ANESTHESIOLOGY

Opioid- and Motor-sparing with Proximal, Mid-, and Distal Locations for Adductor Canal Block in Anterior Cruciate Ligament Reconstruction

A Randomized Clinical Trial

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ABSTRACT

Background: The ideal location for single-injection adductor canal block that maximizes analgesia while minimizing quadriceps weakness after painful knee surgery is unclear. This triple-blind trial compares ultrasound-guided adductor canal block injection locations with the femoral artery positioned medial (proximal adductor canal), inferior (mid-adductor canal), and lateral (distal adductor canal) to the sartorius muscle to determine the location that optimizes postoperative analgesia and motor function. The hypothesis was that distal adductor block has (1) a superior opioid-sparing effect and (2) preserved quadriceps strength, compared with proximal and mid-locations for anterior cruciate ligament reconstruction.

Methods: For the study, 108 patients were randomized to proximal, mid-, or distal adductor canal injection locations for adductor canal block. Cumulative 24-h oral morphine equivalent consumption and percentage quadriceps strength decrease (maximum voluntary isometric contraction) at 30 min postinjection were coprimary outcomes. The time to first analgesic request, pain scores, postoperative nausea/vomiting at least once within the first 24 h, and block-related complications at 2 weeks were also evaluated.

Results: All patients completed the study. Contrary to the hypothesis, proximal adductor canal block decreased 24-h morphine consumption to a mean ± SD of 34.3 ± 19.1 mg, ($P < 0.0001$) compared to 64.0 ± 33.6 and 65.7 ± 22.9 mg for the mid- and distal locations, respectively, with differences [95% CI] of 29.7 mg [17.2, 42.2] and 31.4 mg [21.5, 41.3], respectively, mostly in the postanesthesia care unit. Quadriceps strength was similar, with 16.7%:13.4%:15.3% decreases for proximal:mid:distal adductor canal blocks. The nausea/vomiting risk was also lower with proximal adductor canal block (10 of 34, 29.4%) compared to distal location (23 of 36, 63.9%; $P = 0.005$). The time to first analgesic request was longer, and postoperative pain was improved up to 6 h for proximal adductor canal block, compared to mid- and distal locations.

Conclusions : A proximal adductor canal injection location decreases opioid consumption and opioid-related side effects without compromising quadriceps strength compared to mid- and distal locations for adductor canal block in patients undergoing anterior cruciate ligament reconstruction.

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Adductor canal nerve block is useful for a range of knee surgeries, although the optimal injection location has not been defined
- Unfortunately, analgesia achieved using adductor canal block is sometimes accompanied by unwanted motor block

What This Article Tells Us That Is New

- Proximal adductor canal injections were associated with lower first 24-h morphine consumption than when injections were more distal
- Decreases in quadriceps strength were similar whether the injection was made in a proximal, mid-, or distal adductor canal location

The important opioid- and motor-sparing effects of the adductor canal block have made it an important component of multimodal analgesia for patients undergoing knee surgery.[1–4] The adductor canal block involves the injection of local anesthetic into the adductor canal, which is a fascial compartment bordered by the sartorius, adductor, and vastus medialis muscles and traditionally described to house the saphenous nerve.[5,6] Recent cadaveric and volunteer studies have sought to improve our understanding of the neural contents of the adductor canal in relation to the sensory innervation of the knee,[7–11] which had been largely based on a single report published over half a century ago.[12] As such, conventional descriptions of the adductor canal

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are now being redefined, and different approaches to performing adductor canal block, corresponding to the relative sonographic positions of the sartorius muscle and the femoral artery from the apex of the femoral triangle down to the adductor hiatus, have recently been investigated, but with inconsistent or even conflicting results. Indeed, randomized clinical trials in the setting of total knee arthroplasty have reported that a proximal adductor canal injection location may confer superior analgesia,[13,14] whereas recent cadaveric and volunteer studies[10,15–17] propose that a distal injection location for adductor canal block should be superior because the local anesthetic not only reaches the saphenous nerve but also spreads to the popliteal plexus,[16,17] thus extending analgesia to the posterior knee compartment.

Efforts to maximize analgesia and minimize quadriceps weakness using adductor canal block are especially timely because painful knee surgery is increasingly shifting from the inpatient to outpatient setting.[18] This randomized controlled trial aims to identify the ideal injection location for adductor canal block that optimizes postoperative analgesia and motor function after outpatient anterior cruciate ligament reconstruction. Based on preclinical evidence,[10,15–17] we specifically aimed to show that a distal adductor canal injection location for adductor canal block confers the best pain control while preserving motor strength. We therefore tested the hypotheses that a distal adductor canal injection location (1) provides superior opioid-sparing effect and (2) preserves quadriceps motor strength compared to a proximal or mid-adductor canal injection location for adductor canal block in adult patients undergoing ambulatory anterior cruciate ligament reconstruction.

Materials and Methods

This clinical trial was approved by the Research Ethics Board at Women's College Hospital (2015-0046-B) and was registered at the website CinicalTrials.gov[19] (NCT02554864; registration September 18, 2015). The trial protocol is available by request. Patient accrual took place between February 2016 and January 2018 at Women's College Hospital, a free-standing ambulatory care center in Toronto, Canada, affiliated with the University of Toronto. In preparing this report, we adhered to the Consolidated Standards of Reporting Trials (CONSORT) guidelines.[20,21]

Study Participants

We recruited American Society of Anesthesiologists classification I–III adult patients (18 to 50 yr) with a body mass index of at least 35 kg/m^2 scheduled to undergo elective unilateral ambulatory anterior cruciate ligament reconstruction. All participants in this prospective, randomized, parallel-arm, patient-, anesthesiologist- and assessor-blinded, superiority clinical trial provided written informed consent. We excluded patients in case of preexisting neurologic deficits or neuropathy affecting the operative limb; pregnancy; mental or psychiatric disorders preventing assessment; chronic pain or opioid dependence (at least 30 mg of oxycodone or equivalent per day); allergy to any component of multimodal analgesia or to local anesthetics; and contraindications to peripheral nerve blocks, including skin infections at block site or bleeding disorders. We preidentified potentially eligible patients from surgeons' booking lists before surgery. Those patients were then interviewed by the research coordinator during the preadmission clinic visit arranged in advance of the surgical date; the coordinator confirmed eligibility, described the study, and provided an information leaflet detailing the procedures involved.

