DARING DISCOURSE

# Adductor Canal Block Versus Femoral Canal Block for Total Knee Arthroplasty: A Meta-Analysis
## What Does the Evidence Suggest?

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Due to the invasiveness of total knee arthroplasty (TKA), the procedure is often associated with extreme postoperative pain. In fact, 23% of patients cite at home pain as "severe/extreme" after surgery, whereas 54% of the patients indicate "severe pain at least some of the time."[1] Moreover, it has been suggested that postoperative pain can also interfere with the recovery process,[2] which can put patients at an increased risk for postoperative complications including infections, loosening of the joint, and reflex sympathetic dystrophy.[3] Different techniques can be used preoperatively to complement the effects of general anesthesia, including femoral nerve block (FNB) and adductor canal block (ACB)/saphenous nerve block.

Femoral nerve block has traditionally been an efficient method to reduce postoperative pain after TKA. For instance, Chan et al[4] found that FNB decreased pain scores at 24 hours as compared with a sham procedure. Moreover, Jadon et al[5] observed that FNB is a more efficient method of analgesia as compared with IV fentanyl. However, FNB has been found to have postsurgical complications, including severe quadriceps muscle weakness.[6] Certainly, surgical causes such as tourniquet-related weakness or surgical quadriceps dysfunction must also be considered, but femoral nerve blockade–related weakness can be explained by the anatomy of the nerve targeted in the FNB. The femoral nerve not only comprises sensory branches, but also contains motor branches that innervate muscles of the upper and lower leg. The motor nerve involvement of the FNB is what leads to muscle weakness, which can alter the ability of the patient to ambulate properly and can increase the risk of postoperative falls. As such, ACB is a method of analgesia that has recently sparked tremendous interest in the scientific community due to its potential benefits over FNB; however, this approach itself does not come without controversy.

Adductor canal block is thought to be as effective as FNB in reducing postoperative pain.[7] In addition to having similar pain scores reported by patients, ACB has been thought to be associated with better quadriceps strength postoperatively in comparison to FNB. Theoretically, this is intuitive because the saphenous nerve, a component of the adductor canal and the nerve targeted in ACB, is a purely sensory branch of the femoral nerve. Due to the lack of motor impairment with ACB, quadriceps muscle function is preserved. This may ultimately lead to better ambulation after TKA.

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## METHODS

The recent emergence of many RCTs comparing FNB and ACB further demonstrates the growing inquiry toward the use of these nerve blocks in patients undergoing TKA. Specifically, an increasing number of RCTs on the topic have been published during the past 2 years. In response, we conducted a meta-analysis on the topic. A full search strategy was developed (Appendix 1, Supplemental Digital Content 1, http://links.lww.com/AAP/A158), and any clinical trial that randomly allocated adult patients (>18 years old) undergoing TKA to either FNB or ACB was considered for eligibility. Two independent reviewers (N.H. and T.G.F.) screened different electronic databases including MEDLINE, EMBASE, Cochrane Library, DARE, and related citations within PubMed from inception to January 30, 2015, for potential articles. Searches were conducted to locate both published and unpublished articles.

The methodological quality for each included article was evaluated using the Cochrane tool for assessment of risk of bias.[8] Questions in this tool related to randomization, blinding, and outcome data reporting. For each question, the risk of bias was reported as low risk, unclear risk, or high risk as assessed by 2 independent reviewers (N.H. and P.P.). An overall risk of bias assessment was also made for each trial to allow for subgroup analysis. The overall study was classified as (1) low risk of bias if all questions were answered as low risk, (2) unclear risk of bias if at least one question was answered as unclear risk whereas the rest were low risk, or (3) high risk of bias if at least one of the questions was answered as high risk.[8] To assess the agreement between the 2 reviewers, an unweighted κ was calculated.

An $I^2$ statistics test was used to calculate heterogeneity. The threshold for conducting subgroup analyses was an $I^2$ greater than 40%. As suggested by the Cochrane Handbook for Systematic Reviews, an $I^2$ greater than this value suggests that heterogeneity may be present.[8] If heterogeneity was present, it was explored on the basis of overall study quality and type of blockade (continuous vs single injection block).

## RESULTS

### Study Characteristics

A total of 6 studies met our specific preinclusion criteria (Fig. 1). A detailed description of all included studies can be found in Table 1. Briefly, a total of 408 patients undergoing TKA were

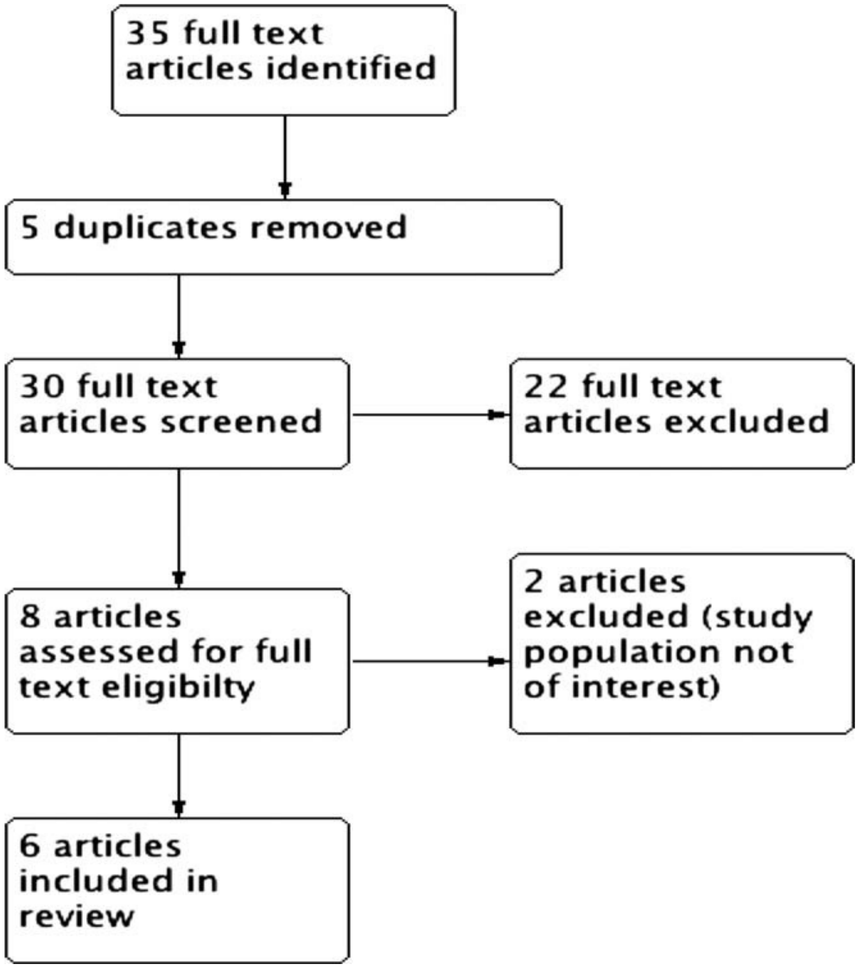


**FIGURE 1.** Flow diagram of study inclusion.

evaluated (n = 447 knees). On average, the mean age of the patients included in each of the studies ranged from 63.7 to 70.0 years. Of the 6 studies, 3 used a continuous nerve block[9–11] and 3 used a single-shot nerve block.[12–14] All 6 of the studies assessed postoperative pain at various lengths of follow-up. Five of the studies assessed pain using the visual analog scale (VAS),[9–13] whereas only one reported pain using the numeric rating scale (NRS).[14] Similarly, quadriceps muscle strength was measured by 5 studies[9,11–14]; however, the reporting of this outcome differed from study to study. Due to these differences, quadriceps strength could not be pooled, and thus, a graphical representation of the effects found by each study was made.

