Everybody Knows That the Dice Are Loaded

How Can We Block the Nerves That Innervate the Knee Joint Without Blocking the Nerves That Innervate That Joint?

André P. Boezaart, MD, PhD† and Hari K. Parvataneni, MD†*

In arguably the best and most beautifully illustrated account of the innervation of the knee joint to date, a truly international group of very accomplished authors from Denmark, Austria, and Canada—Drs Bendtsen, Moriggl, Chan, and Børglum—asks in this issue whether there is a nerve block or combination of nerve blocks available, discovered or not yet discovered, for the management of postoperative pain associated with total knee arthroplasty (TKA) that does not interfere with the motor function of the leg.[1] The most daring part of their discourse, if one translates the question that they ask, is of course the question itself: How can we block the nerves that innervate the knee without blocking the nerves that innervate the knee? This, as they elegantly demonstrate, is the real challenge, because, with the exception of the saphenous nerve (the infrapatellar branch of which is often transected during the anteromedial approach to TKA), all the nerves that innervate the knee joint and surrounding tissue (the pain generators following TKA) are mixed motor and sensory nerves—and everybody knows we should not block the motor nerves. Until we have a drug that can selectively block the sensory and pain fibers of a nerve, this may well be a bridge too far.

It was not long ago (a few decades) that patients who received total joint replacement were kept in the hospital for weeks and were not mobilized immediately but rehabilitated progressively as the physiologic responses from surgery abated. Since that time, there has been a progressive shift toward anesthetic and surgical optimization to allow for immediate rehabilitation starting even the day of surgery. The focus of all anesthetic work in this regard had been on safer options for anesthesia and pain control. Selective nerve blocks, especially continuous femoral nerve block (CFNB), have become the criterion standard for this. Now, the main focus, including of this article,[1] seems to be on providing optimal analgesia for TKA via nerve blocks while preserving muscle function (especially the quadriceps muscles). And, of course, everybody knows that we have to preserve the quadriceps function with our nerve blocks to optimize the surgical outcome. But does everybody really know this? Is this a scientific fact? Or is it perhaps dogma, folklore, culture, or belief that is not based on solid scientific evidence? Can what we do to block all the nerves that innervate the knee joint for a day or two really have a detrimental effect on the outcome of TKA in the short, medium, and long run? We must confront the question: "What has the most significant and prolonged effect on muscle (especially quadriceps function) during the recovery phase of TKA: pain control modality, the disease itself, or the surgery?"

While we would not be daring enough to venture into politics, this question reminds one a bit of the arguments around global warming. Everybody knows that the earth is warming and that we humans are causing it. Similarly, everybody knows that with continuous nerve blocks (CNBs) we may paralyze one or more of the quadriceps muscles, which worsens the surgical outcome of TKA. But does everybody know that? Over many millions or billions (who knows) of years, the earth has been warming and cooling in cycles lasting millions of years, and now we as humans think we can, in our short time here, influence this. Similarly, can we negatively influence the outcome of TKA with our short-term worsening of the quadriceps muscle function?

Humans compulsively, impulsively, intuitively, and repeatedly feel the need to explain and control (or feel in control of) events that we may not fully understand. Quadriceps (and other muscle) function is clearly weakened by surgery and arthrogenic muscle inhibition (AMI), in addition to any preoperative weakness.[2,3] This persists for weeks and months after surgery and is a variable independent of anesthetic or surgical type (patient factors are a major contributor).[4–7] Why is there pressure on us to address this long-term multifactorial issue simply with nerve block techniques that are a factor for 24 to 48 hours, at the most (if at all)?