Randomization and Blinding

We randomized consented study participants on a 1:1:1 ratio to one of three study groups (proximal, mid-, and distal adductor canal block) using a computer-generated list of random numbers in varying block sizes (four to six). An investigator with no further involvement in the study generated the allocation sequence using the Web site Randomization.com,[2] and concealed the allocation results in sealed opaque sequentially numbered envelopes that were provided to the research coordinator. On the day of surgery, and after obtaining informed consent, the research coordinator provided one envelope per patient to the anesthesiologist in the block room who performed the block procedures. The anesthesiologist who administered the block had no further role in the study; the surgeons, anesthesiologists, and nurses providing intra- and postoperative care, as well as the research coordinator assessing outcomes, were all kept blinded to allocation results.

Study Groups

The three adductor canal block locations were identified by ultrasound scanning to achieve one of the following three sartorius muscle sonographic configurations relative to the femoral artery (fig. 1) according to group allocation: (1) femoral artery medial to the sartorius muscle (proximal adductor canal group); (2) femoral artery inferior to the sartorius muscle (mid-adductor canal group); and (3) femoral artery lateral to the sartorius muscle (distal adductor canal group).

Preoperative Procedures

Pulse oximetry, electrocardiogram, and noninvasive blood pressure were applied, and IV access was secured upon arrival to the block room. Study participants received midazolam 1 to 2 mg IV and/or fentanyl 25 to 50 μg IV for anxiolysis and analgesia, as needed, before adductor canal block.

Block Technique

Patients were placed supine with the operative knee slightly flexed and externally rotated. Sterility of the anterior thigh was achieved using a combination of 2% chlorhexidine and 70% isopropyl alcohol preparation solution. With ultrasound

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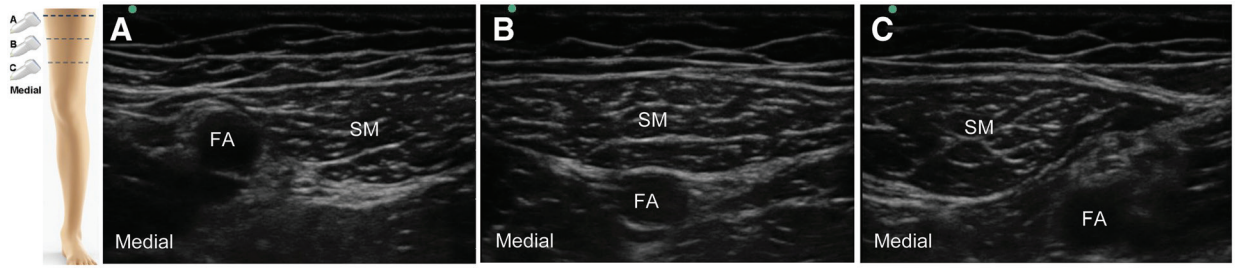

Fig. 1. Relative ultrasound probe positions and sonographic configurations of the sartorius muscle and femoral artery examined in this study. These include the muscle in lateral (*A*), superimposed (*B*), and medial position (*C*) relative to the artery. FA, femoral artery; SM, sartorius muscle.

screen faced away from the patient, a high frequency (5 to 12MHz range) linear ultrasound probe (Sonosite M-Turbo) protected by a 3M Tegaderm (3M Health Care, USA) dressing was positioned perpendicular to the skin in the medial upper-thigh region. The probe was moved either cephalad or caudad from its initial position to achieve the prespecified sonographic configuration of the sartorius muscle in relation to the femoral artery, as described above. After administration of 1 to 3 ml of 2% lidocaine to anesthetize the skin, a 22-gauge 5-cm stimulating needle (Stimuplex A50; B. Braun, Germany) was inserted into the skin using an in-plane technique and advanced until the needle tip was positioned between the femoral artery and the sartorius muscle. Injection was performed in the prespecified location, regardless of whether the saphenous nerve and/or any other nerves within the adductor canal were visualized. After negative aspiration for blood, 20 ml of 1:1 of ropivacaine 0.5% and lidocaine 2% with epinephrine 1:200,000 was injected incrementally more than 1 to 2 min as per our institutional practice. This volume has been reported to block the saphenous nerve in the adductor canal and also spread to the popliteal plexus.[16,17]

Block Assessment

Sensory block assessment was conducted using a pinprick to test sensation before adductor canal block (baseline) and then every 5 min after local anesthetic injection until either 30 min had elapsed or surgery commenced. Sensation was tested in the distribution of the saphenous nerve (medial calf), as well as on the anterior, medial, lateral, and posterior–medial aspects of the operative knee, above the patella. Sensation was rated as 2 for normal sensation, 1 for diminished sensation, and 0 for no sensation. We defined adductor canal block success as evidence of sensory block onset, *i.e.* loss of sensation to pinprick (sensory score of 1 or lower), over the operative knee within 30 min after the end of local anesthetic injection. For patients in whom block success was not achieved within the 30-min assessment period, we planned to handle the relevant data using intention-to-treat analysis.