## Risk of Bias of Included Studies

The risk of bias was assessed by 2 independent reviewers (N.H. and P.P.). The raw agreement between the reviewers was found to be 86% and the unweighted κ was calculated to be 0.75, which represents excellent agreement. Most of the studies had a low risk of bias for all evaluated parameters as per the Cochrane Guidelines (Fig. 2). One study had a high risk of bias due to incomplete outcome reporting and lack of blinding.[10] The authors of this study stated that they were going to evaluate quadriceps muscle strength; however, these data were not reported. All 6 studies had good follow-up rates and few incomplete data.

## Pain

Overall, pain was assessed by 6 different studies at various follow-up times.[9–14] Three studies assessed pain at 4 hours postoperation using the visual analog scale.[9–11] At 4 hours postoperation, pain was not found to be significantly different between ACB and FNB (MD, −0.07; 95% confidence interval [CI], −2.59 to 2.45; $I^2 = 61\%$, $P = 0.96$) (Fig. 3). Pain was assessed at 24 hours postoperation by 5 studies[9–12,14] and once again, no significant difference was found between ACB and FNB (SMD, −0.04; 95% CI, −0.73 to 0.65; $I^2 = 27\%$, $P = 0.91$) (Fig. 4). Finally, pain was assessed at 48 hours postoperation by 3 studies.[11,12,14] No significant difference was found between ACB and FNB at this follow-up time (SMD, −0.06; 95% CI, −0.33 to 0.21, $I^2 = 0\%$, $P = 0.68$) (Fig. 5).

At 4 hours postoperation, heterogeneity was higher than the predefined 40% cutoff, although it was found to be nonsignificant ($P = 0.08$). This supported our choice to conduct subgroup analyses. Data were first stratified for the type of block used. This did not resolve the heterogeneity, and furthermore, no significant difference in pain score was found between single[11] versus continuous[9,10] nerve blocks ($P = 0.98$). Data were then stratified by risk of bias and heterogeneity was resolved. Studies of a low risk of bias[9–11] (MD, 0.99; 95% CI, −1.81 to 3.78; $I^2 = 22\%$, $P = 0.49$) and studies of a high risk of bias[10] ($P = 0.10$) both reported no

**TABLE 1.** Study Characteristics

| Reference | Methods | Participants/Hips | Intervention (Total) [Mean Age ± SD] | Comparison(s) (Total) [Mean Age] FNB | Anesthetics Used | Outcomes | Key Results |
|---|---|---|---|---|---|---|---|
| Jaeger, 2013 | RCT; Denmark | 48 patients; 48 knees | ACB (n = 22) [70 ± 8.0] | FNB (n = 26) [66 ± 9.0] | 30 mL of ropivacaine 0.5% followed by a 0.2% ropivacaine at a rate of 8 mL/h for the next 24 h | Quadriceps strength, adductor muscle strength, pain, opioid consumption, adverse events | Quadriceps strength was significantly higher for patients receiving ACB (52% of baseline) in comparison to FNB (18% of baseline) ($P = 0.004$)<br>No significant difference in pain between ACB and FNB ($P = 0.16$) |
| Kim, 2014 | RCT; USA | 93 patients; 93 knees | ACB (n = 46) [68 ± 9.4] | FNB (n = 47) [67.6 ± 11.3] | ACB—15 mL of 0.5% of bupivacaine with 5 μg/mL epinephrine<br>FNB—30 mL of 0.25% of bupivacaine with 5 μg/mL epinephrine | Quadriceps strength, pain, opioid consumption, adverse events | No statistical difference in pain between ACB and FNB at 6–8 h ($P = 0.0190$), 24 h ($P = 0.0103$), or 48 h ($P = 0.005$)<br>Quadriceps strength was significantly higher in the ACB group at 6–8 h ($P < 0.0001$)<br>ACB did not have significantly higher quadriceps strength at 24 or 48 h ($P = 0.99$) |
| Shah, 2014 | RCT; India | 98 patients; 98 knees | ACB (n = 48) [68.31 ± 7.56] | FNB (n = 50) [65.94 ± 7.22] | 30 mL injection of ropivacaine 0.75% followed by repeated injections of ropivacaine 0.25%, 30 mL at an interval of 4 h until 8:00 A.M. on the morning of the second day after surgery | Pain, ambulation time, mobility | ACB displayed significantly better postoperative outcomes in comparison to FNB for time to ambulation (TUG, 10 min and 30 s) and early functional recovery ($P < 0.001$)<br>No significant difference in pain between the 2 groups at 4, 8, 24, or 48 h follow-up ($P < 0.05$) |
| Grevstad, 2014 | RCT, Denmark | 50 patients; 50 knees | ACB (n = 25) | FNB (n = 25) | 30 mL ropivacaine 0.2% | Quadriceps strength, pain, mobility | Quadriceps strength was significantly higher in the ACB group at 2 h follow-up ($P < 0.0001$)<br>Postoperative pain did not significantly differ between the 2 groups at all follow-up times ($P > 0.05$)<br>Before block, 2 of 25 patients in each group were unable to perform TUG, after block this number increased to 7 in the FNB group and decreased to 0 in the ACB group |
| Memtsoudis, 2014 | RCT, USA | 59 patients; 118 knees | ACB (n = 30; left ACB, right FCB) | FCB (n = 29; left FCB, right ACB) | ACB—15 mL bupivacaine 0.25%<br>FNB—30 mL of bupivacaine 0.25% | Quadriceps strength, pain, patient satisfaction | Quadriceps strength was not significantly different between the 2 groups at 6–8, 24, and 48 h follow-up ($P > 0.05$)<br>Pain at rest was not significantly different between the 2 groups at 6–8, 24, and 48 h follow-up ($P > 0.05$) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Zhang, 2014 | RCT, Beijing Jishuitan Hospital | 60 patients; 40 knees | ACB (n = 30) [63.7 ± 5.8] | FNB (n = 30) [61.9 ± 6.7] | 20 mL of 0.33% ropivacaine initially then patients used electronic analgesic pumps to administer 0.2% ropivacaine through the catheter (continuous dose being 5 mL/h, and the bolus dose being 5 mL, with a lock time of 30 min)<br>Catheter withdrawn 48 h postoperation | Quadriceps strength, pain, adverse events | No significant difference in pain between ACB and FNB at 4 h ($P = 0.392$), 24 h ($P = 0.109$), 48 h ($P = 0.608$)<br>No significant difference in pain between ACB and FNB with movement at 4 h ($P = 0.624$), 24 h ($P = 0.167$), 48 h ($P = 0.279$)<br>Median quadriceps strength was significantly higher with ACB in comparison to FNB at 4 h ($P = 0.010$), 24 h ($P = 0.003$), 48 h ($P = 0.001$) |

significant difference in pain between ACB and FNB. In addition, there were no significant differences between the low and high risk of bias subgroups ($P = 0.10$).

