Continuous Ultrasound-Guided Adductor Canal Block for Total Knee Arthroplasty: A Randomized, Double-Blind Trial

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BACKGROUND: Adductor canal blocks have shown promise in reducing postoperative pain in total knee arthroplasty patients. No randomized, controlled studies, however, evaluate the opioid-sparing benefits of a continuous 0.2% ropivacaine infusion at the adductor canal. We hypothesized that a continuous adductor canal block would decrease postoperative opioid consumption.

METHODS: Eighty subjects presenting for primary unilateral total knee arthroplasty were randomized to receive either a continuous ultrasound-guided adductor canal block with 0.2% ropivacaine or a sham catheter. All subjects received a preoperative single-injection femoral nerve block with spinal anesthesia as is standard of care at our institution. Cumulative IV morphine consumption 48 hours after surgery was evaluated with analysis of covariance, adjusted for baseline characteristics. Secondary outcomes included resting pain scores (numeric rating scale), peak pain scores during physical therapy on postoperative days 1 and 2, quadriceps maximum voluntary isometric contraction, distance ambulated during physical therapy, postoperative nausea and vomiting, and satisfaction with analgesia.

RESULTS: Eighty subjects were randomized, and 76 completed the study per-protocol. The least-square mean difference in cumulative morphine consumption over 48 hours (block − sham) was −16.68 mg (95% confidence interval, −29.78 to −3.59, \( P = 0.013 \)). Total morphine use between 24 and 48 hours (after predicted femoral nerve block resolution) also differed by least-square mean −11.17 mg (95% confidence interval, −19.93 to −2.42, \( P = 0.013 \)). Intention-to-treat analysis was similar to the per-protocol results. Functional outcomes revealed subjects in the adductor canal catheter group had better quadriceps strength (\( P = 0.010 \)) and further distance ambulated (\( P = 0.034 \)) on postoperative day 2.

CONCLUSIONS: A continuous adductor canal block for total knee arthroplasty reduces opioid consumption compared with that of placebo in the first 48 hours after surgery. Other outcomes including quadriceps strength, distance ambulated, and pain scores all show benefit from an adductor canal catheter after total knee arthroplasty but require further study before being interpreted as conclusive. (Anesth Analg 2014;118:1370–7)

Continuous femoral nerve blocks are routinely used for prolonged and focused analgesia after total knee arthroplasty and are superior to systemic opioids alone.1 However, while the femoral nerve is the primary afferent nerve of the knee, it also supplies motor innervation to the anterior thigh. Consequently, femoral nerve blockade is associated with quadriceps weakness, which compromises balance and pivoting maneuvers, and may result in increased fall risk.2–5

The adductor canal block, a primarily sensory block, may offer a favorable alternative to the continuous femoral nerve block as quadriceps function is largely preserved.6 Preliminary studies of continuous adductor canal blocks for postoperative analgesia after total knee arthroplasty are encouraging.7–9 Anatomically, this block is performed along the femoral nerve, distal to most of the efferent branches to the quadriceps muscle,10–15 preserving quadriceps strength. Previous studies using a continuous adductor canal block delivered boluses of 0.75% ropivacaine at repeated intervals, not as a continuous infusion.8,9 There are significant pharmacokinetic and pharmacodynamic differences between high-concentration boluses and low-concentration infusions; therefore, the efficacies of these 2 methods may not be equivalent.

In this single-center, randomized, parallel-group, placebo-controlled, double-blinded trial, we investigated the effect of the continuous adductor canal block on analgesia compared with that of placebo in subjects undergoing total knee arthroplasty. We hypothesized that continuous adductor canal block would reduce opioid consumption by at least 25% compared with that of placebo.