Motor block assessment was conducted before performing adductor canal block (baseline) and then every 5 min after local anesthetic injection until either 30 min had elapsed or surgery commenced. Motor blockade was assessed using a handheld electromechanical dynamometer (MicroFET2; Hoggan Health Industries Inc., USA) to evaluate the strength of the quadriceps femoris. While seated at the edge of the stretcher with their legs dangling, patients were asked to extend their knee against an isometric dynamometer. The maximum voluntary isometric contraction force needed to sustain an extended knee position was measured to quantify quadriceps motor strength.

Intraoperative Care

Standard intraoperative monitoring was applied for all patients. All patients received a standard general anesthetic by an anesthesiologist blinded to the group allocation. General anesthesia was induced using fentanyl 1 to 3 μg/kg IV and propofol 2 to 4 mg/kg IV. A laryngeal mask airway or endotracheal tube was used for airway management during surgery. Patients who required endotracheal intubation were paralyzed with rocuronium 0.6 mg/kg. General anesthesia was maintained with desflurane 2 to 6% in a 40:60 mixture of oxygen and air. For intubated patients, positive pressure ventilation was initiated with a tidal volume of 8 to 10 ml/kg, and the rate was adjusted to maintain an end-tidal P_{CO_2} of 30 to 40 mmHg. Supplemental doses of fentanyl 1 to 2 μg/kg and/or hydromorphone 0.005 to 0.0075 mg/kg IV were administered to treat hemodynamic increases of more than 15% above preinduction baseline values. Desflurane was discontinued at the beginning of skin suturing. Muscle relaxation was reversed with neostigmine 50 μg/kg and glycopyrrolate 5 to 10 μg/kg if necessary. All patients received ondansetron 4 mg as antiemetic prophylaxis.

Postoperative Management

All patients were transferred to the postanesthesia care unit at the end of surgery, where they remained until the institutional discharge criteria were met.[23] Postoperative pain measured using a visual analog rating scale (10-cm scale where 0 = no pain and 10 = excruciating pain) was assessed every 15 min. Visual analog scale scores of 4 or higher or

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patient requests for pain medications were managed by blinded nursing staff using IV fentanyl 25 to 50 μg every 5 to 10 min as needed, followed by IV hydromorphone 0.2 to 0.4 mg every 5 to 10 min as needed. Once oral intake was initiated, patients received oral analgesic preparations as needed in the form of oxycodone 5 mg, 1 to 2 tabs every 4 h. Postoperative nausea and vomiting in hospital was treated with ondansetron 4 mg IV, followed by dimenhydrinate 25 to 50 mg IV and metoclopramide 10 mg IV, as needed. Discharge medications included acetaminophen 1 g every 6 h, celecoxib 200 mg twice daily, in addition to oxycodone 5 mg, 1 to 2 tabs every 4 h as needed. Discharged patients were provided with a home diary to document their pain scores, analgesic consumption, block-related complications, opioid-related side effects, and satisfaction with during the first 24 h after surgery. The diary was returned to the investigators using a prestamped, self-addressed envelope.

Follow-up

All patients received a scripted telephone call from the research coordinator on day 1 postoperatively, as well as at 2 weeks postoperatively, to ensure compliance with the study diary, assess the level of functionality, and identify the presence or absence of block-related complications in the operative limb. Any block-related complications were followed up until complete resolution.

Outcome Measures

All outcome data were collected by a research coordinator blinded to the group allocation. Testing of our hypotheses entailed two primary outcomes that were examined independently across the three study groups, followed by intergroup comparisons between the distal adductor canal location on one hand and the mid and proximal locations on the other. The first primary outcome was cumulative postoperative analgesic consumption, converted to oral morphine equivalents,[24] during the first 24 h after anterior cruciate ligament reconstruction, as a measure of the analgesic effect of adductor canal block. The second primary outcome was the proportional change from the baseline dynamometer reading of maximal voluntary isometric contraction during knee extension of the operative limb at 30 min after the block, as a measure of the effect of adductor canal block on quadriceps femoris muscle strength.

Secondary outcomes included: (1) a proportion of patients in whom block success is documented; (2) incidence of block-related complications during block (vascular puncture, hematoma formation, systemic toxicity, paresthesia); (3) incidence of falls and near falls during the first 24 h after anterior cruciate ligament reconstruction; (4) return to baseline functionality (using quality of recovery QoR-15 scale) at 24 h; and (5) incidence of postoperative neurologic symptoms (persistent numbness or paresthesia, weakness, or nonsurgical pain in the operative extremity) at 14 days postoperatively.

Analgesic outcomes included: (1) intraoperative analgesic requirements (converted to IV morphine equivalents)[24]; (2) time (min) to first analgesic request; (3) time (min) to discharge readiness from hospital; (4) pain severity (at rest) visual analog scale scores (cm) upon postanesthesia care unit admission, and at 6, 12, 18, and 24 h postoperatively; (5) area under curve for rest pain during the first 24 h postoperatively; (6) postoperative analgesic consumption during in-hospital recovery (converted to oral morphine equivalent),[24] and at 6, 12, 18 and 24 h; (7) proportion of patients experiencing postoperative nausea and vomiting at least once during in-hospital recovery and the first 24 h postoperatively; and (8) patient satisfaction with analgesia measured on a visual analog scale (where 0 = least satisfied and 10 = most satisfied) at 24 h postoperatively.

Statistical Analysis

We aimed to test the hypotheses that distal adductor canal injection location (1) decreases cumulative 24-h oral morphine equivalent consumption and (2) preserves quadriceps motor strength, as measured by maximal voluntary isometric contraction, at 30 min after the block, compared to mid- and proximal adductor canal locations for adductor canal block in patients having ambulatory anterior cruciate ligament reconstruction. These hypotheses were tested independently, requiring an adjusted type-I error estimate equivalent to 0.025. The analysis was based on a two separate one-way ANOVA with both 24-h morphine equivalent consumption and quadriceps motor strength at 30 min as primary outcomes. Therefore, for all primary and secondary outcomes, we first tested for the presence of a difference across all three groups. If and only if former testing detected a difference in any outcome, we proceeded to test for superiority of the distal adductor canal group over the mid- and proximal adductor canal groups.