It is important to note that postoperative opioid consumption was assessed by 2 studies.[9,14] Although this outcome could not be pooled due to variability in outcome measurement, each of the studies found no significant difference ($P > 0.05$) between postoperative opioid consumption between ACB and FNB.

### Quadriceps Strength

Due to the variability in outcome measurement, statistical pooling could not be conducted due to the wide variation in reporting between the included studies. As such, the data were effectively summarized in a graphical representation (Fig. 6). Four studies reported quadriceps muscle strength at less than 8 hours postoperation.[11–14] Three of these studies[11–13] reported a significant improvement in quadriceps muscle strength after using an ACB, whereas 1 study[14] found no significant difference. Again, 4 studies reported quadriceps strength at 24 hours postoperation.[9,11,12,14] Here, 2 studies[9,11] reported a significant increase in quadriceps strength after an ACB and 2 studies[12,14] reported no significant difference between the groups. Finally, at 48 hours postoperation, only one study[11] reported a significant increase in quadriceps strength with ACB use and 2 studies[12,14] reported no significant difference. It is important to note that no single study reported a significant improvement in quadriceps strength when using an FNB.

## DISCUSSION

### Block Reliability

Upon first impression, one may erroneously deduce that the evidence seems to suggest that no difference exists between ACB and FNB about postoperative pain and that ACB may be associated with quicker recovery of postoperative quadriceps strength; however, a closer look at the evidence suggests that this may not be the case. Specifically, questions immediately arise that pertain to defining the anatomical basis of the adductor canal.

Recently, concern has been raised about the RCT conducted by Jaeger et al.[6] In this trial, which was included in our meta-analysis, the authors compare ACB and FNB for postoperative pain and quadriceps strength after TKA. However, recent letters have framed the question: What exactly defines the adductor canal? Anatomically, Bendsten et al[15] suggested that the adductor canal extends from the apex of the femoral triangle to the adductor hiatus, which is the proximal one third of the thigh, with the canal itself being covered from the apex of the femoral triangle to the adductor hiatus by the vastoadductor membrane. Bendsten et al[15] further suggest that Jaeger et al[6] may have actually performed a subsartorial block within the femoral triangle due the possible location of the block within the mid thigh rather than the proximal one third. In reply to this, Jaeger et al[16] contest that the inherent nature of the block being in the midthigh region, which lies between the anterior superior iliac spine and the base of the patella, actually does place it within the adductor canal rather than the femoral triangle. Specifically, they support this through the fact that the sartorius muscle roofs the adductor canal, whereas the femoral triangle has no muscular roof.[16]

Thus, when one evaluates the currently available evidence using meta-analysis, these anatomical factors may confound our interpretation.

### Methodological Limitations

In addition to the question raised previously, our meta-analysis raises a concern about the lack of availability of current

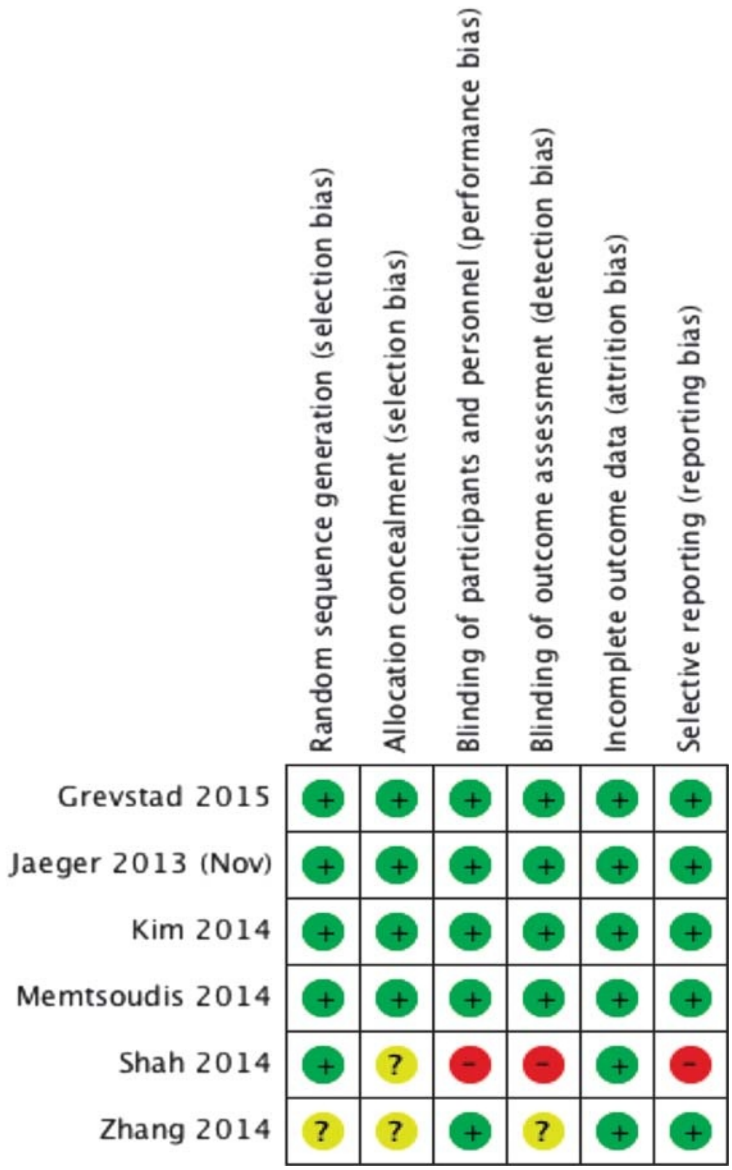


**FIGURE 2.** Risk of bias summary of included studies.

evidence. Although we reported that 6 randomized trials were conducted on the topic, each of these lacked standardized outcome reporting about quadriceps strength. Although we may be able to suggest that both ACB and FNB provide similar outcomes about postoperative pain, quadriceps strength needs to be better measured with standard and quantifiable measures, which allow for pooling.

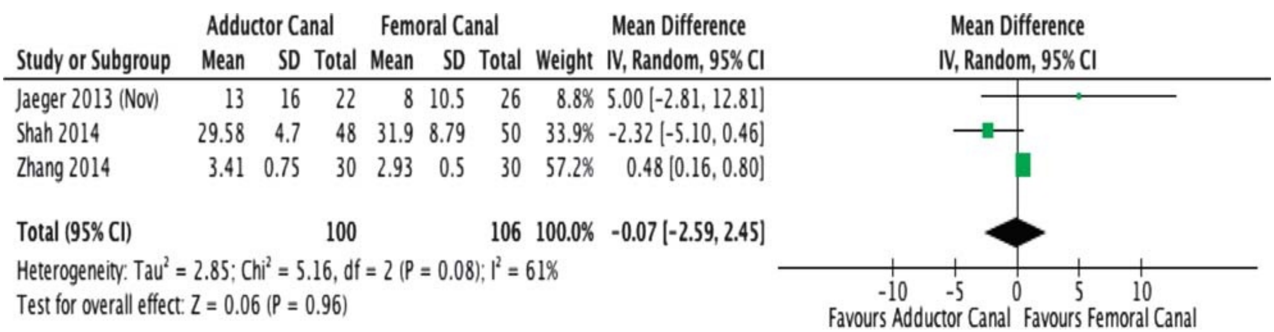


**FIGURE 3.** Pain at 4 hours postoperation.

| Study or Subgroup | Adductor Canal Mean | SD | Total | Femoral Canal Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Jaeger 2013 (Nov) | 18 | 15 | 22 | 12 | 15 | 26 | 0.6% | 6.00 [-2.52, 14.52] |
| Kim 2014 | 3.1 | 2.3 | 46 | 2.8 | 2.3 | 47 | 31.6% | 0.30 [-0.63, 1.23] |
| Memtsoudis 2014 | 2.81 | 2.42 | 29 | 2.47 | 2.47 | 30 | 21.7% | 0.34 [-0.91, 1.59] |
| Shah 2014 | 24.37 | 4.07 | 48 | 25.7 | 3.78 | 50 | 15.5% | -1.33 [-2.89, 0.23] |
| Zhang 2014 | 5.18 | 2.68 | 30 | 5.31 | 0.31 | 30 | 30.5% | -0.13 [-1.10, 0.84] |
| **Total (95% CI)** | | | **175** | | | **183** | **100.0%** | **-0.04 [-0.73, 0.65]** |

Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 5.46$, df = 4 (P = 0.24); $I^2 = 27\%$
Test for overall effect: Z = 0.11 (P = 0.91)

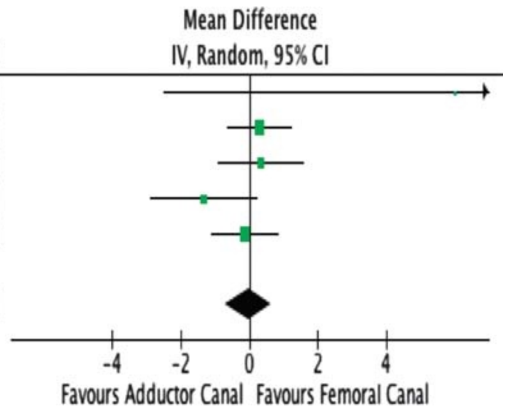


**FIGURE 4.** Pain at 24 hours postoperation.

| Study or Subgroup | Adductor Canal Mean | SD | Total | Femoral Canal Mean | SD | Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Kim 2014 | 4.3 | 2.2 | 46 | 4.8 | 3 | 47 | 43.8% | -0.19 [-0.60, 0.22] |
| Memtsoudis 2014 | 4.12 | 2.72 | 29 | 3.88 | 2.52 | 30 | 27.9% | 0.09 [-0.42, 0.60] |
| Zhang 2014 | 1.71 | 0.25 | 30 | 1.71 | 0.25 | 30 | 28.4% | 0.00 [-0.51, 0.51] |
| **Total (95% CI)** | | | **105** | | | **107** | **100.0%** | **-0.06 [-0.33, 0.21]** |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.77$, df = 2 (P = 0.68); $I^2 = 0\%$
Test for overall effect: Z = 0.42 (P = 0.68)

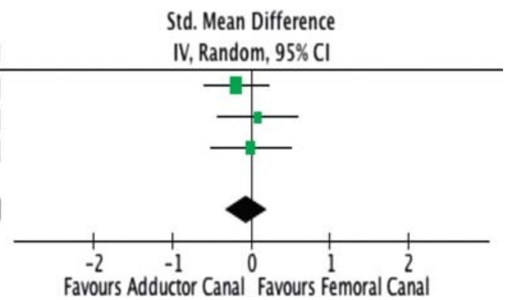


**FIGURE 5.** Pain at 48 hours postoperation.

With the lack of current information on motor blockade, it is very difficult to conclude which type of block may be more superior.

Another important methodological issue of current research is the relatively smaller sample sizes. Across 6 RCTs in this review, there were only a total of 408 patients. Smaller sample sizes allow for greater variability of the results and provide a less precise measurement of effect. A single, concise meta-analysis composed of several smaller randomized trials should theoretically increase the effect size by pooling the results from multiple studies; however, variability can still be present. Further, large-scale studies are necessary and, of necessity, would have to be multicenter, to provide better external validation of the results.

## Implications

Regional anesthesia is an excellent opportunity to achieve good pain control with minimal adverse effects, such as avoiding sedation and potential gastrointestinal adverse effects commonly

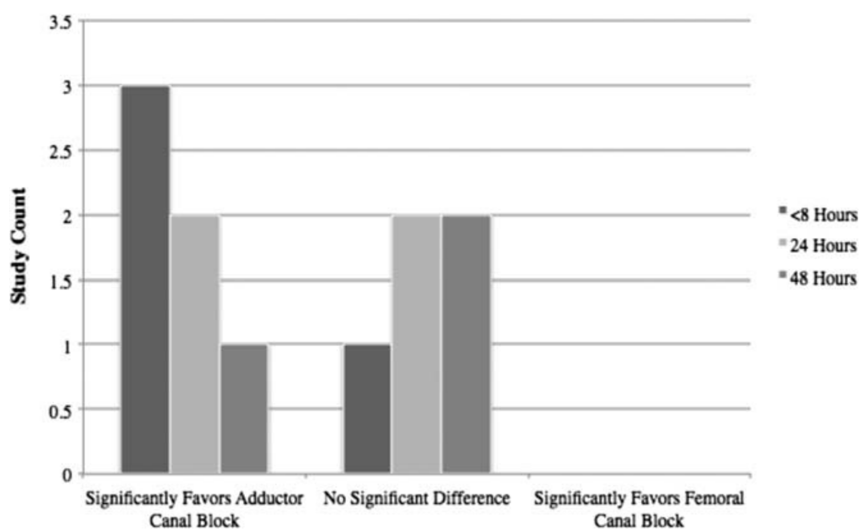


**FIGURE 6.** ACB versus FNB for quadriceps strength.

associated with narcotics. Surgeons, however, may be reluctant to use FNB in patients undergoing TKA as it delays rehabilitation and increases the risk of falls.[1,9,12] The opportunity to perform an ACB with the same pain control benefits but without the motor weakness makes it an attractive option in maximizing patient comfort while still enabling early aggressive rehabilitation. With this being said, it is imperative that randomized trials define the adductor canal in a consistent matter that is correct at an anatomical level because this would help alleviate concerns about the true type of block being performed.

## CONCLUSIONS

The success of TKA is currently measured by the rapid return to normal ambulatory function. Most successful rehabilitative programs include immediate postoperative weight bearing and active and passive full range of motion, which require the patient to have full motor control. Adductor canal block remains an attractive alternative to FNB for pain control and motor strength preservation after TKA; however, the anatomical location of the adductor canal needs to be better defined to ensure little consistency in the type of block performed. Until this fact is completely understood, we cannot safely suggest that an ACB provides optimal outcomes in comparison to FNB for TKA.

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ORIGINAL ARTICLE

# The Nerves of the Adductor Canal and the Innervation of the Knee
## *An Anatomic Study*

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**Background and Objectives:** Adductor canal block contributes to analgesia after total knee arthroplasty. However, controversy exists regarding the target nerves and the ideal site of local anesthetic administration. The aim of this cadaveric study was to identify the trajectory of all nerves that course in the adductor canal from their origin to their termination and describe their relative contributions to the innervation of the knee joint.

**Methods:** After research ethics board approval, 20 cadaveric lower limbs were examined using standard dissection technique. Branches of both the femoral and obturator nerves were explored along the adductor canal and all branches followed to their termination.