METHODS

Subjects

After IRB approval (Benaroya Research Institute, Virginia Mason Medical Center, Seattle, Washington) on February 1, 2012, 140 consecutive subjects undergoing unilateral total
knee arthroplasty were evaluated for participation in this study. Eighty subjects provided written consent to participate in this single-center, randomized, parallel-group, placebo-controlled, double-blind trial. Inclusion criteria were adult (age >18 years) patients and ASA physical status I to III undergoing primary, unilateral total knee arthroplasty. The study was conducted between April 2012 and November 2012. Exclusion criteria were contraindications to peripheral nerve or neuraxial blockade, allergy to opioids or local anesthetics, chronic opioid use (>1 month of 60 mg morphine oral equivalents daily), and subject refusal. Using computer-generated random assignment concealment with sealed envelopes, subjects were allocated to receive either an adductor canal catheter \((n = 40)\) or a sham catheter \((n = 40)\). Aside from the investigators performing the blocks, all other researchers, anesthesia personnel, surgeons, physician assistants, nurses, and the study participants were blinded to the randomization of each subject.

**Preoperative Preparation**

All subjects received both oral multimodal analgesia and a preoperative ultrasound-guided femoral nerve block, as is standard practice in our institution and absolutely required by our IRB. Multimodal analgesia consisted of oral acetaminophen (975 mg), celecoxib (400 mg), and gabapentin (900 mg) as indicated per subject medical history and allergies. For the femoral nerve block, a high-frequency linear array ultrasound transducer (SonoSite M-Turbo, Bothell, WA) was used to identify the femoral artery and nerve. A 21-gauge, 100-mm Stimuplex needle (B Braun, Melsungen, Germany) was then placed near the femoral nerve under ultrasound guidance, using an in-plane technique. A peri-neural injection was performed with 20 mL of 0.5% ropivacaine with 1:400,000 epinephrine. After femoral nerve block placement, all subjects received a spinal anesthetic with 12.5 mg plain bupivacaine for surgical anesthesia. No intrathecal opioids were used. During the femoral nerve block and spinal placement, the primary anesthesia team provided sedation with fentanyl (range 0–250 mcg) and midazolam (range 0–5 mg).

**Intraoperative**

In the operating room, all subjects received continuous propofol infusion during surgery for intraoperative sedation. Propofol was titrated to a Ramsay Sedation Score of 5. No intraoperative opioids were administered. Surgical technique and prosthesis selection were left to each individual surgeon. Based on varied practices among surgeons, a subset of them performed local infiltration with 30 mL 0.25% bupivacaine and 10 mg morphine.\(^1\)

**Catheter Insertion Procedure**

All catheters were placed by one of the investigators or a regional anesthesia fellow under the direct supervision of one of the senior investigators in the postanesthesia care unit immediately after surgery. A high-frequency linear array ultrasound transducer (SonoSite M-Turbo, Bothell, WA) was used to identify the adductor canal. The transducer was placed at the mid-thigh, half the distance between the inguinal crease and the patella. Next, the superficial femoral artery was identified dorsal/lateral to the sartorius muscle in short-axis. At this level, the hyperechoic structure located lateral/anterior to the artery was identified as the target catheter site at the adductor canal.

For subjects in the adductor canal catheter group, a 17-gauge Tuohy needle was placed lateral to the superficial femoral artery and within the adductor canal, using an in-plane ultrasound technique (Fig. 1). Up to 10 mL of sterile 0.9% normal saline was injected for hydrodissection during needle advancement and within the adductor canal to confirm proper needle tip positioning. A flexible 19-gauge open tip epidural-type catheter (Flexitip, Arrow International, Reading, PA) was advanced 1 to 2 cm into the adductor canal. The needle was removed, and the continuous catheter was secured with surgical glue and covered in a clear occlusive dressing. The catheter was attached to a portable electronic infusion pump (AmbIT, Summit Medical Products, Sandy, UT).

For subjects in the sham catheter group, a 17-gauge Tuohy needle was placed within the sartorius muscle to minimize the invasiveness of the procedure.\(^1\) Up to 10 mL of sterile, 0.9% normal saline was injected for hydrodissection during needle advancement. A similar flexible 19-gauge epidural-type catheter was placed into the sartorius muscle. The continuous catheter was secured with surgical glue and covered in a clear occlusive dressing. On completion of the sham block, the catheter was attached to a similar portable electronic infusion pump.
Catheter Infusate
Subjects in the adductor canal group received a continuous infusion of 0.2% ropivacaine at 8 mL/h with a 400 mL reservoir. For sham group subjects, the infusion pumps contained an empty de-aired bag programmed to run at the same setting of 8 mL/h. All infusion pumps and reservoirs were held in a completely opaque bag and sealed with tape. Weights were added to the sham group bags to make the size and weight similar in both groups.