The only direct controlling factor related to this subject is pain-related AMI. Optimal pain control that is safe and includes modalities to reduce inflammation via the inflammatory cascade should be the strategy—not muscle-sparing approaches for muscles that have already been weakened by surgery and

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AMI. As we better understand the neural mechanisms of AMI, may CNB even improve muscle function in the long run and enhance rehabilitation?[2,3] Are we chasing a false target—shorter-term blockade with an obsession about motor-sparing options? Should we not be focusing instead on a means of obtaining longer-term pain control via blockade? Perhaps we should be considering continuous postdischarge blockade options to make rehabilitation virtually opioid-free (safety) while improving rehabilitation and range of motion because patients are experiencing less pain (efficacy). If the inflammatory cascade was somehow related to painful stimuli (perhaps via AMI),[2,3] it would confer an additional benefit to this change in philosophy.

If we accept, in an even more daring discourse, that increased postoperative quadriceps muscle dysfunction caused by nerve blockade does not negatively affect the surgical outcome in the long run, thus removing this issue from the equation, then providing effective analgesia to the knee would be uncomplicated and very effective. All we have to do would be to obey Hilton's Law of Anatomy (1862), which states that any nerve that innervates a group of muscles that moves a joint also innervates that joint and the skin that overlies the joint.[8,9] The work of Hébert-Blouin and colleagues[10] in 2013 that challenged this law and this soon-to-become classic account of the innervation of the knee joint by Bendtsen and colleagues[1] clearly illustrate that Hilton's Law is alive and well, with the nerve to the rectus femoris muscle the only glaring exception, as it supplies sensory innervation to the hip joint only and not the knee joint, while it does innervate a muscle that moves it. (In the defense of Hilton, though, his law states "group" of muscles and not individual muscles.)

From that, it should be abundantly clear that to effectively block pain generated by TKA, or any other major lower-extremity joint surgery for that matter, we have to block all the nerves that originate from the entire lumbosacral plexus (LSP), similar to having to block the entire brachial plexus to provide analgesia for major surgery to any major upper-extremity joint. Because CFNB is a more complete nerve block as outlined in the article by Bendtsen et al,[1] and perhaps blocking the afferent neural pathways of AMI, may there be any basis for blockade prior to surgical trauma to reduce the postoperative AMI and inflammatory response? If so, CFNB would be better than any of the lesser blocks in terms of coverage. Only a continuous LSP block would be superior.

Most of the research done to compare one approach to block one part of the LSP with another (adductor canal block with CFNB, for example) has unfortunately been lacking scientific validity. In almost every one of the studies, patients were divided into 2 groups: one group with the one block and the other group with the other block (and universally without a control group with no block "for ethical reasons"). Pain and quadriceps motor function—both extremely inaccurate and subjective measurements—were the major metrics, while all the patients in both groups received very effective multimodal analgesia—"for ethical reasons." In 1 study, all patients in both groups even received effective epidural analgesia, with the authors reporting no difference in pain but a difference in quadriceps function.[11] From this, they concluded that adductor canal block is superior to CFNB for pain associated with TKA. None of the studies reports on unwanted opioid adverse effects—the very reason we do CNBs in the first place. Meanwhile, Memtsoudis and colleagues[12] basically ended the debate on an increased risk of falling specifically due to peripheral nerve blockade.

Our research and clinical focus should therefore not be on the possible (and mostly irrelevant) negative influence of any short-term muscle inhibition, but on the vast positive effects of nerve blockade, possibly even decreasing AMI. Peripheral nerve blockade, especially CFNB, has had tremendous efficacy, improved safety, and reduced adverse effects after major joint replacement surgery, and our efforts going forward should focus on improved multimodal pain control, as well as tempering the local effects of surgery (other than pain) that result in AMI—including inflammation, swelling, and other injury cascades.[2] Furthermore, we should focus on early postoperative ambulation, early improvement of range of motion, early discharge from the hospital with or without longer-term ambulatory CNBs, and preoperative and postoperative rehabilitation of the quadriceps dysfunction caused by the disease and, much more importantly, by the surgery. We seem to be (mis)focused on selective, short-term blocks for TKA, as affirmed by this Bendtsen article. That's how it goes, ...everybody knows... (with apologies to Leonard Cohen).