**Results:** Both the saphenous nerve (SN) and the nerve to vastus medialis (NVM) were consistently identified, whereas branches of the anterior obturator nerve were inconsistently present. The NVM contributed significantly to the innervation of the knee capsule, through intramuscular, extramuscular, and deep genicular nerves. The SN had a relatively more modest contribution through superficial infrapatellar and posterior branches as well as contributing to the origin of the deep genicular nerves.

**Conclusions:** The results suggest that both the SN and NVM contribute to the innervation of the anteromedial knee joint and are therefore important targets of adductor canal block. Given the site of exit of both nerves in the distal third of the adductor canal, the midportion of the adductor canal is suggested as an optimal site of local anesthetic administration to block both target nerves while minimizing the possibility of proximal spread to the femoral triangle.

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Total knee arthroplasty (TKA), a common surgical procedure for patients with advanced knee arthritis, is increasing in prevalence in societies with aging populations.[1,2] A systematic review of the literature that included 112 randomized controlled trials (RCTs) suggests that severe pain is common after TKA, especially in the first 24 hours postoperatively and during active range of motion.[3] On the basis of a subset of 19 RCTs, this review recommended femoral nerve block as an effective intervention to reduce pain in the first 48 hours after surgery.[3] Femoral nerve block, however, may accentuate the quadriceps muscle weakness commonly seen in the postoperative period, as evidenced by its effects on the Timed-Up-and-Go Test and the 30-Second Chair Stand Test.[4,5]

In recent years, an increased interest in expedited care pathways and enhanced early mobilization after TKA has driven the search for more peripheral sites of local anesthetic administration in an attempt to preserve postoperative quadriceps strength. The adductor canal, also known as the subsartorial or Hunter canal, has been proposed as one such location.[6–8] Early data suggest that adductor canal block (ACB) may contribute to adequate analgesia within a multimodal analgesic regimen.[6–8] The adductor canal begins at the apex of the femoral triangle and ends at the adductor hiatus, where the femoral artery becomes the popliteal artery, proximal to the adductor tubercle. This intermuscular tunnel is triangular in cross section and lies posterior to the sartorius muscle, serving as a passageway for the major neurovascular bundle of the thigh from its proximal origin in the femoral triangle on its way to the popliteal fossa, being in anatomic continuity with these 2 compartments. However, the specific nerves through which ACB provides knee analgesia is poorly understood. Although it has been suggested that the analgesic effect is essentially the result of saphenous nerve (SN) blockade,[9,10] the degree of analgesia reported in clinical studies seems to exceed that expected from an isolated SN block. The nerve to vastus medialis (NVM) also courses in the adductor canal. Although usually regarded as an exclusively motor nerve, some early anatomic studies reported a contribution to the innervation of the joint capsule and the medial retinaculum.[11,12] These early studies, however, did not describe the full trajectory of the NVM relative to the adductor canal and its entry point into the capsule of the knee joint. More detailed anatomic investigation is required to better understand the innervation of the knee joint, and to propose possible sites of local anesthetic administration within the adductor canal to maximize analgesia while minimizing motor blockade for TKA. Therefore, the aim of this cadaveric study was to identify and determine the trajectory of all nerves that course in the adductor canal from their origin to their termination and describe their relative contributions to the innervation of the knee joint. Branches of both the femoral and obturator nerves (ONs) were explored.

## METHODS

The study protocol was approved by the University of Toronto Health Sciences Research Ethics Board. Twenty cadaveric lower limbs (4 men and 16 women) with a mean age 85.3 ± 5.3 years were used in this study. No further demographic data (such as height, weight, or ethnic background) may be provided in compliance with local regulations (the Anatomy Act of Ontario and the Chief Coroner's office regulations). Specimens having visible signs of previous lower limb pathology or surgery were excluded. Six limbs were unembalmed, 2 light-embalmed, and 12 formalin-embalmed.

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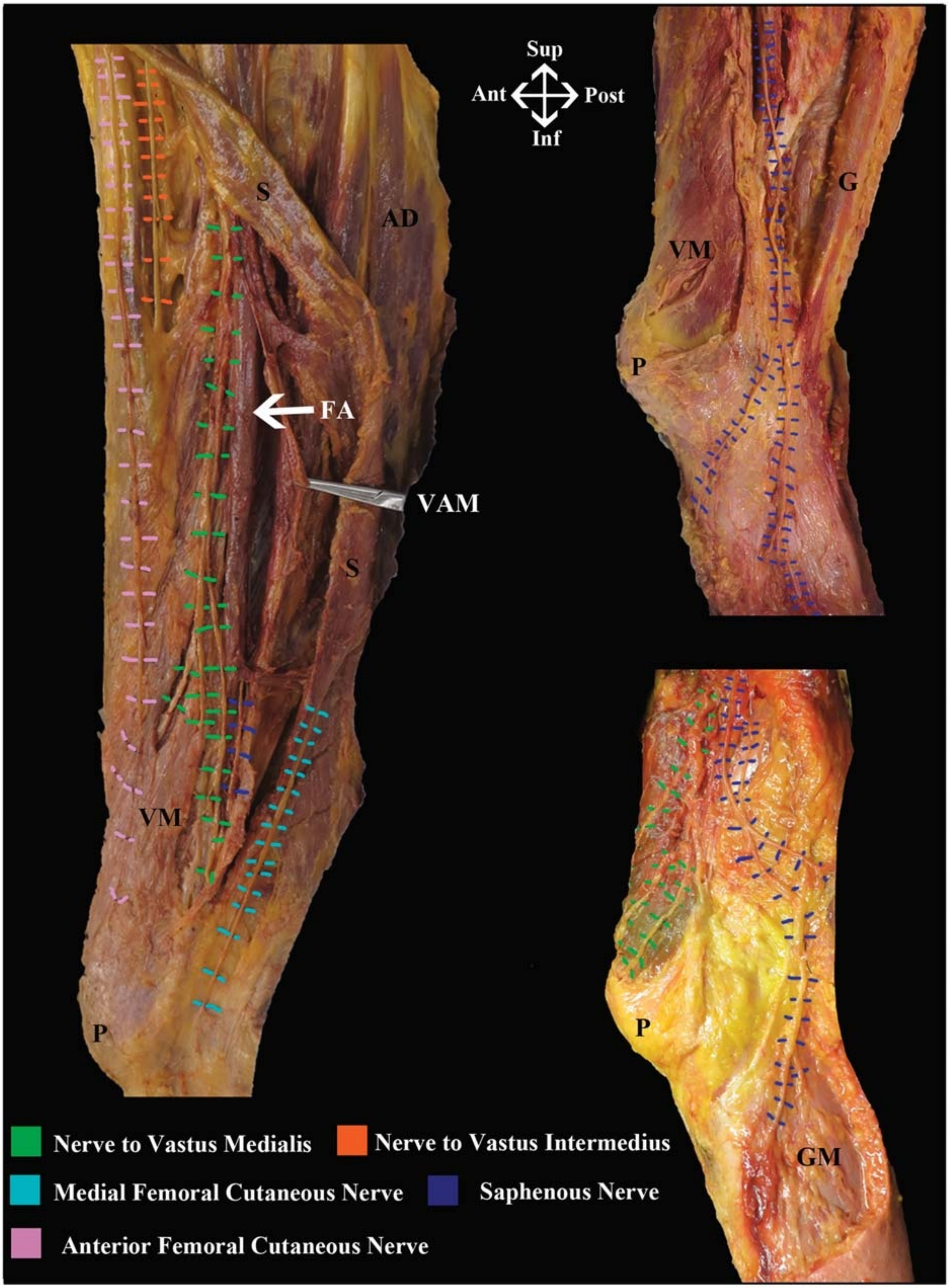


**FIGURE 1.** Anteromedial innervation of the knee. The sartorius muscle has been reflected medially to expose the adductor canal. The vastoadductor membrane has been reflected medially with forceps to expose the contents of the adductor canal. AD, Adductor muscle compartment; FA, femoral artery; G, gracilis; GM, gastrocnemius; P, patella; VM, vastus medialis.