To inform our sample size calculation, we used our own institutional data to estimate the cumulative 24-h opioid consumption and quadriceps maximal voluntary isometric contraction at 30 min after adductor canal block. Based on this data, we estimated that patients who received a proximal adductor canal injection for adductor canal block would require 65.7 ± 13.2 mg of oral morphine equivalents during the first 24 h after ambulatory anterior cruciate ligament reconstruction. We considered the minimum clinically important difference in oral morphine consumption to be 30 mg of oral morphine, which corresponds to a treatment effect of 0.75. Those patients also experienced a 16 ± 6% decrease in quadriceps maximal voluntary isometric contraction at 30 min after adductor canal block compared to baseline; we considered this difference, which corresponds to a treatment effect of 0.78, to be clinically important. We therefore selected the smaller treatment effect (0.75) as representative of the impact of proximal adductor canal block on opioid consumption and quadriceps strength.

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Our sample size calculation sought to detect a difference between the three study groups corresponding to a treatment effect size of 0.75 in both 24-h oral morphine equivalent consumption and maximal voluntary isometric contraction at 30 min after adductor canal block. Using a type-I error estimate (α) = 0.025 and 80% power ($1 - \beta$), we estimated that 30 patients/group were needed to detect such a difference using a two-sided test of superiority. We inflated the sample size by 20% to account for potential attrition resulting from incomplete follow-up or patient drop-out, to 36 patients/group, or 108 in total.

We used SPSS for Windows statistical package (version 25; IBM, USA) in our analysis. We performed our ANOVA under the assumptions that (1) the source populations were normally distributed, (2) the study groups had equal variances, and (3) the three study groups were independent. We used the Shapiro–Wilk test to confirm normality of data distribution. We conducted all analyses using an intention-to-treat approach.

Two separate one-way ANOVAs combined with the independent two-sample Student's *t* test for *post hoc* testing were used in analyzing continuous data. The one-sample paired *t* test was used in analyzing decrease in quadriceps strength within each group. The chi-square or Fisher exact test combined with the Mann–Whitney U test for *post hoc* testing was used in analyzing categorical data. Where needed, the Kruskal–Wallis test combined with the Mann–Whitney–Wilcoxon U test for *post hoc* testing was used in analyzing ordinal data (pain scores, satisfaction scores, and quality of recovery scores). The Kaplan–Meier survival analysis with right censoring combined with the log-rank test (under the assumptions of proportional hazards, linear covariate relationships, and independence) was used in analyzing time-to-event outcomes (time to first analgesic request and time to discharge readiness). Continuous data are reported as means ± SD or mean [95% CI, CI]; categorical data are reported as numbers (percentages).

According to the Bonferroni correction, the two-tailed *P* value threshold of statistical significance was set at 0.025 for each of the two primary outcomes and at 0.05 for the secondary outcomes. Furthermore, for and the one-way ANOVA comparisons among the three groups, the two-tailed *P*-value threshold was set at 0.008 (0.025 of 3) for the two primary outcomes, and at 0.017 (0.05 of 3) for the secondary outcomes. For repeated outcome measurements, the *P* values were corrected using the Bonferroni–Holm adjustment.[25]

Results

We assessed 231 patients for eligibility; of these, 123 were excluded (87 did not meet exclusion criteria, 28 declined, 3 had revision anterior cruciate ligament reconstruction, 2 had their surgery cancelled, and 3 had a change in their surgical procedure). The CONSORT[20,21] flow-diagram showing patient progress through the study phases is depicted in figure 2. A total of 108 patients were randomized to the three adductor canal injection locations examined, all of whom (proximal n = 34, mid n = 38, distal n = 36) received the study interventions, completed their follow-up, returned their diaries (no missing data), and were included in the data analysis. All study subjects demonstrated sensory block onset before surgery, indicative of adductor canal block success. The data for both primary outcomes were complete, and missing data for secondary outcomes were minimal. The baseline demographic characteristics of patients in the three study groups were similar, with no clinically meaningful differences (table 1).

Assessment of the first primary outcome, postoperative 24-h cumulative oral morphine equivalent consumption, suggested the presence of a difference across the three study groups ($P < 0.001$); and the comparisons between adductor canal locations suggested that the proximal location (34.3 mg [27.6, 41.0]) was superior ($P < 0.0001$) compared to the mid (64.0 mg [53.0, 75.0]) and distal (65.7 mg [58.0, 73.4]) locations (table 2). Contrary to our hypothesis, the difference in postoperative 24-h cumulative oral morphine consumption between proximal and distal adductor canal locations favored the proximal location by a clinically important difference [95% CI] of 31.4 mg [21.5, 41.3]. The majority of this difference occurred during the postanesthesia care unit stay. There were no differences between distal and mid adductor canal location for this outcome.

Furthermore, examination of the interval opioid consumption revealed the presence of a difference across the three groups during in-hospital recovery ($P < 0.001$) but not at any other time point postoperatively (table 2; fig. 3). A proximal adductor canal location decreased postoperative in-hospital oral morphine requirements by 30.0 mg [17.7, 42.3] and 31.9 mg [22.8, 41.0] ($P < 0.0001$) compared to mid and distal adductor canal locations, respectively. There were no differences between distal and mid adductor canal locations for this outcome. Analysis of the second primary outcome, the percentage decrease from baseline of the maximal voluntary isometric contraction measurement of quadriceps strength did not detect any differences across ($P = 0.731$) at 30 min after adductor canal block (table 2) or at any other time points (fig. 4).