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The Optimal Analgesic Block for Total Knee Arthroplasty

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Abstract: Peripheral nerve block for total knee arthroplasty is ideally motor sparing while providing effective postoperative analgesia. To achieve these goals, one must understand surgical dissection techniques, distribution of nociceptive generators, sensory innervation of the knee, and nerve topography in the thigh.

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What is the optimal peripheral nerve block, or block combination, that is motor sparing while providing effective analgesia after total knee arthroplasty (TKA)? To answer this question, one must understand the surgical dissection techniques, distribution of nociceptive generators, sensory innervation of the knee, and nerve topography in the thigh.

Surgical Dissection and Knee Nociceptors

An arthrotomy including an intra-articular excision is an essential part of TKA. A typical medial parapatellar arthrotomy involves a longitudinal, midline incision through the integument (skin and subcutaneous tissue) extending from 5 cm proximal to the superior pole of the patella to the tibial tuberosity. Further dissection through the medial retinacular complex (deep fascia, retinacular ligaments, and fibrous capsule) along the medial border of the quadriceps tendon, the patella, and the patellar ligament ensues. The knee joint is then opened by a synovial membrane incision to allow removal of the menisci, cruciate and transverse ligaments, infrapatellar fat pad, and osteophytes. Cartilages of the femoral and tibial condyles and the back of the patella are resected and the femoral and tibial bony surfaces are surgically shaped to fit the metal components of the knee prosthesis.

Pain arising from nociceptive nerve endings are located in the synovial membrane,[1] fibrous capsule,[1,2] cruciate ligaments,[3–5] peripheral part of the menisci and the perimeniscular part of the fibrous capsule,[6,7] infrapatellar fat pad, extra-articular retinacular ligaments,[8,9] and the integument.[1] The cartilages with adjacent cortical and trabecular bone contain no nociceptors.

Sensory Innervation of the Knee

The human knee joint is innervated by an anterior and a posterior group of sensory nerves.[10,11] The anterior group consists of branches from the femoral nerve which innervate the knee anteromedially, as well as the lateral femoral cutaneous nerve, the common peroneal nerve, and the femoral nerve branch to the lateral vastus muscle which innervate the knee anterolaterally.[10] Branches of the femoral nerve to the knee are primarily the saphenous nerve and the so-called middle (or intermediate) and medial femoral cutaneous nerves (together called the anterior femoral cutaneous branches according to International Anatomical Terminology). Additionally, femoral sensory nerve branches to the knee derive from the muscular nerves to the lateral, intermedius, and medial vastus muscles. Thus, a medial parapatellar arthrotomy, which is the most common arthrotomy for TKA, through the anteromedial integument of the knee and the extra-articular medial retinacular complex will evoke pain mediated by the infrapatellar branch of the saphenous nerve, the medial retinacular nerve (the terminal branch of the medial vastus muscle nerve), and the anterior branch of the medial femoral cutaneous nerve.[1,2,11] The medial parapatellar arthrotomy will not affect the extra-articular nerve branches to the anterolateral part of the knee from the common peroneal nerve, the lateral and intermedius vastus muscle nerves, and the lateral femoral cutaneous nerve. The intra-articular excision evokes pain from structures innervated by the posterior group.

The posterior group consists of the popliteal nerve plexus that ramifies around the genicular vasculature in the popliteal fossa. The popliteal nerve plexus is derived from the tibial nerve and the posterior branch of the obturator nerve.[1,11] The posterior group supplies intra-articular innervation to the menisci, the perimeniscular joint capsule, the cruciate ligaments, the infrapatellar fat pad, and the posterior part of the fibrous knee capsule.[10]

Topography of the Femoral Nerve and Its Branches in the Femoral Triangle and the Adductor Canal

