

The Nerves of the Adductor Canal and the Innervation of the Knee

An Anatomic Study

David Burckett-St. Laurant, MBBS, FRCA,* Philip Peng, MBBS, FRCPC,†‡ Laura Girón Arango, MD,§
Ahtsham U. Niazi, MBBS, FCARCSI, FRCPC,†‡ Vincent W.S. Chan, MD, FRCPC, FRCA,†‡
Anne Agur, BScOT, MSc, PhD,|| and Anahi Perlas, MD, FRCPC†‡

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.

From the *Department of Anaesthesia, University Hospital of Wales, Cardiff, United Kingdom; †Department of Anesthesia, University of Toronto; ‡Department of Anesthesia, University Health Network, Toronto, Ontario, Canada; §Department of Anesthesia, Universidad CES, Medellín, Colombia; and ||Department of Anatomy, University of Toronto, Toronto, Ontario, Canada.

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Address correspondence to: Anahi Perlas, MD, FRCPC, Department of Anesthesia, University Health Network, 399 Bathurst St, Toronto, Ontario, Canada M5T 2S8 (e-mail: Anahi.Perlas@uhn.ca).

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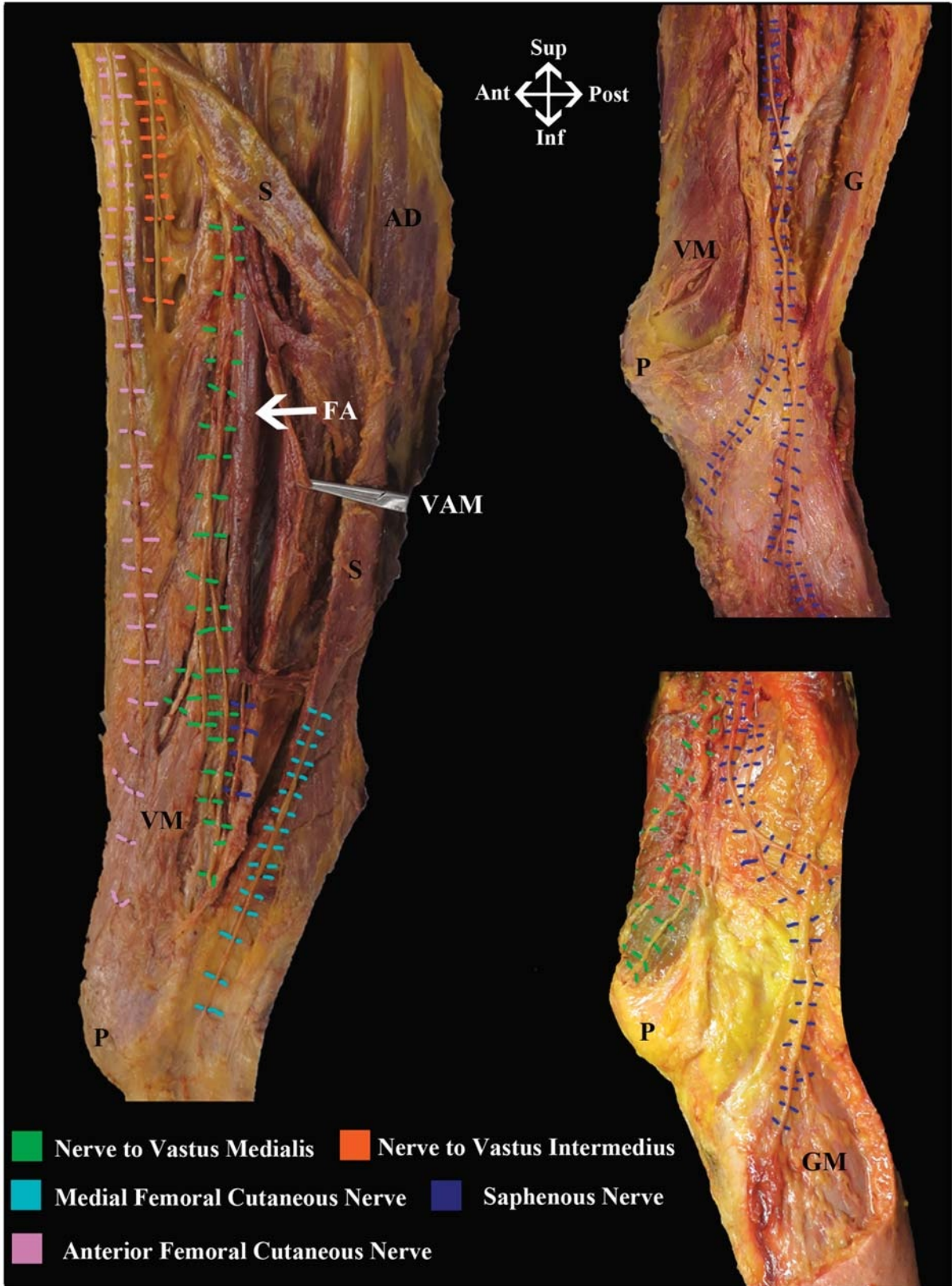