The three study groups had similar ($P = 0.562$) opioid requirements intraoperatively (table 2). The time to first analgesic request was greater in the proximal group by 14 min [4, 24] ($P = 0.006$) compared to the Distal group. There were no differences in the other comparisons for this outcome (table 2). Nonetheless, this did not translate into differences in discharge readiness, because differences in this outcome were not statistically significant. The proximal group also had lower pain severity scores at rest upon arrival in the postanesthesia care unit and at 6 h postoperatively by a median [interquartile range] of 1.4 cm [0.5, 2.4] ($P = 0.007$) and 1.0 cm [0.5, 1.5] ($P = 0.001$), respectively, compared to the Distal group (table 2; fig. 5). There

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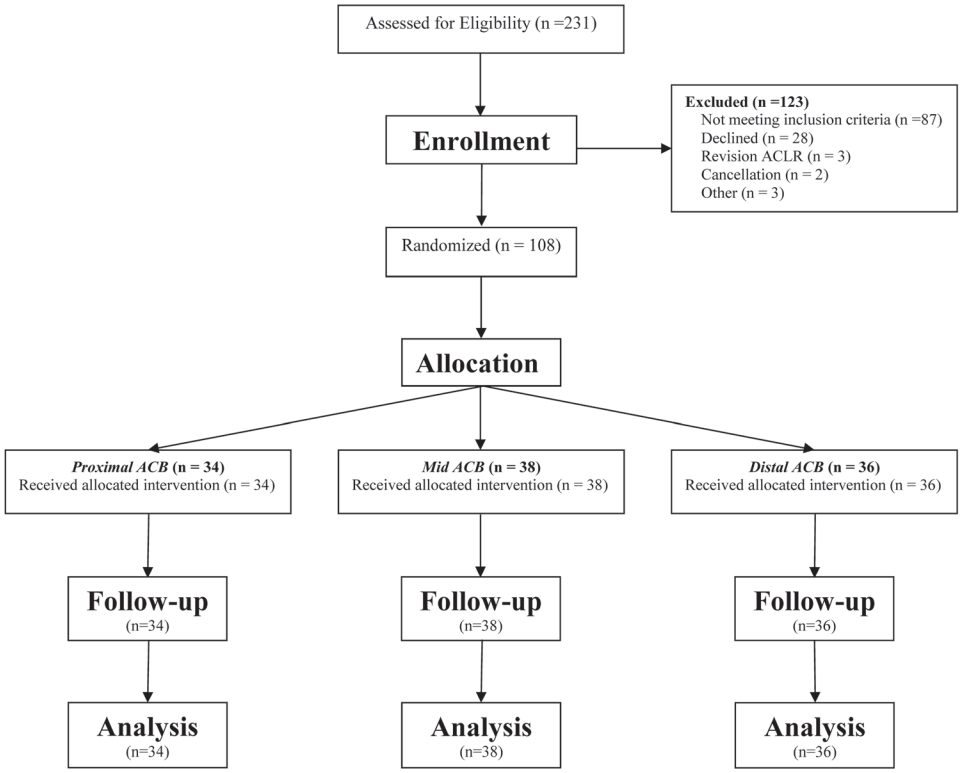

Fig. 2. Consolidated Standards of Reporting Trials (CONSORT) flow diagram showing patient progress through the study phases. ACB, adductor canal block; ACLR, anterior cruciate ligament reconstruction.

Table 1. Baseline Demographic Characteristics

Parameter	Proximal ACB (N = 34)	Mid ACB (N = 38)	Distal ACB (N = 36)
Age, yr	30 [28, 33]	31 [28, 33]	29 [27, 32]
Sex, female/male	12/24	14/24	13/23
BMI, kg/m^2)	25.5 [24.3, 26.7]	25.6 [24.3, 26.9]	25.8 [24.6, 27.0]
ASA status, I/II/III	30/4/0	28/10/0	32/3/1
Surgical side, left/right	16/18	16/22	20/16
Block procedural time, min	4 [3, 5]	5 [4, 6]	4 [3, 5]
Graft, hamstring/bone–patellar tendon–bone	11/23	13/25	9/27
Duration of surgery, min	90 [85, 95]	85 [77, 93]	95 [85, 105]

The values are expressed as the means [95% CI] or as absolute numbers.
ACB, adductor canal block; ASA, American Society of Anesthesiologists; BMI, body mass index.

were no differences between the other groups at these time points. Furthermore, there were no differences in rest pain severity scores between all of the three groups beyond 6 h. When rest pain severity was examined over the first 24 h after anterior cruciate ligament reconstruction using the area under the curve, there were statistically significant differences in all three comparisons, with the proximal group corresponding to the least pain severity, followed by the mid group and then the distal group.

There were no differences in the rates of postoperative nausea and vomiting during in-hospital recovery; however, patients in the proximal group had a significantly lower rate of postoperative nausea and vomiting (10 of 34, 29.4%) during the first 24 h after anterior cruciate ligament reconstruction, compared to the distal group (23 of 36, 63.9%, $P = 0.005$). No differences were observed in the other comparisons. Finally, patients' ratings of their satisfaction with postoperative pain control were similar between groups (table 2).