Femoral nerve branches that innervate the anteromedial part of the knee lie in the femoral triangle (FT) and the adductor canal (AC). The inguinal ligament is the base of the FT, and its apex is the intersection of the medial borders of the sartorius and adductor longus muscles (Fig. 1). The intersection of the medial border of the sartorius muscle and the lateral border of the adductor longus muscle corresponds to the apex of the iliopectineal fossa (IPF), which is a proximal subset of the FT (Figs. 1, 2G). At the inguinal ligament level, the femoral nerve, and the accompanying artery and vein lie on the pectineus and iliopsoas muscles in the IPF. At the apex of the IPF, the femoral neurovascular bundle dives subsartorially deep into the groove of the FT (Fig. 2, B and C). The saphenous nerve and the femoral artery (FA) and femoral vein exit the FT at its apex and enter the AC (Figs. 2D, 3A–F), which is the short neurovascular passageway from the FT to the popliteal fossa. Inside the AC, the neurovascular bundle is sandwiched between the adductor muscles (longus and magnus) posteromedially, the medial vastus muscle anterolaterally, and the vastoadductor membrane (VAM) anteromedially (Figs. 2D–F, 3A–F). Inside the AC, the femoral vessels deviate away from the saphenous nerve and dive deeper and more lateral until they pass through the distal opening of the AC—the adductor hiatus—to become the popliteal artery and vein (Figs. 2E–F, 3C–F).

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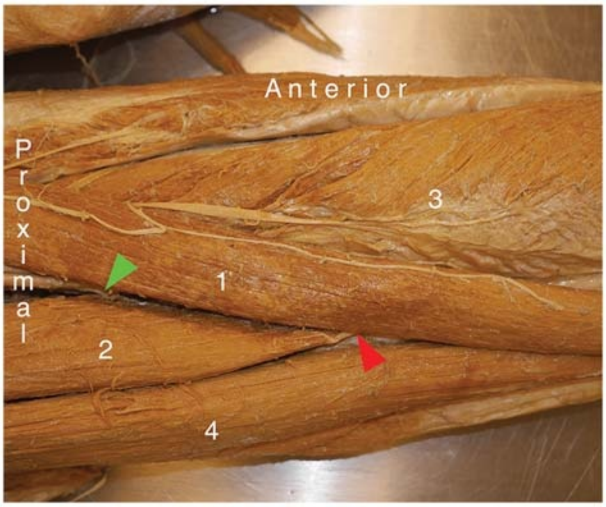

FIGURE 1. The figure shows the medial thigh with the sharply demarcated intersection (red arrowhead) between the medial margins of the sartorius (1) and adductor longus (2) muscles. This is per definition the apex of the FT and indicates the level of the proximal end of the AC. Medial vastus (3) and gracilis (4) muscles; intersection (green arrowhead) between the medial margin of sartorius and lateral margin of adductor longus muscles, which corresponds to the apex of the IPF.

The AC is a musculoaponeurotic tunnel that is roofed anteromedially in its entire length by the strong VAM, extending across the femoral vessels from the medial vastus muscle anterolaterally to the adductor longus and magnus muscles posteromedially (Figs. 2D–F, 3C, 4). The VAM is thinner proximally and thicker distally. The VAM separates the AC proper from the subsartorial space (or subsartorial compartment) between the sartorius muscle and the VAM. However, the subsartorial space extends beyond the distal margin of the VAM. The subsartorial space contains the "subsartorial plexus," which is made by anastomoses between the posterior branch of the medial femoral cutaneous nerve, the anterior branch of the obturator nerve and the saphenous nerve. The plexus innervates the integument of the inferomedial thigh, which is not affected by the medial parapatellar arthrotomy.

The Location of the "Adductor Canal" in the Thigh

The AC is often quoted to be in the middle third of the thigh. However, the definition of the thigh varies. Whereas the classic *Gray's Anatomy* textbook defines the thigh as the region between the inguinal crease and the knee joint,[12] others define it as the region between the anterior superior iliac spine (ASIS) and the base of the patella. Thus, "the middle of the thigh" can be somewhere in the AC based on Gray's definition but in the FT based on the other definitions (Fig. 2C). The midpoint between the ASIS and the base of the patella is located at the level of the FT in most human beings.[13–16] In a recent dissection study, the main find was that the proximal opening of the AC was distal to the midpoint