FIGURE 1. Anteromedial innervation of the knee. The sartorius muscle has been reflected medially to expose the adductor canal. The vastoadductor membrane has been reflected medially with forceps to expose the contents of the adductor canal. AD, Adductor muscle compartment; FA, femoral artery; G, gracilis;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

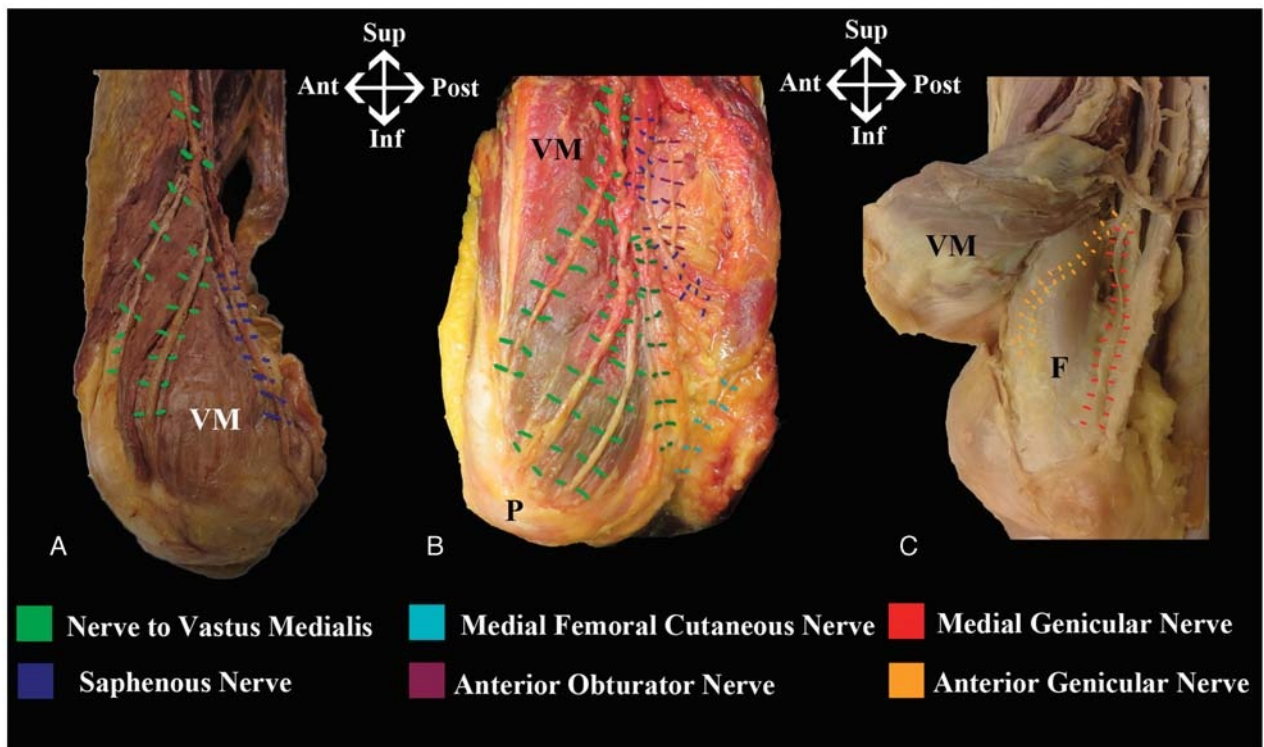


FIGURE 2. Distal and deep innervation of the knee joint. Note that in images (A) and (B) superficial muscle fibers of the vastus medialis have been removed to expose several deep intramuscular branches coursing through the muscle and ending in the anterior knee capsule. In (C), the entire vastus medialis 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 Dellon¹³ 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 al¹⁵ 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