Recordings and Measurements
Blinded research personnel performed all clinical assessments and data collection.

Morphine Consumption
Subjects received standardized IV patient-controlled analgesia (PCA) with hydromorphone (0.2 mg demand dose/8-minute lockout) through the morning of postoperative day 1. A morphine PCA (1 mg demand dose/8-minute lockout) was used if hydromorphone was contraindicated. After PCA discontinuation at 08:00 AM on postoperative day 1, all patients were transitioned to oral opioid analgesics. Dosing of oral opioid analgesics was standardized, based on reported pain scores. IV and oral opioid consumption were recorded from the electronic medical record during the 48 hours after surgery and converted to IV morphine equivalents.18

Objective Quadriceps Strength
Quadriceps strength of each subject was evaluated by maximum voluntary isometric contraction (MVIC) preoperatively, on postoperative day 1, and on postoperative day 2 by a blinded research investigator. Each subject made 3 attempts to achieve the highest peak pounds of force value at each of the measurement intervals. The maximum force achieved was recorded and used for analysis.

Functional Status
Maximum knee flexion on postoperative day 1 and 2 was assessed by physical therapy (PT). Two PT sessions were conducted each day.

Distance Ambulated
During each PT session on both postoperative days, subjects were asked to ambulate as far as possible. The total distance the subject ambulated was recorded in feet.

Numerical Rating Scale Score
Pain assessments on the operative limb were made preoperatively at rest. Pain assessments were also made at peak pain levels during PT in the morning and afternoon sessions of postoperative day 1 and postoperative day 2.

Patient Satisfaction
Subjects were asked to give a dichotomous verbal assessment (“Satisfied” or “Unsatisfied”) of the quality of analgesia during the first and second postoperative days.

Adverse Events
Each day research personnel directly asked subjects about their incidence of nausea and vomiting. In addition, the electronic record was reviewed for any treatment of nausea and vomiting on the first and second postoperative days. Both the nursing staff and the investigators tracked all events that would limit participation in MVIC testing or PT sessions along with any occurrence of subject falls.

Statistical Methodology
The sample size was calculated based on an unpublished retrospective review performed at our institution, assuming a mean morphine consumption of 69 mg in the sham group and a pooled standard deviation (SD) of 22 mg. To have >80% power to see a reduction of 25% or more in the block group, with an overall 2-sided type-I error rate of 0.05, 36 subjects with morphine consumption data through 48 hours were required. Four additional subjects in each arm were recruited to prevent loss of power due to early withdrawal. Power and type-I error spending adjustments for secondary outcomes were not considered in the study design, so inference should be based on the primary outcome.

Baseline characteristics were compared using the t test for independent samples for continuous variables, and the χ2 test or Fisher exact test for categorical variables, as appropriate. Morphine consumption was analyzed using analysis of covariance (ANCOVA), adjusted for age (included as a continuous covariate),19 gender, ASA physical status class (I and II versus III), local infiltration, and preoperative celecoxib. Other medications did not have enough variability to be included in the statistical models (all subjects received acetaminophen and 78 of 80 subjects received gabapentin). The primary hypothesis was a comparison of mean morphine consumption within 48 hours for patients who completed the study per protocol. As a sensitivity analysis, these models were repeated including patients who did not complete the study per protocol (Intention-to-treat [ITT] populations). Morphine use was collected through 48 hours regardless of protocol deviations.

Pain scores were based on an 11-point numeric rating scale (NRS), and the decision was made a priori to use the Mann-Whitney U test to assess differences in the distributions because pain data are typically right-skewed. Changes from baseline pain were assessed as a sensitivity analysis, although presurgical pain is less correlated with postoperative pain than in other interventions. Differences in the distribution of length of stay were assessed using the Mann-Whitney U test. Distance ambulated and quadriceps strength were compared using the t test for independent samples. Seated knee flexion, subject satisfaction, postoperative analgesia, and incidence of adverse effects were compared using the χ2 test or Fisher exact test.