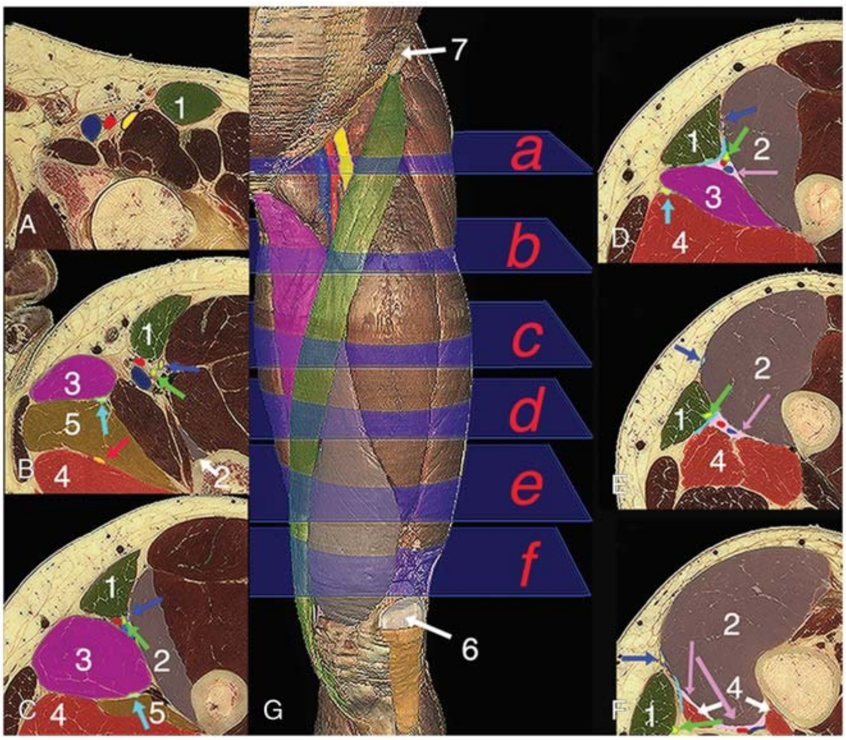

FIGURE 2. The figure shows 6 cross sections (A–F) of a thigh (G). The levels are as follows: the inguinal crease (A); the apex of the IPF (B); the midpoint between the ASIS and the base of patella (C); the apex of the FT—ie, the proximal end of the AC (D); the midpoint of the VAM (E); the adductor hiatus—ie, the distal end of the AC (F). Sartorius (1); medial vastus (2); adductor longus (3); adductor magnus (4); and adductor brevis (5); patella (6); ASIS (7). Femoral artery and vein are red and blue profiles, respectively (A–G). The nerves are yellow: femoral nerve (A, G); saphenous nerve (green border and arrow, B–F); medial vastus nerve (blue border and arrow, B–F); anterior obturator branch (cyan border and arrow, B–D); posterior obturator branch (red border and arrow, B); AC (pink area and arrow, D–F); VAM (cyan stripe, D–F). Modified excerpt from VH Dissector with permission from Touch of Life Technologies Inc (www.toltech.net). Built on real anatomy from the National Library of Medicine's Visible Human Project.