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Table 2. Results

Outcome	Proximal ACB (N = 34)	Mid ACB (N = 38)	Distal ACB (N = 36)	*P* Value: Overall Group Effect*	*P* Value: Distal *vs.* Mid†	*P* Value: Distal *vs.* Proximal†	*P* Value: Mid *vs.* Proximal†
Postoperative 24-h cumulative oral morphine equivalent consumption, mg‡	34.3 [27.6, 41.0]	64.0 [53.0, 75.0]	65.7 [58.0, 73.4]	< 0.001§	0.8	< 0.0001§	< 0.0001§
Postoperative in-hospital oral morphine equivalent consumption, mg	13.4 [8.6, 18.2]	43.4 [31.7, 55.1]	45.3 [37.2, 53.4]	< 0.001§	0.8	< 0.0001§	< 0.0001§
Quadriceps motor strength (maximum voluntary isometric contraction)							
Preblock baseline (pound-force)	33.4 [30.8, 36.1]	32.9 [30.1, 35.7]	30.8 [27.8, 33.8]	0.381	N/A	N/A	N/A
At 30 min (pound-force)	27.8 [25.7, 29.9]	28.5 [25.8, 31.2]	26.1 [23.4, 28.8]	0.373	N/A	N/A	N/A
Percentage reduction at 30 min‖	16.7%	13.4%	15.3%	0.731	N/A	N/A	N/A
One sample paired *t* test (t-critical)	5.4 (2.0)	3.3 (2.0)	3.5 (2.0)	N/A	N/A	N/A	N/A
Intraoperative opioid consumption, converted to oral morphine (mg)	60.6 [53.7, 67.5]	56.1 [48.9, 63.3]	60.0 [54.0, 67.2]	0.562	N/A	N/A	N/A
Time-to-first analgesic request (min)	29 [20, 38]	21 [14, 28]	15 [10, 20]	0.020§	0.14	0.006§	0.154
Time to discharge readiness (min)	169 [154, 184]	172 [159, 185]	179 [164, 194]	0.572	N/A	N/A	N/A
Rest pain VAS scores, cm							
In postanesthesia care unit	2.0 [1.4, 2.7]	2.7 [1.9, 3.5]	3.4 [2.7, 4.1]	0.040§	0.23	0.007§	0.184
At 6 h	1.4 [1.0, 1.8]	1.7 [1.3, 2.1]	2.4 [2.0, 2.8]	0.004§	0.017	0.001§	0.313
At 12 h	1.8 [1.2, 2.4]	2.3 [1.8, 2.8]	2.5 [2.1, 2.9]	0.093	N/A	N/A	N/A
At 18 h	1.7 [1.2, 2.2]	1.8 [1.2, 2.4]	2.2 [1.8, 2.6]	0.282	N/A	N/A	N/A
At 24 h	1.8 [1.2, 2.4]	2.2 [1.6, 2.8]	2.4 [2.0, 2.8]	0.263	N/A	N/A	N/A
AUC for postoperative VAS scores during the first 24 h, cm h	6.8 [6.7, 6.8]	8.2 [8.1, 8.2]	10.0 [9.9, 10.1]	< 0.001§	< 0.0001§	< 0.0001§	< 0.0001§
Sensory confirmation of ACB onset at 30 min after ACB	34 (100)	38 (100)	36 (100)	1.000	N/A	N/A	N/A
Incidence of postoperative nausea and vomiting							
During in-hospital recovery	6 (17.6)	11 (28.9)	14 (38.9)	0.143	N/A	N/A	N/A
At 24 h	10 (29.4)	15 (39.5)	23 (63.9)	0.020§	0.04	0.005§	0.373
Incidence of falls and near falls during the first 24 h	0 (0)	0 (0)	0 (0)	1.000	N/A	N/A	N/A
Patient satisfaction with pain relief at 24 h (VAS)	6.6 [5.9, 7.3]	6.7 [5.8, 7.6]	6.8 [6.0, 7.4]	0.943	N/A	N/A	N/A
Incidence of block-related complications during block (vascular puncture, hematoma formation, systemic toxicity, paresthesia), n/N	0 (0)	0 (0)	0 (0)	1.000	N/A	N/A	N/A
Incidence of postoperative neurologic symptoms at 2 weeks (numbness, paresthesia, weakness, pain), n/N	0 (0)	0 (0)	0 (0)	1.000	N/A	N/A	N/A
Quality of recovery (QoR-15) scores at 24 h	94 [86, 101]	91 [82, 100]	89 [82, 97]	0.722	N/A	N/A	N/A

*The threshold of statistical significance for overall group effect is 0.05, except for primary outcomes, where the threshold is 0.025. †Values are expressed as the means [95% CI], median [interquartile range], or absolute numbers (percentages). ‡Primary outcomes. §Statistically significant. ‖The threshold of statistical significance for intergroup tests is 0.017, except for primary outcomes, where the threshold is 0.008.

ACB, adductor canal block; AUC, area under the curve; N/A, not applicable; n/N, n (percentage); VAS, visual analog scale.

None of the patients in the three groups experienced any block-related complications or any new neurologic symptoms at the 2-week follow-up (table 2). There were no incidents of falls or near falls among the study participants, and there was no difference in the ability to return to baseline activity at 24 h after anterior cruciate ligament reconstruction, as measured by the QoR-15 scale.

Discussion

Compared to distal and mid-adductor canal injection locations, a proximal injection location for adductor canal block provided greater opioid-sparing effects without compromising quadriceps motor strength for patients undergoing ambulatory anterior cruciate ligament reconstruction. A proximal adductor canal injection location also increased the time to first analgesic request, decreased postoperative pain scores between 0 and 6 h, and decreased the risk of postoperative nausea and vomiting in the first 24 h after anterior cruciate ligament reconstruction, in comparison with mid-and distal adductor canal locations. These results were unexpected and contrary to our own hypothesis, which had been based on previous cadaveric and volunteer studies.[16,17] Nonetheless, we can postulate two potential anatomical explanations to support our current findings. First, some of the local anesthetic injected near the apex of the femoral triangle (*i.e.*, proximal adductor canal location) may spread sufficiently cephalad to reach the posterior division of the femoral nerve, whereupon the smaller sensory pain fibers are preferentially anesthetized compared to the larger motor