RESULTS
Eighty subjects were recruited for this study. Forty subjects in the sham arm completed the study protocol and were analyzed for the primary outcome. Thirty-six subjects completed the study protocol in the adductor canal block arm and were analyzed for the primary outcome. Four subjects were excluded due to protocol violations (Fig. 2). Of the 4 subjects excluded, 1 subject’s infusion was unintentionally terminated during the night, another was excluded after a nurse and the subject became unblinded
to the subject’s randomization assignment, and 2 subjects requested to withdraw from the study. There were no significant differences between groups in demographic data including age, sex, body mass index, oral preoperative multimodal analgesia consumed, or surgical use of local infiltration (Table 1).

**Morphine Consumption**

Total mean morphine consumption over 48 hours was less in the adductor canal block group compared with that of the sham group. After adjustment for baseline covariates, the least-square mean (LSM) morphine consumption was 63.4 mg (95% confidence interval (CI), 51.9–74.8) in the sham group and 46.7 mg (95% CI, 34.9–58.5) in the block group ($P = 0.013$) (Table 2). To assess the impact of specific covariates on morphine consumption, individual analyses were performed with each covariate excluded. Exclusion of each individual covariate revealed that age was the only one that significantly affected opioid consumption (Table 3). Two subjects randomized to the sham group consumed 182 and 170 mg of IV morphine equivalents over 48 hours, respectively. When these values were truncated to the third highest value of 117 mg, the results in both groups remained significantly different though the LSM difference was reduced from 16.7 to 12.6 mg. Otherwise, diagnostic plots from the ANCOVA model showed acceptable residuals.

To differentiate opioid use after presumed resolution of the single-injection femoral nerve block, total morphine use between 24 and 48 hours after surgery was compared and was also significantly different by treatment: LSM 41.6 mg (95% CI, 34.0–49.3) for the sham group and 30.5 mg (95% CI, 22.6–38.4) for the block group ($P = 0.013$) (Table 2). Cumulative opioid consumption shows increasing opioid requirements in the sham group beginning at 24 hours after surgery (Fig. 3). Analyses of morphine consumption including the subjects with protocol deviations or early withdrawal (ITT population) were similar to the results restricted to patients who completed the study per protocol (Table 2). No difference in total mean morphine consumption was demonstrated in those 25 subjects who received surgical local infiltration (53.1 mg ± 27.9) compared with those who did not (51.5 mg ± 37.2) ($P = 0.85$).

**Objective Quadriceps Strength**

Both the adductor canal block and the sham groups demonstrated a significant decrease in MVIC postoperatively compared with that of baseline values ($P = 0.0003$ and $P < 0.0001$, respectively) on postoperative day 1. There was no difference in strength between groups on postoperative day 1 ($P = 0.746$). However, quadriceps strength was significantly greater in the block group on postoperative day 2 compared with that of placebo ($P = 0.010$) (Table 4).

**Functional Status and Distance Ambulated**

The block group showed a statistically significant improvement in maximum distance ambulated compared with that of the sham group on postoperative day 2: 378.4 ± 335.4 vs...
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243.7 ± 298.8 ft (P = 0.034). There was no difference between the groups in knee flexion (Table 4).

**Pain Scores**

The median resting NRS pain scores were evaluated preoperatively and then in 6-hour intervals after surgery in each subject. Peak NRS scores were also measured during both PT sessions on postoperative days 1 and 2. The median pain scores at the 18 hours (2 vs 4) (P = 0.009), 24 hours (3 vs 5) (P = 0.003), and 30 hours (3 vs 4) (P = 0.039) time points were significantly reduced for the block group compared with that of the sham group (Fig. 4). At 48 hours, the pain scores were not significantly different (P = 0.31). A post hoc noninferiority test at 48 hours demonstrated that the block group was highly unlikely to be more than one-third of a point worse than the sham group (P = 0.048). The peak median pain scores during PT also showed statistically significant reductions for the block group at the

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### Table 1. Demographic Data, Preoperative Multimodal Analgesia Consumption, and Surgical Intervention

