and Smiths Medical (St. Paul, Minnesota). The other authors declare no competing interests.

Reproducible Science

Full protocol available from Dr. Abdallah: abdallahf@smh.ca. Raw data available from Dr. Abdallah: abdallahf@smh.ca.

Correspondence

Address correspondence to Dr. Brull: Department of Anesthesia, Women's College Hospital, University of Toronto, 76 Grenville St., Toronto, Ontario, M5S 1B2, Canada. richard.brull@wchospital.ca. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.

References

1. Bach BR Jr: Revision anterior cruciate ligament surgery. Arthroscopy 2003; 19(suppl 1):14–29
2. Tierney GS, Wright RW, Smith JP, Fischer DA: Anterior cruciate ligament reconstruction as an outpatient procedure. Am J Sports Med 1995; 23:755–6
3. Tierney E, Lewis G, Hurtig JB, Johnson D: Femoral nerve block with bupivacaine 0.25 percent for postoperative analgesia after open knee surgery. Can J Anaesth 1987; 34:455–8
4. Mulroy MF, Larkin KL, Batra MS, Hodgson PS, Owens BD: Femoral nerve block with 0.25% or 0.5% bupivacaine improves postoperative analgesia following outpatient arthroscopic anterior cruciate ligament repair. Reg Anesth Pain Med 2001; 26:24–9
5. Williams BA, Kentor ML, Vogt MT, Irrgang JJ, Bottegal MT, West RV, Harner CD, Fu FH, Williams JP: Reduction of verbal pain scores after anterior cruciate ligament reconstruction with 2-day continuous femoral nerve block: A randomized clinical trial. ANESTHESIOLOGY 2006; 104:315–27
6. Wulf H, Löwe J, Gnutzmann KH, Steinfeldt T: Femoral nerve block with ropivacaine or bupivacaine in day case anterior crucial ligament reconstruction. Acta Anaesthesiol Scand 2010; 54:414–20
7. Muraskin SI, Conrad B, Zheng N, Morey TE, Enneking FK: Falls associated with lower-extremity-nerve blocks: A pilot investigation of mechanisms. Reg Anesth Pain Med 2007; 32:67–72
8. Luo TD, Ashraf A, Dahm DL, Stuart MJ, McIntosh AL: Femoral nerve block is associated with persistent strength deficits at 6 months after anterior cruciate ligament reconstruction in pediatric and adolescent patients. Am J Sports Med 2015; 43:331–6
9. 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; 34:578–80
10. 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; 55:14–9
11. 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; 118:409–15
12. Grevstad U, Mathiesen O, Valentiner LS, Jaeger P, Hilsted KL, Dahl JB: Effect of adductor canal block *versus* femoral nerve block on quadriceps strength, mobilization, and pain after total knee arthroplasty: A randomized, blinded study. Reg Anesth Pain Med 2015; 40:3–10
13. Albrect A, Wedel DJ: Orthopedics, Regional Anesthesia and Analgesia. Edited by Brown DL. Philadelphia, Saunders, 1996, pp 548–57
14. Horner G, Dellon AL: Innervation of the human knee joint and implications for surgery. Clin Orthop 1994; 301:221–6
15. Bushnell BD, Sakryd G, Noonan TJ: Hamstring donor-site block: Evaluation of pain control after anterior cruciate ligament reconstruction. Arthroscopy 2010; 26:894–900
16. Atkinson HD, Hamid I, Gupte CM, Russell RC, Handy JM: Postoperative fall after the use of the 3-in-1 femoral nerve

block for knee surgery: A report of four cases. J Orthop Surg (Hong Kong) 2008; 16:381–4

17. Mochizuki T, Akita K, Muneta T, Sato T: Anatomical bases for minimizing sensory disturbance after arthroscopically-assisted anterior cruciate ligament reconstruction using medial hamstring tendons. Surg Radiol Anat 2003; 25:192–9

18. Espelund M, Fomsgaard JS, Haraszuk J, Mathiesen O, Dahl JB: Analgesic efficacy of ultrasound-guided adductor canal blockade after arthroscopic anterior cruciate ligament reconstruction: A randomised controlled trial. Eur J Anaesthesiol 2013; 30:422–8

19. El Ahl MS: Femoral nerve block *versus* adductor canal block for postoperative pain control after anterior cruciate ligament reconstruction: A randomized controlled double blind study. Saudi J Anaesth 2015; 9:279–82

20. Moher D, Schulz KF, Altman DG: The CONSORT statement: Revised recommendations for improving the quality of reports of parallel-group randomised trials. Lancet 2001; 357:1191–4

21. Schulz KF, Altman DG, Moher D; CONSORT Group: CONSORT 2010 Statement: Updated guidelines for reporting parallel group randomised trials. BMC Med 2010; 8:18