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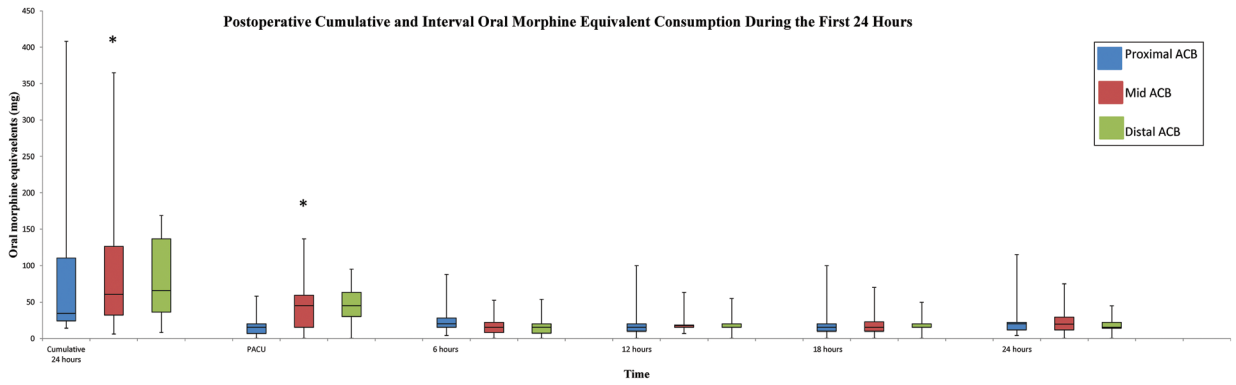

Fig. 3. Plot of the effect of the three adductor canal block locations on cumulative (primary outcome) and interval postoperative oral morphine equivalent consumption during the first 24 h after anterior cruciate ligament repair. Proximal adductor canal block reduces cumulative 24-h oral morphine equivalent consumption, as well as consumption during postanesthesia care unit stay. *Bars* represent means; *boxes* represent interquartile ranges; and *error bars* represent ranges. ACB, adductor canal block; PACU, postanesthesia care unit. *Statistically significant difference between the three study groups (Bonferroni correction).

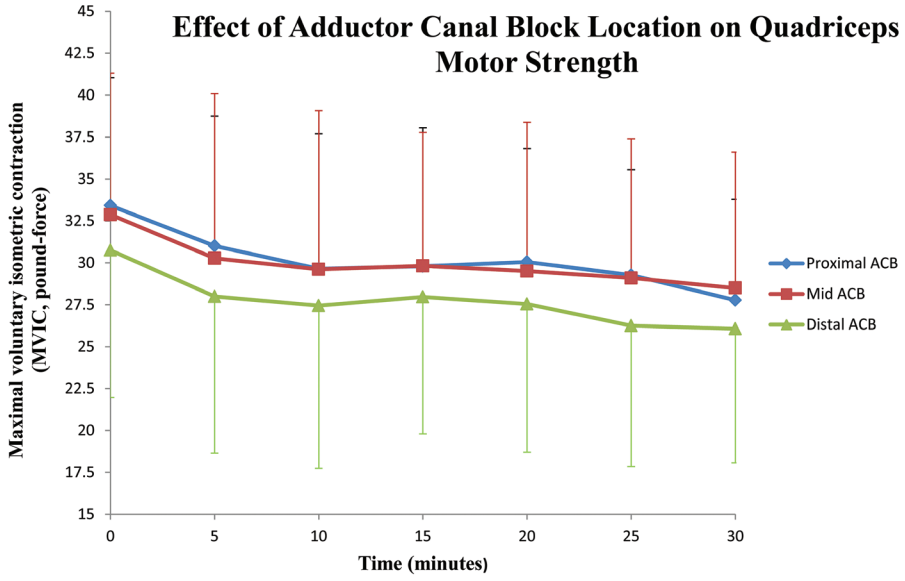

Fig. 4. Effect of adductor canal block location on quadriceps muscle strength, as measured by isometric dynamometer during maximal isometric contraction. The means and SD (*error bars*) of the percentage of maximal voluntary isometric contraction (MVIC) preserved are examined up to 30 min postblock. Time 0 h corresponds to admission to the postanesthesia care unit. The difference is not statistically significant at any of the time points (Bonferroni–Holm correction). ACB, adductor canal block.

fibers. The second explanation, which we believe is more plausible because of the observed motor preservation compared to femoral nerve block *per se*,[26] may be that a proximal injection location provides a more comprehensive block of the terminal sensory nerves that innervate of the knee joint, as has been proposed by some anatomical studies.[10,18] Indeed, more recent anatomical observations published after the initiation of the present trial suggest that distal adductor canal block locations may not be ideal to block the infrapatellar branch of the saphenous nerve, the medial femoral cutaneous nerves, and the medial vastus nerve.[8] Moreover, when injected in the proximal location, the 20-ml volume used in the present study may have resulted in local anesthetic diffusion along fascial planes to reach the popliteal plexus.[16,17]

This is the first clinical study to investigate different injection locations for adductor canal block in the setting