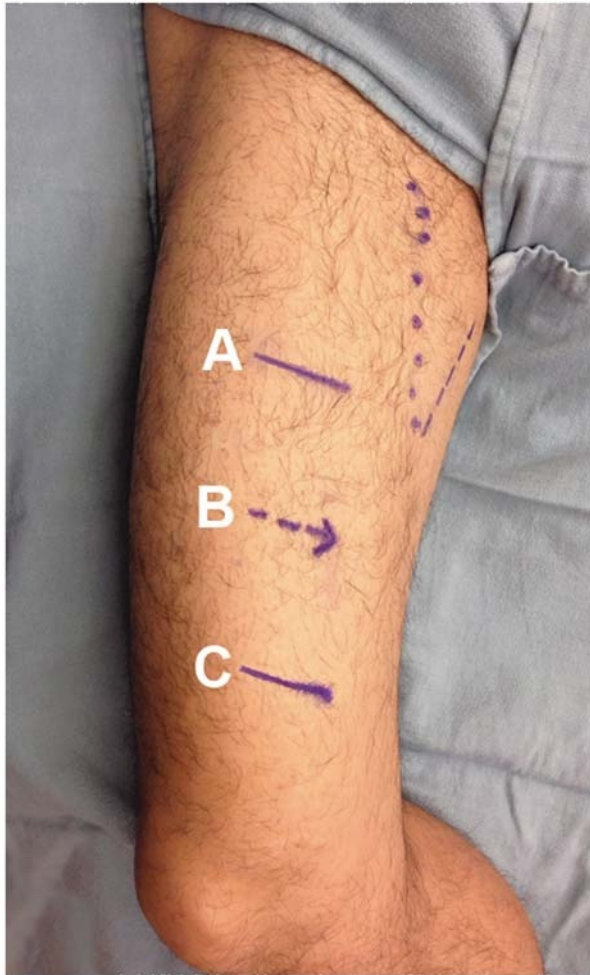


FIGURE 3. Surface anatomy of the right thigh as delineated by ultrasound examination. The medial borders of the sartorius (dotted line) and adductor longus muscles (broken line) have been mapped distally to their intersection at the apex of the femoral triangle. A corresponds to a sonographic plane at 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 al⁴ 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 al²⁷ 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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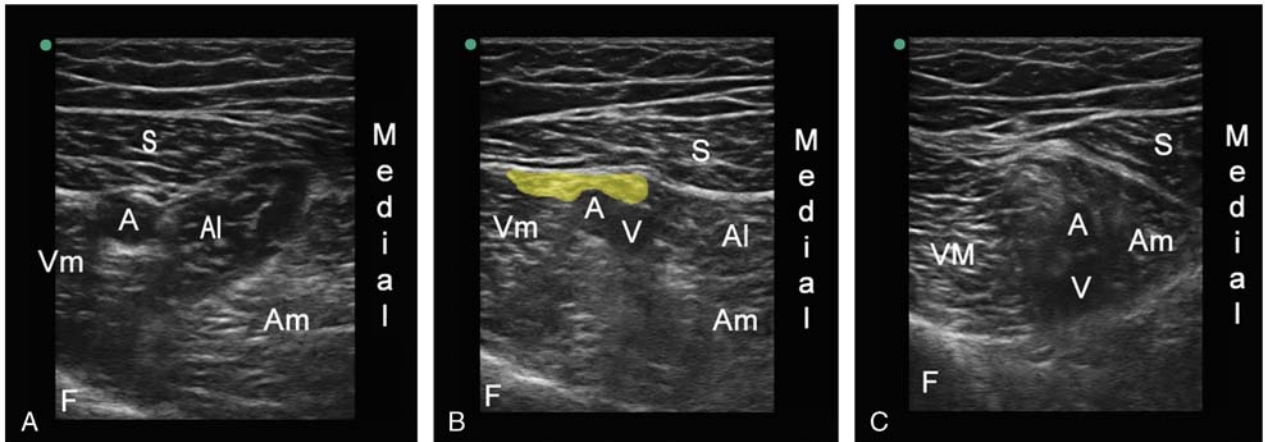


FIGURE 4. A, Axial ultrasound scan of the right thigh at the apex of the femoral triangle. Note the point of intersection of the medial borders of the sartorius and adductor longus muscles. A, Femoral artery; Al, adductor longus; AM, adductor magnus; F, femur; S, sartorius; VM, vastus medialis. B, Axial 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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