**TABLE 1.** The Nerves of the Adductor Canal and Their Relative Contribution to the Innervation of the Anteromedial Knee Joint

| Nerve | Origin Within the Adductor Canal, n (%) | Contribution to Knee Innervation |
|---|---|---|
| NVM (via intramuscular branches) | 20 (100) | +++ |
| NVM (via extramuscular branch) | 7 (35) | ++ |
| SN (via infrapatellar branch) | 11 (55) | ++ |
| Deep plexus of mixed NVM and SN origin (via deep genicular nerves) | 18 (90) | +++ |
| Anterior ON (via small anastomotic branches) | 2 (10) | +/− |

The skin was removed from the specimen to expose the femoral nerve and its branches in the femoral triangle. The sartorius muscle and the vastoadductor membrane (the connective tissue "roof" of the canal) were removed to expose the neurovascular structures in the adductor canal. The nerves, the femoral artery and vein and their branches were carefully mobilized. The femoral vein and its tributaries were excised. The NVM and its branches were traced throughout the adductor canal up to their entry point into the vastus medialis muscle and to their termination. The SN and its branches were followed through the adductor canal to their termination except the sartorial branch which was followed into the subcutaneous tissues of the medial aspect of the leg. The anterior and posterior branches of the ON were revealed at the obturator foramen and followed through their course to document entry into the adductor canal if present. Any other independent branches identified in the adductor canal were followed to determine if they entered the capsule of the knee joint. The course of each nerve and its branches were photographed and documented throughout the dissection process. All branches entering the capsule of the knee joint were identified and their entry point recorded. The patterns of innervation to the knee joint were identified and compared among specimens.

## RESULTS

In all specimens, the 2 main nerves (SN and NVM) were found to course in the adductor canal (Fig. 1). Their relative contributions to the innervation of the knee joint are summarized in Table 1.

### Saphenous Nerve

The SN entered the adductor canal immediately lateral to the femoral artery at the apex of the femoral triangle, and coursed along the entire length of the adductor canal (Fig. 1). In all 20 specimens, the SN diverged from the femoral artery distally in the canal before it emerged subcutaneously between the sartorius and gracilis muscles (Fig. 1). A sartorial branch continuing distally along the medial aspect of the leg was observed in all 20 specimens (Fig. 1). In contrast, an infrapatellar branch innervating the skin just inferior to the patella was present in only 11 specimens (Fig. 1). The infrapatellar branch originated in the proximal third of the adductor canal in one specimen and distally in the medial

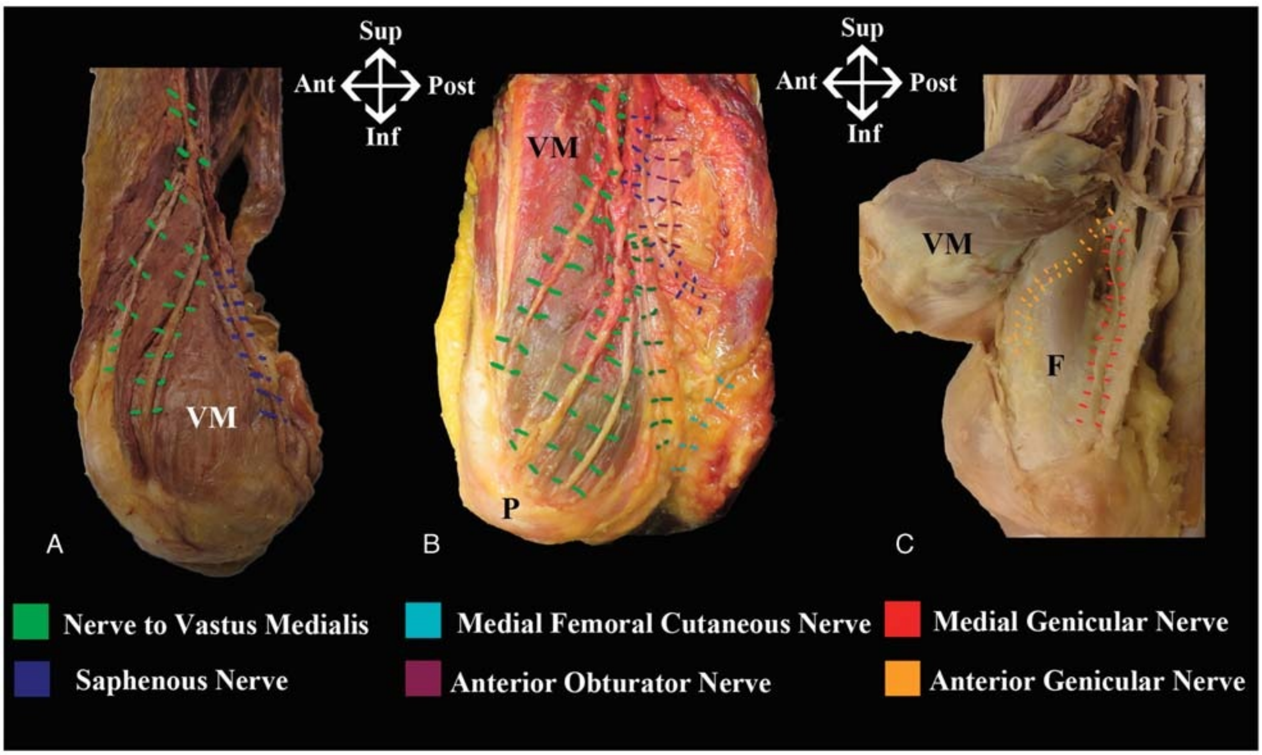


**FIGURE 2.** Distal and deep innervation of the knee joint. Note that in images (A) and (B) superficial muscle fibers of the vastus medialis have been removed to expose several deep intramuscular branches coursing through the muscle and ending in the anterior knee capsule. In (C), the entire vastus medialis muscle has been reflected anteriorly to expose the anterior and medial genicular nerves coursing on the surface of the femur towards the deep knee capsule. F, Femur; P, patella; VM, vastus medialis.

aspect of the knee in the remaining 10. It is interesting to note that an additional posteromedial branch of the SN was found in 3 of the 9 specimens that did not have an infrapatellar branch (Fig. 1).