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Continuous adductor canal block group (n = 36)</th>
<th>Sham catheter group (n = 40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>67 ± 10</td>
<td>70 ± 10</td>
<td>0.27</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>11 (30.6%)</td>
<td>15 (37.5%)</td>
<td>0.52</td>
</tr>
<tr>
<td>Body mass index</td>
<td>31 ± 6</td>
<td>31 ± 7</td>
<td>0.93</td>
</tr>
<tr>
<td>ASA physical status I/II/III</td>
<td>0/29/7</td>
<td>1/31/8</td>
<td></td>
</tr>
<tr>
<td>Celebrex, n</td>
<td>24</td>
<td>30</td>
<td>0.42</td>
</tr>
<tr>
<td>Gabapentin, n</td>
<td>35</td>
<td>39</td>
<td>1.00</td>
</tr>
<tr>
<td>Acetaminophen, n</td>
<td>36</td>
<td>40</td>
<td>1.00</td>
</tr>
<tr>
<td>Local infiltration, n</td>
<td>11</td>
<td>14</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Values are shown as mean ± SD or number and %.

### Table 2. Morphine Consumption

<table>
<thead>
<tr>
<th></th>
<th>Continuous adductor canal block group (n = 36)</th>
<th>Sham catheter group (n = 40)</th>
<th>Difference (block − sham)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary outcome</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total milligram use in 48 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completed study</td>
<td>46.68</td>
<td>63.36</td>
<td>−16.68</td>
<td>0.013</td>
</tr>
<tr>
<td>ITT (sensitivity)</td>
<td>45.62</td>
<td>61.77</td>
<td>−16.15</td>
<td>0.012</td>
</tr>
<tr>
<td>Total milligram use from 24 to 48 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completed study</td>
<td>30.47</td>
<td>41.64</td>
<td>−11.17</td>
<td>0.013</td>
</tr>
<tr>
<td>ITT (sensitivity)</td>
<td>29.72</td>
<td>40.34</td>
<td>−10.61</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Least-square means (LSM), 95% confidence intervals (CI), and P values from ANCOVA models, adjusted for age (P < 0.001), gender (P = 0.30), ASA physical status class (I and II vs III, P = 0.054), local infiltration (P = 0.56), and preoperative celecoxib (P = 0.013). The intention-to-treat (ITT) population included 4 subjects on the block arm who did not complete the study per-protocol. All opioid consumption measurements through 48 hours were available for these patients. With no covariate adjustment, the least-square mean difference between block and sham was −12.97, 95% CI, (−28.47 to 2.52), P = 0.099 for the study completer set and −13.82, 95% CI, (−28.65 to 1.02), P = 0.0674 for the ITT population.

### Table 3. Impact of Single Covariate Exclusion on Morphine Consumption

<table>
<thead>
<tr>
<th>Excluding covariate</th>
<th>Continuous adductor canal block group (n = 36)</th>
<th>Sham catheter group (n = 40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>46.71</td>
<td>57.52</td>
<td>0.17</td>
</tr>
<tr>
<td>Sex</td>
<td>44.75</td>
<td>62.01</td>
<td>0.01</td>
</tr>
<tr>
<td>ASA physical status I/II vs III</td>
<td>41.64</td>
<td>58.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Local infiltration</td>
<td>47.79</td>
<td>64.15</td>
<td>0.01</td>
</tr>
<tr>
<td>Preoperative celecoxib</td>
<td>48.43</td>
<td>65.98</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Least-square means (LSM), 95% confidence intervals (CI), and P values from ANCOVA models when the individual covariate is excluded. All single covariate exclusion models remain statistically significant (P < 0.05) except when age is excluded. The impact of age on opioid consumption is well documented in the literature.19

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Figure 3. Cumulative opioid consumption. Values are displayed in mean IV morphine equivalents (MEQ) and standard errors over 48 hours after surgery.
morning sessions on postoperative days 1 ($P = 0.014$) and 2 ($P = 0.017$) (Fig. 5).

**Patient Satisfaction**

On postoperative day 1, 94% of subjects in the block group and 65% of subjects in the sham group reported satisfaction with their analgesic regimen ($P = 0.002$). No difference was found in patient satisfaction on postoperative day 2 (Table 4).