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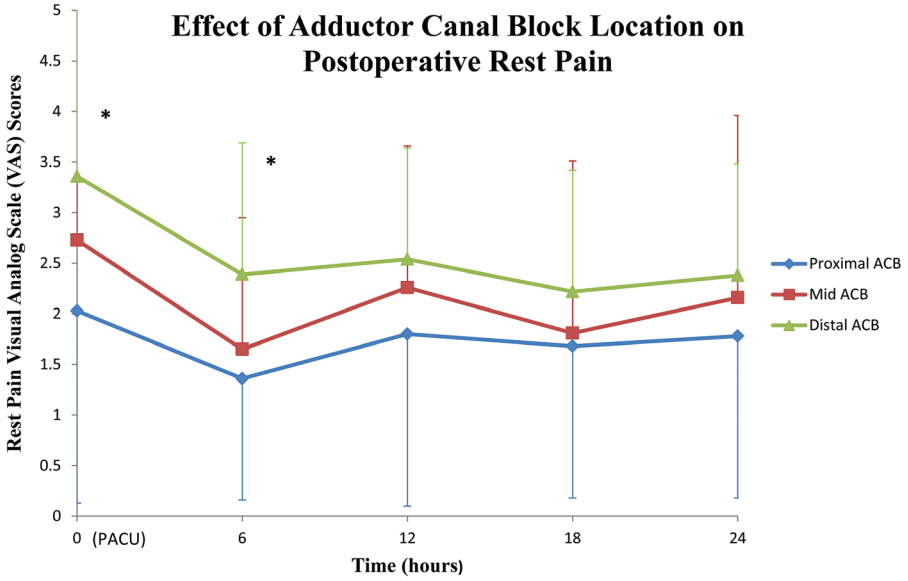

Fig. 5. Effect of ACB location on postoperative rest pain scores, as measured in visual analog scale (VAS) pain scores. The means and SD (*error bars*) of rest pain VAS scores are examined up to 24 h postsurgery. Time 0 h corresponds to admission to the PACU. The proximal ACB location is superior to the distal location at 0 and 6 h postsurgery. ACB, adductor canal block; PACU, postanesthesia care unit. *Statistically significant difference between the three study groups (Bonferroni–Holm correction).

of ambulatory anterior cruciate ligament reconstruction. Previous trials that have investigated different injection locations in the setting of continuous adductor canal block for total knee arthroplasty[13,14,27] have failed to detect any differences in pain scores on the day of the surgery, as well as in the 24-h cumulative analgesic consumption. These discrepancies between the present study and those published previously are likely attributable to the use of a continuous catheter-based perineural local anesthetic infusion, the final catheter tip position (which was not known), surgeon-administered periarticular local anesthetic infiltration, spinal anesthesia, and/or delayed (postoperative day 1) assessment of motor weakness. Such fundamental differences restrict the generalizability of knee arthroplasty literature to the setting of ambulatory anterior cruciate ligament reconstruction.

This study marks a departure from the traditional use of surface anatomy landmarks[28,29] to the use of sonographic landmarks for guiding the optimal injection location for adductor canal block. Importantly, this study also adds to our current state of knowledge regarding the analgesic efficacy of adductor canal block in the setting of ambulatory anterior cruciate ligament reconstruction. To date,[30] good quality evidence has been scant, and researchers have not been able to detect any early analgesic benefits of adductor canal block for anterior cruciate ligament reconstruction. Specifically, Espelund *et al.*[31] and Lundblad *et al.*[32] reported that adductor canal block was not better than placebo for decreasing postoperative 24-h cumulative morphine consumption and rest pain at 6 h postoperatively. However, in keeping with our findings in the present study, Espelund *et al.* used a mid-adductor canal block location, whereas Lundblad *et al.* used a very distal (infrapatellar) adductor canal injection location. Notably, the combined 24-h cumulative oral morphine consumption for those two studies is comparable to our own results for the mid and distal locations, underscoring the validity of our conclusions.

Our study is subject to several limitations. First, we detected a robust and clinically important difference in a direction discordant with our own hypothesis. Although unexpected, this underscores the presence of equipoise at the outset of the study, as preclinical evidence pointed to superiority of distal adductor canal injection location,[10,15–17] whereas clinical evidence with limited generalizability from knee arthroplasty using continuous adductor canal block pointed to the superiority of proximal adductor canal location.[14,33] Second, our design lacked a control (no block) group; although evidence supporting the routine use of adductor canal block for anterior cruciate ligament reconstruction has been questioned,[30] adductor canal block is already an integral part of the care standard at our institution. Additionally, in the absence of invasive sham injections, we cannot exclude the possibility of detection and performance biases by the patients and anesthesiologists performing blocks. Third, in terms of outcome selection, we did not specifically evaluate posterior knee pain.[34] Nonetheless, our *post hoc* attempt to explore the role of posterior knee pain by stratifying the analysis according to the type of graft used

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(hamstring *vs*. bone-patellar tendon-bone) suggested no difference in both opioid consumption ($P = 0.55$) and a decrease in quadriceps strength ($P = 0.8$). Fourth, the practical constraints of a busy outpatient center limited our quadriceps strength assessment to 30 min after the block, and postsurgical assessment was not feasible because of splinting and expedited discharge. Fifth, the magnitude of difference in pain scores at 0 and 6 h varied between 1 and 1.4 units among our groups. Although this difference may be small in absolute terms, it is a large relative difference for anterior cruciate ligament reconstruction performed in the setting of multimodal analgesia. It also exceeds what is considered as a clinically important difference in acute pain.[35] Sixth, lack of assessment of dynamic pain as well as long-term functional outcomes is a limitation. Seventh, although we observed consistent differences favoring a proximal adductor canal injection location in several secondary outcomes important to the outpatient setting, such as rates of postoperative nausea and vomiting, time to discharge readiness, and quality of postoperative recovery, these differences were not statistically significant primarily because of lack of sufficient power to examine these outcomes. Finally, our findings are specific to the population, interventions, and clinical settings examined and may not be generalizable to different knee surgeries, local anesthetic volumes, analgesic modalities, or adductor canal block catheter techniques. In conclusion, our results indicate that a proximal adductor canal injection location for adductor canal block decreases opioid consumption and opioid-related side effects without compromising quadriceps motor function compared to a mid or distal adductor canal injection location in patients undergoing ambulatory anterior cruciate ligament reconstruction.

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Competing Interests

The authors declare no competing interests.

Reproducible Science

Full protocol available at: FAbdallah@toh.ca. Raw data available at: FAbdallah@toh.ca.

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