## Nerve to Vastus Medialis

The NVM entered the adductor canal lateral to the femoral artery at the apex of the femoral triangle in all specimens (Fig. 1). Upon entering the canal, the NVM gave rise to 3 to 4 muscular branches that entered the muscle after coursing a short distance in the canal, and readily branched out to supply innervation to the muscle. In contrast, in the distal third of the adductor canal, the NVM gave rise to 1 to 3 additional large intramuscular branches (1 branch in 11 specimens, 2 in 8 specimens, and 3 in 1 specimen). After leaving the distal third of the adductor canal, these branches coursed obliquely from medial to lateral through the belly of the vastus medialis giving no visible branches to the muscle itself but rather terminating distally to the muscle belly in the capsule of the knee joint (Figs. 2A, B). The most proximal branch supplied the anterior capsule superior to the patella, whereas the remaining branches, if present, supplied the medial capsule (Figs. 2A, B).

Additionally, an extramuscular branch of the NVM was found in the distal third of the canal in 7 specimens. This nerve coursed along the medial border of the vastus medialis muscle, and terminated in the medial retinaculum and the medial aspect of the of the knee capsule (Fig. 2B).

## Deep Nerve Plexus

In 18 specimens, both the SN and the NVM gave rise to small branches in the distal third of the adductor canal that formed a deep nerve plexus lying between the femoral artery and the femur. Two nerves originating from this deep nerve plexus, the anterior and medial genicular nerves, coursed deep to the vastus medialis muscle along the femur to innervate the deep anteromedial aspect of the joint capsule (Fig. 2C). These nerves were exposed by reflecting the vastus medialis muscle laterally (Fig. 2C).

## Obturator Nerve

No terminal branches of the ON were found to directly innervate the capsule of the knee joint. In only 2 specimens, we found an anterior branch of the ON entering the adductor canal and anastomosing with the SN, one in the proximal third and one in the distal third of the canal (Fig. 2B).

# DISCUSSION

In this cadaveric study, we define the course of the SN, the NVM, and the ON in the adductor canal and we follow their branches to their termination. Our findings suggest that both the NVM and SN provide innervation to the anteromedial joint capsule. The NVM was found to play a much greater role than anticipated. In addition to its well-known motor function,[10] we found that multiple large transmuscular branches of the NVM consistently innervated the anteromedial joint capsule, and an additional extramuscular branch frequently innervated the subcutaneous tissues over the medial aspect of the knee.

Conversely, we found the contributions of the SN and ON to knee joint innervation to be relatively modest. The SN provided an inconsistent infrapatellar branch (in 11 specimens) and contributed to a deep nerve plexus from which the deep genicular nerves originated. This is in keeping with the findings reported by Gardner.[11] Our observation of an inconsistent branch of the anterior ON entering the adductor canal (in only 2 specimens) was somewhat unexpected given previous clinical studies that suggest ON block contributes to knee analgesia.[12] However, similar to our findings, a previous cadaveric study by Horner and Dellon[13] found ON contributions to knee innervation in only 11% of specimens. These small ON branches that anastomose with the SN upon entering the canal were previously named the "subsartorial plexus" in a historic study by Druner.[14]

Finally, the deep genicular branches observed originating from a deep plexus with mixed contribution from both SN and NVM were also previously documented by Kennedy et al[15] in 15 amputation specimens.

## Clinical Significance

Femoral (with or without sciatic) nerve block was the mainstay of postoperative analgesia for TKA in many centers around the world.[3] It resulted in improved analgesia with an opioid-sparing effect, and enhanced early rehabilitation compared to systemic opioids alone.[16]

Although gait retraining, exercise prescription, and independent ambulation before hospital discharge are widely accepted and long-recognized goals, specific physiotherapy protocols vary among institutions and change over time.[17] For example, the quadriceps weakness that accompanies femoral nerve block may be desirable when passive physiotherapy via a Continuous Passive Motion system is used. However, a current emphasis on active (rather than passive) physiotherapy, earlier ambulation (as soon as 4 hours postoperatively), and shorter hospital stays, are driving many centers to search for analgesic modalities with the least possible motor effects.[18,19]

Within this context, ACB has been proposed as a possible alternative to femoral nerve block to provide analgesia to the anteromedial knee while preserving quadriceps strength. It should be noted that ACB is not yet a well-established or broadly adopted clinical intervention. Clinical data, although growing, are still preliminary. Views differ regarding the neural structures explaining ACB's purported analgesic effect and the "ideal" site of local anesthetic administration. The value of ACB, for TKA in particular, is difficult to assess given that the nerves that course through the adductor canal innervate only the anteromedial joint, with posterolateral innervation originating from the sciatic nerve.

Our findings may contribute to further the understanding of the anatomic basis by which ACB provides knee analgesia, and could have important clinical implications. A recent study of patients undergoing TKA suggested that ACB is essentially an SN block,[9] and it was postulated that the local anesthetic should be injected in the distal third of the canal to selectively block the SN and avoid the NVM.[10,20] However, our results suggest otherwise. In our specimens, the SN had a relatively modest contribution to knee joint innervation and it seems unlikely that an isolated SN block could result in significant knee analgesia, especially for a major surgical procedure like TKA.

Rather, our findings suggest that the NVM plays a much more important role in the innervation of the anteromedial knee joint than previously appreciated, with large intramuscular, extramuscular, and deep plexus branches providing terminal innervation to the knee capsule. Therefore, a combined blockade of the SN and NVM, both of which are consistently present in the AC is desired. Such combined blockade would also better explain the significant analgesic effect and limited motor block reported in early clinical trials.[8,9]

Two RCTs have shown that injection of 15 to 20 mL of local anesthetic in the adductor canal at the mid-thigh level improved postoperative analgesia and enhanced early rehabilitation after TKA compared to placebo.[8,9] Furthermore, 2 retrospective cohort studies suggest that a mid-thigh ACB in addition to intraoperative

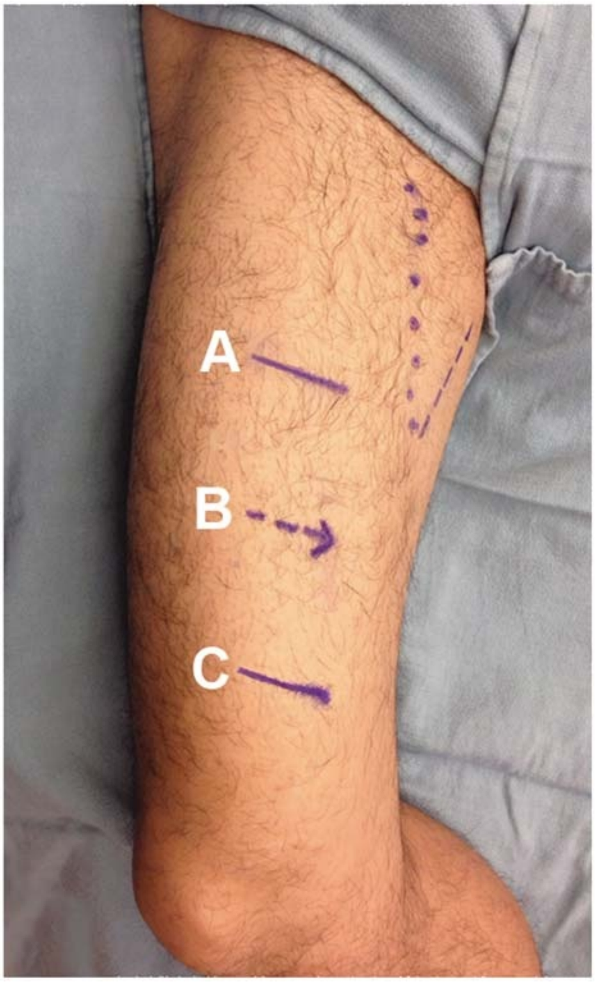


**FIGURE 3.** Surface anatomy of the right thigh as delineated by ultrasound examination. The medial borders of the sartorius (dotted line) and adductor longus muscles (broken line) have been mapped distally to their intersection at the apex of the femoral triangle. A corresponds to a sonographic plane at the apex of the femoral triangle. B corresponds to a suggested ideal local anesthetic injection site in the mid-adductor canal. C corresponds to the distal end of the adductor canal at the level of the adductor hiatus.