**Adverse Events**

No differences were found in the incidence of nausea or vomiting between groups (Table 5). No evidence of visible infection at any catheter site was found during routine follow-up while subjects were in the hospital. No falls were recorded in either arm during the study period. We did not observe any events consistent with nerve injury. No other complications were reported.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Continuous adductor canal block group, ($n = 36$)</th>
<th>Sham catheter group, ($n = 40$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadriceps strength (maximum lbs of force)</td>
<td>45.1 ± 28</td>
<td>36.5 ± 19</td>
<td>0.12</td>
</tr>
<tr>
<td>Preoperative</td>
<td>24.9 ± 20.5</td>
<td>23.3 ± 20.1</td>
<td>0.746</td>
</tr>
<tr>
<td>POD 1</td>
<td>34.3 ± 25.3</td>
<td>21.2 ± 17</td>
<td>0.01</td>
</tr>
<tr>
<td>Distance ambulated (ft)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POD 1</td>
<td>163.5 ± 247</td>
<td>89.8 ± 122.4</td>
<td>0.098</td>
</tr>
<tr>
<td>POD 2</td>
<td>378.4 ± 335.4</td>
<td>243.7 ± 198.8</td>
<td>0.034</td>
</tr>
<tr>
<td>Seated knee flexion (none/&lt;30°/&gt;30°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POD 1</td>
<td>1/17/18</td>
<td>1/21/18</td>
<td>0.91</td>
</tr>
<tr>
<td>POD 2</td>
<td>2/9/25</td>
<td>2/12/26</td>
<td>0.92</td>
</tr>
<tr>
<td>Patient analgesia satisfaction, n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POD 1 satisfied</td>
<td>34</td>
<td>26</td>
<td>0.002</td>
</tr>
<tr>
<td>POD 2 satisfied</td>
<td>33</td>
<td>35</td>
<td>0.72</td>
</tr>
<tr>
<td>Postoperative non-opioid analgesia</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>NSAID</td>
<td>22</td>
<td>26</td>
<td>0.73</td>
</tr>
<tr>
<td>Acetaminophen</td>
<td>31</td>
<td>38</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Values are shown as mean ±SD, actual number, or median.

$POD =$ postoperative day; $lbs =$ pounds; $° =$ degrees; NSAID = nonsteroidal anti-inflammatory drugs.

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**Table 5. Side Effects**

<table>
<thead>
<tr>
<th></th>
<th>Continuous adductor canal block group, ($n = 36$)</th>
<th>Sham catheter group, ($n = 40$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nausea</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>POD 1</td>
<td>17</td>
<td>25</td>
<td>0.18</td>
</tr>
<tr>
<td>POD 2</td>
<td>4</td>
<td>10</td>
<td>0.15</td>
</tr>
<tr>
<td>Vomiting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POD 1</td>
<td>12</td>
<td>10</td>
<td>0.42</td>
</tr>
<tr>
<td>POD 2</td>
<td>2</td>
<td>5</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Values are shown as actual number. $POD =$ postoperative day.

There was a subset of subjects from both groups who could not complete any PT sessions on either postoperative day 1 or 2. Two subjects could not participate because of medical reasons (1 block group; 1 sham group). Two subjects could not participate because of quadriceps weakness (1 block group; 1 sham group). One subject
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was unable to participate secondary to pain during PT (sham group).

**DISCUSSION**

This is the first randomized, placebo-controlled study investigating the opioid-sparing effect of a continuous 0.2% ropivacaine infusion at the adductor canal in patients undergoing total knee arthroplasty. Our results demonstrate that a continuous adductor canal block decreases opioid consumption in the first 48 hours after total knee arthroplasty. In addition, this study shows evidence of improvement in clinically relevant postsurgical outcomes including distance ambulated and pain with the use of a continuous adductor canal block. These secondary end points require confirmation with further prospective trials to make accurate inference.