22. Piaggio G, Elbourne DR, Pocock SJ, Evans SJ, Altman DG; CONSORT Group: Reporting of noninferiority and equivalence randomized trials: Extension of the CONSORT 2010 statement. JAMA 2012; 308:2594–604

23. Andersen HL, Andersen SL, Tranum-Jensen J: The spread of injectate during saphenous nerve block at the adductor canal: A cadaver study. Acta Anaesthesiol Scand 2015; 59:238–45

24. Jæger P, Zaric D, Fomsgaard JS, Hilsted KL, Bjerregaard J, Gyrn J, Mathiesen O, Larsen TK, Dahl JB: Adductor canal block *versus* femoral nerve block for analgesia after total knee arthroplasty: A randomized, double-blind study. Reg Anesth Pain Med 2013; 38:526–32

25. Jenstrup MT, Jæger P, Lund J, Fomsgaard JS, Bache S, Mathiesen O, Larsen TK, Dahl JB: Effects of adductor-canal-blockade on pain and ambulation after total knee arthroplasty: A randomized study. Acta Anaesthesiol Scand 2012; 56:357–64

26. Tsui BC, Ozelsel T: Ultrasound-guided transsartorial perifemoral artery approach for saphenous nerve block. Reg Anesth Pain Med 2009; 34:177–8; author reply 178

27. Bohannon RW: Measuring knee extensor muscle strength. Am J Phys Med Rehabil 2001; 80:13–8

28. Abdallah FW, Johnson J, Chan V, Murgatroyd H, Ghafari M, Ami N, Jin R, Brull R: Intravenous dexamethasone and perineural dexamethasone similarly prolong the duration of analgesia after supraclavicular brachial plexus block: A randomized, triple-arm, double-blind, placebo-controlled trial. Reg Anesth Pain Med 2015; 40:125–32

29. Aldrete JA: The post-anesthesia recovery score revisited. J Clin Anesth 1995; 7:89–91

30. Dmitrienko A, Tamhane AC: Gatekeeping procedures with clinical trial applications. Pharm Stat 2007; 6:171–80

31. Canadian Pharmacists Association: Compendium of Pharmaceuticals and Specialties: The Canadian Drug Reference for Health Professionals, 45th edition. Ottawa, Canada, Canadian Pharmacists Association, 2010

32. Deloach JK, Boezaart AP: Is an adductor canal block simply an indirect femoral nerve block? ANESTHESIOLOGY 2014; 121:1349–50

33. Silverman DG, O'Connor TZ, Brull SJ: Integrated assessment of pain scores and rescue morphine use during studies of analgesic efficacy. Anesth Analg 1993; 77:168–70

34. Matava MJ, Prickett WD, Khodamoradi S, Abe S, Garbutt J: Femoral nerve blockade as a preemptive anesthetic in patients undergoing anterior cruciate ligament reconstruction: A prospective, randomized, double-blinded, placebo-controlled study. Am J Sports Med 2009; 37:78–86

35. Frost S, Grossfeld S, Kirkley A, Litchfield B, Fowler P, Amendola A: The efficacy of femoral nerve block in pain reduction for outpatient hamstring anterior cruciate ligament reconstruction: A double-blind, prospective, randomized trial. Arthroscopy 2000; 16:243–8

36. Mascha EJ, Turan A: Joint hypothesis testing and gatekeeping procedures for studies with multiple endpoints. Anesth Analg 2012; 114:1304–17

37. Westfall PH, Krishen A: Optimally weighted, fixed sequence and gatekeeper multiple testing procedures. J Stat Plan Infer 2001; 99:25–40

38. Cheung CW, Qiu Q, Ying AC, Choi SW, Law WL, Irwin MG: The effects of intra-operative dexmedetomidine on postoperative pain, side-effects and recovery in colorectal surgery. Anaesthesia 2014; 69:1214–21

39. Farrar JT, Berlin JA, Strom BL: Clinically important changes in acute pain outcome measures: A validation study. J Pain Symptom Manage 2003; 25:406–11

40. Goslin BR, Charteris J: Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases. Scand J Rehabil Med 1979; 11:105–9

41. Roos E, Ekdah C, Roos H: Isokinetic knee extensor strength and functional performance in healthy female soccer players. Scand J Med Sci Sports 1998; 8:257–64

42. Kvist J: Rehabilitation following anterior cruciate ligament injury: Current recommendations for sports participation. Sports Med 2004; 34:269–80

43. Krishnan C, Williams GN: Evoked tetanic torque and activation level explain strength differences by side. Eur J Appl Physiol 2009; 106:769–74

44. Kwofie MK, Shastri UD, Gadsden JC, Sinha SK, Abrams JH, Xu D, Salviz EA: The effects of ultrasound-guided adductor canal block *versus* femoral nerve block on quadriceps strength and fall risk: A blinded, randomized trial of volunteers. Reg Anesth Pain Med 2013; 38:321–5