local infiltration of the knee joint provides similar analgesia and greater postoperative ambulation compared to continuous femoral nerve blocks.[21,22]

Given the anatomic continuity of the adductor canal with the femoral triangle proximally and the popliteal fossa distally, other nerves outside the canal could conceivably be unintentionally blocked, especially if large volumes of local anesthetic solution were injected close to the proximal or distal borders of the canal. In fact, a proximal injection at the apex of the femoral triangle has been previously advocated.[23,24] This will no doubt provide adequate analgesia but may also result in significant quadriceps weakness secondary to rectus femoris, vastus lateralis, and vastus intermedius block as previously documented in case reports.[25,26]This degree of weakness may not be desirable if preservation of motor function is a clinical priority. Similarly, an injection of a large volume of local anesthetic in the distal part of the adductor canal, close to the adductor hiatus, could conceivably result in local anesthetic spread to the popliteal fossa and possibly involve branches of the sciatic nerve. Once again, this may on the one hand contribute to knee analgesia, but it could also result in varying degrees of foot and ankle weakness.

The findings of the current study suggest that if a "pure" ACB is desired (ie, involving almost exclusively the SN and NVM), then the midportion of the adductor canal (the midpoint between the proximal and distal ends) could be an ideal site of local anesthetic administration (Figs. 3 and 4B). An injection in the mid-adductor canal is proximal enough to cover both the SN and the transmuscular branches of the NVM before they enter the bulk of the muscle as well as limit spread to the popliteal fossa, while distal enough to minimize spread to the femoral triangle. This line of thought is in keeping with clinical studies that report limited weakness from an injection of local anesthetic in the mid-adductor canal. Indeed, Jaeger et al[4] reported that healthy subjects retain 92% of the baseline quadriceps strength after an ACB in the mid-thigh. In addition, in an RCT of 50 patients after TKA, Grevstad et al[27] reported that a postoperative ACB at the mid-thigh level nearly doubled quadriceps strength by reducing dynamic pain and facilitating range of motion, suggesting limited block-related quadriceps weakness.

The proximal and distal ends of the canal are conventional anatomic sites that do not readily correlate with well-defined external surface anatomic landmarks, but they can be easily identified with ultrasound imaging (Figs. 3 and 4). The proximal end of the canal is the site where the medial border of the sartorius muscle crosses over the medial border of the adductor longus muscle and can be located more distally in the thigh than commonly appreciated (Fig. 4A). The distal end is the site where the femoral artery diverges from the sartorius muscle and becomes deep, passing through the adductor hiatus on its way to the popliteal fossa (Fig. 4C). We suggest then, that the proximal and distal ends of the canal should be identified before needle insertion to correctly ascertain the injection site within the adductor canal proper.

Limitations of the present study include a relatively small sample size and the investigation of the innervation of only the anterior and medial aspects of the knee. Posterolateral knee innervation is currently understood to originate mostly from branches of the sciatic nerve but further anatomic studies are required to provide a detailed description of the terminal branches and their trajectories. In addition, the "ideal" site of local anesthetic administration described here is based on anatomic findings, and requires further study in the clinical setting.

## CONCLUSIONS

This anatomic study suggests that the combination of both SN and NVM provides substantial innervation to the anteromedial aspect of the knee joint including the joint capsule and the medial retinaculum. The NVM, in particular, played a more important role than commonly appreciated in the clinical literature, whereas the ON contributed to the subsartorial plexus in a small proportion of cases. The results of this study suggest that the midportion of the adductor canal could be an optimal site for local anesthetic administration, proximal enough to consistently block the SN and NVM while minimizing spread to the popliteal fossa, and distal enough to avoid significant spread to the femoral triangle. Our findings warrant further study in the clinical setting, and additional anatomic studies are required to define the detailed innervation of the posterolateral knee joint.

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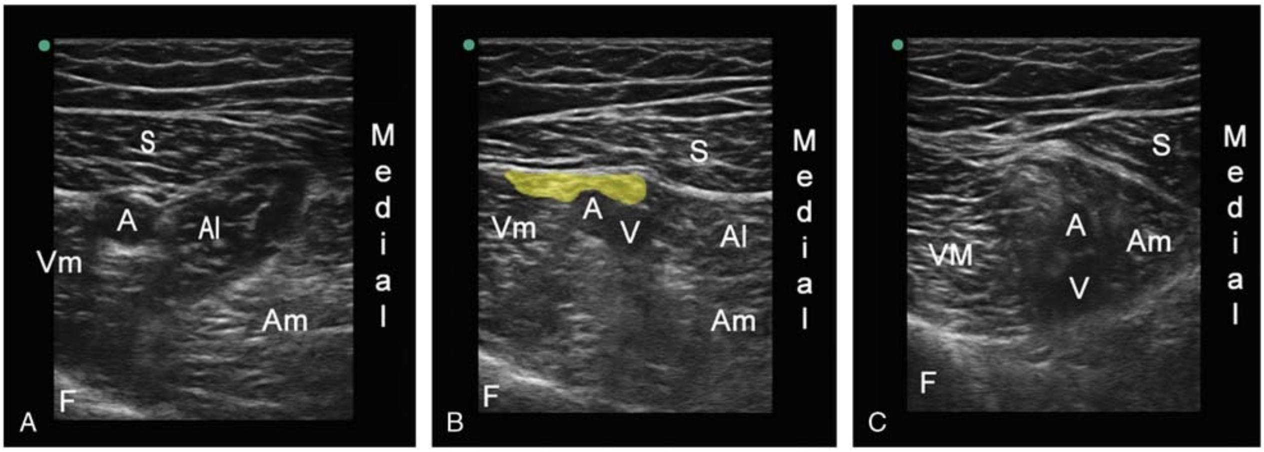


**FIGURE 4.** A, Axial ultrasound scan of the right thigh at the apex of the femoral triangle. Note the point of intersection of the medial borders of the sartorius and adductor longus muscles. A, Femoral artery; Al, adductor longus; AM, adductor magnus; F, femur; S, sartorius; VM, vastus medialis. B, Axial ultrasound scan of the right thigh in the mid-adductor canal. Note both adductor longus and magnus muscles are noticeable. The area shaded in yellow represents the most common location of the SN and NVM, anterolaterally to the femoral vessels. A, Femoral artery; Al, adductor longus; AM, adductor magnus; F, femur; S, sartorius; V, femoral vein; VM, vastus medialis. C, Axial ultrasound scan in the distal end of the right adductor canal. Note the adductor longus is no longer present at this level. The adductor magnus has a fibrous lateral edge corresponding to the adductor hiatus and the femoral vein has rotated and is posterior to the femoral artery in its passage to the popliteal fossa. A, Femoral artery; Am, adductor magnus; F, femur; S, sartorius; V, femoral vein; VM, vastus medialis.

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