Our primary outcome analysis (total mean morphine consumption) controls for all other variables that may reasonably be considered to affect opioid consumption. Age and opioid consumption are inversely related, with opioid consumption decreasing with increasing age. The impact of single covariate exclusion on the primary outcome analysis confirms this relationship between age and opioid consumption while revealing minimal impact on opioid consumption from the other covariates (Table 3). Acetaminophen and gabapentin were not included in these models, but since the use of these drugs was not different by treatment, it is unlikely that this would have affected our findings. Included in the final models were block randomization assignment, age, gender, body mass index, ASA physical status class, preoperative celecoxib use, and local infiltration by surgeon. The per protocol and ITT populations were remarkably consistent and demonstrated similar significant differences in mean opioid consumption between the sham group and block group.

We found a 40% decline in quadriceps strength from baseline in both block and sham subjects after total knee arthroplasty, >24 hours after the single-injection femoral nerve block. Decreased quadriceps strength after total knee arthroplasty can be due to nerve blockade, postoperative pain, and surgical trauma, resulting in decreased quadriceps function. While we observed an objective decrease in MVIC after total knee arthroplasty in all study subjects, the adductor canal block group subjects had stronger quadriceps strength compared with that of placebo on postoperative day 2. Though our results on quadriceps strength are a secondary outcome of this study, these findings are supported by previous studies of adductor canal blocks that demonstrate minimal quadriceps weakness in volunteers. Jaeger et al. showed preserved quadriceps strength in healthy volunteers with adductor canal block compared with femoral nerve block with only an 8% reduction in quadriceps strength in the adductor canal block group from baseline.

In addition, we found a significant difference in both resting and active pain scores for subjects with a continuous adductor canal block versus placebo. Median pain scores were reduced by at least 1 point on a 0 to 10 point scale at multiple time intervals. Our results support the findings by Jenstrup et al. who demonstrated decreased pain and enhanced mobility in subjects after total knee arthroplasty with an adductor canal block compared with that of placebo, using a perineural catheter to give intermittent high-concentration boluses of ropivacaine into the adductor canal. There are, however, potentially significant differences in the pharmacodynamics and pharmacokinetics of intermittent boluses versus continuous infusions. We demonstrated improvement in opioid use, pain scores, and functional outcomes using a continuous infusion at a lower concentration.

Our study does have several limitations. First, both groups received a preoperative single-injection femoral nerve block as our IRB required. A femoral nerve block using 20 mL of 0.5% ropivacaine in both groups is predicted to provide an analgesic effect of approximately 12 hours with some intersubject variability. Results after resolution of the required femoral nerve block show that cumulative opioid consumption begins to diverge between groups after 16 hours (Fig. 3). Therefore, all statistically significant results after 24 hours highlight the efficacy of a continuous 0.2% ropivacaine infusion at the adductor canal compared with that of placebo. However, the analgesic efficacy of an adductor block for the first 24 hours after total knee arthroplasty (relative to placebo or femoral block) and the overall role of this technique remain to be defined.

Second, a subset of each group received surgical local infiltration (approximately 34% in each group) that potentially contributed to reducing morphine consumption postoperatively. However, the subjects receiving local infiltration were equally distributed across randomized treatment assignment (Table 1). Post hoc morphine consumption analysis revealed no statistical difference in opioid consumption between those receiving local infiltration and those who did not. Therefore, the cohort of subjects receiving local infiltration was minimally affected by this intervention.

In conclusion, a continuous infusion of 0.2% ropivacaine at the adductor canal decreased opioid consumption while improving ambulation and pain compared with that of placebo in subjects undergoing a primary unilateral total knee arthroplasty. In addition, this regional technique may improve other clinically relevant outcomes. Opioid use, quadriceps motor strength, nociception, and PT participation are all interrelated factors and reflect the global postoperative course of patients. Future studies are required to confirm improvements in other clinically relevant end points, because this study was not designed to provide inference for these end points about subjects outside this trial.

**DISCLOSURES**

**Name:** Neil A. Hanson, MD.

**Contribution:** This author helped design and conduct the study, analyze the data, and write the manuscript.

**Attestation:** Neil A. Hanson has seen the original study data, reviewed the data analysis, approved the final manuscript, and is the author responsible for archiving the study files.

**Conflicts of Interest:** The author has no conflicts of interest to declare.

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**Contribution:** This author helped conduct the study and write the manuscript.

**Attestation:** Cindy Jo Allen has seen the original study data, reviewed the data analysis, and approved the final manuscript.

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