45. Kim DH, Lin Y, Goytizolo EA, Kahn RL, Maalouf DB, Manohar A, Patt ML, Goon AK, Lee YY, Ma Y, Yadeau JT: Adductor canal block *versus* femoral nerve block for total knee arthroplasty: A prospective, randomized, controlled trial. ANESTHESIOLOGY 2014; 120:540–50

46. Holm S: A simple sequentially rejective multiple test procedure. Scan J Statist 1979; 6:65–70

47. Espelund M, Grevstad U, Jaeger P, Hölmich P, Kjeldsen L, Mathiesen O, Dahl JB: Adductor canal blockade for moderate to severe pain after arthroscopic knee surgery: A randomized controlled trial. Acta Anaesthesiol Scand 2014; 58:1220–7

48. Tetzlaff JE, Andrish J, O'Hara J Jr, Dilger J, Yoon HJ: Effectiveness of bupivacaine administered *via* femoral nerve catheter for pain control after anterior cruciate ligament repair. J Clin Anesth 1997; 9:542–5

49. Peng P, Claxton A, Chung F, Chan V, Miniaci A, Krishnathas A: Femoral nerve block and ketorolac in patients undergoing anterior cruciate ligament reconstruction. Can J Anaesth 1999; 46:919–24

50. Williams BA, Bottegal MT, Kentor ML, Irrgang JJ, Williams JP: Rebound pain scores as a function of femoral nerve block duration after anterior cruciate ligament reconstruction: Retrospective analysis of a prospective, randomized clinical trial. Reg Anesth Pain Med 2007; 32:186–92

51. Farid IS, Heiner EJ, Fleissner PR: Comparison of femoral nerve block and fascia iliaca block for analgesia following reconstructive knee surgery in adolescents. J Clin Anesth 2010; 22:256–9

52. Svediene S, Andrijauskas A, Ivaskevicius J, Saikus A: The efficacy comparison of on-demand boluses with and without basal infusion of 0.1 % bupivacaine *via* perineural femoral catheter after arthroscopic ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2013; 21:641–5

53. Oh SJ, Hatanaka Y, Ohira M, Kurokawa K, Claussen GC: Clinical utility of sensory nerve conduction of medial femoral cutaneous nerve. Muscle Nerve 2012; 45:195–9

54. 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; 39:81–2

55. Williams BA, Kentor ML, Vogt MT, Williams JP, Chelly JE, Valalik S, Harner CD, Fu FH: Femoral-sciatic nerve blocks for complex outpatient knee surgery are associated with less postoperative pain before same-day discharge: A review of 1,200 consecutive cases from the period 1996–1999. ANESTHESIOLOGY 2003; 98:1206–13

56. Sakura S, Hara K, Ota J, Tadenuma S: Ultrasound-guided peripheral nerve blocks for anterior cruciate ligament reconstruction: Effect of obturator nerve block during and after surgery. J Anesth 2010; 24:411–7

57. Abdallah FW, Brull R: Sciatic nerve block for analgesia after total knee arthroplasty: The jury is still out. Reg Anesth Pain Med 2012; 37:122–3; author reply 123–4

58. Xing JG, Abdallah FW, Brull R, Oldfield S, Dold A, Murnaghan ML, Whelan DB: Preoperative femoral nerve block for hip arthroscopy: A randomized, triple-masked controlled trial. Am J Sports Med 2015; 43:2680–7

59. Mariano ER, Kim TE, Wagner MJ, Funck N, Harrison TK, Walters T, Giori N, Woolson S, Ganaway T, Howard SK: A randomized comparison of proximal and distal ultrasound-guided adductor canal catheter insertion sites for knee arthroplasty. J Ultrasound Med 2014; 33:1653–62

60. Jæger P, Koscielniak-Nielsen ZJ, Hilsted KL, Fabritius ML, Dahl JB: Adductor canal block with 10 mL *versus* 30 mL local anesthetics and quadriceps strength: A paired, blinded, randomized study in healthy volunteers. Reg Anesth Pain Med 2015; 40:553–8

61. Lundblad M, Kapral S, Marhofer P, Lönnqvist PA: Ultrasound-guided infrapatellar nerve block in human volunteers: Description of a novel technique. Br J Anaesth 2006; 97:710–4

62. Höher J, Kersten D, Bouillon B, Neugebauer E, Tiling T: Local and intra-articular infiltration of bupivacaine before surgery: Effect on postoperative pain after anterior cruciate ligament reconstruction. Arthroscopy 1997; 13:210–7

63. Koh IJ, Chang CB, Seo ES, Kim SJ, Seong SC, Kim TK: Pain management by periarticular multimodal drug injection after anterior cruciate ligament reconstruction: A randomized, controlled study. Arthroscopy 2012; 28:649–57