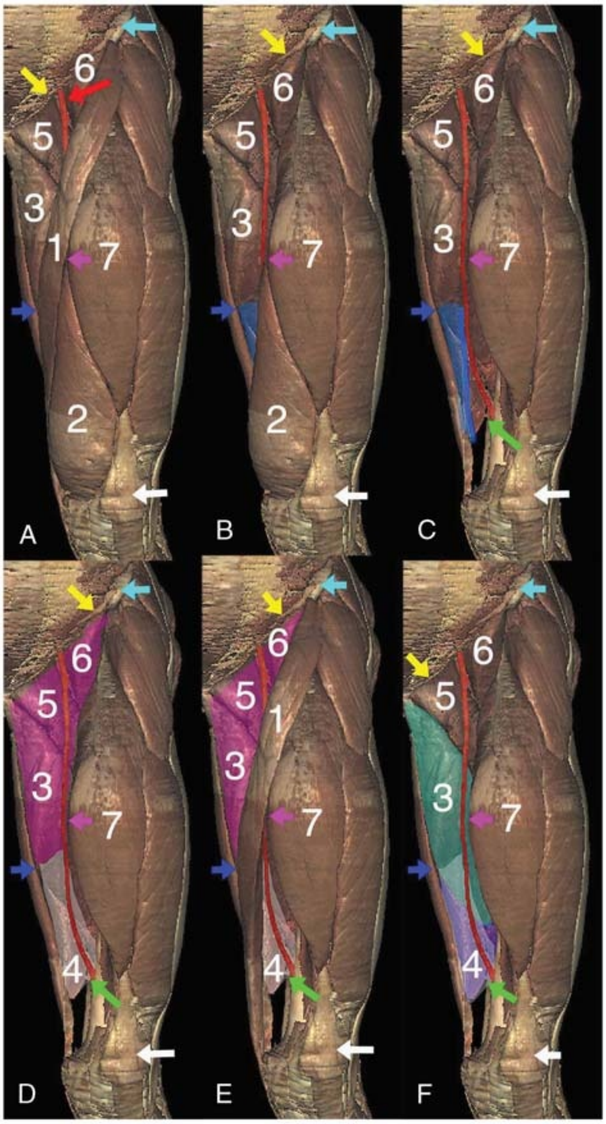

FIGURE 3. The figure shows the location of the FT and the AC in a thigh. The FA (red arrow, A) and femoral vein are the only structures that extend from the base of the FT to the exit of the AC (ie, the adductor hiatus, green arrow, C–F). The base of the FT (FT = pink area, D–E) is the inguinal ligament (yellow arrows, A–F). The apex of the FT (blue arrow, A–F) indicates the proximal end of the AC (AC = white area, D–F). The AC is roofed by the VAM (VAM = blue area, B–C). The midpoint (pink arrow, A–F) between the ASIS (cyan arrows, A–F) and the base of patella (white arrows, A–F) is in the FT in most human beings. Sartorius (1), medial vastus (2), adductor longus (3), adductor magnus (4), pectineus (5), iliopsoas (6), rectus femoris (7) muscles. In (F), the adductors longus (3) and magnus (4, with its tendineous insertion in black) are marked with green and purple, respectively, in (F). Modified excerpt from VH Dissector with permission from Touch of Life Technologies Inc (www.toltech.net). Built on real anatomy from the National Library of Medicine's Visible Human Project.

of the thigh from ASIS to base of patella in 13 of 17 specimens (mean distance, 6.5 cm).[16] Periarterial injection anterolateral to the FA midway between the ASIS and the base of the patella is best labeled a "Femoral Triangle Block." In our opinion, the term "Adductor Canal Block" should be reserved exclusively to describe an injection directly into the AC proper (Fig. 2E) distal to apex of the FT (Fig. 2D). This might be clinically highly relevant, because local anesthetic injected into the FT may conceivably result in a different analgesic effect from that injected into the AC proper after TKA.

It is easy to differentiate the FT and the proximal, middle, and distal parts of the AC with ultrasound (Fig. 5, A–D). We consider it obsolete to differentiate between the FT and the AC based on surface landmarks and recommend the use of ultrasound.

Femoral Nerve Block in the FT

The femoral nerve divides proximally in the FT into multiple branches along a 4- to 7-cm-long segment of the femoral nerve between the inguinal ligament and the inguinal crease or just distal to the crease.[17–19] At the level of the inguinal crease, all the branches of the femoral nerve lie close together.[18] A femoral nerve block is often achieved by local anesthetic injection around all the femoral nerve branches inside the proximal part of the FT. Not only does this provide effective anesthesia of the knee in the anteromedial region, it can also cause paralysis of the quadriceps muscles, because motor branches of the femoral nerve to the rectus femoris muscle and the vastus muscles all come off in the IPF. Thus, a femoral nerve block can impede ambulation and increase the risk of fall.[20]

Subsartorial Femoral Nerve Block in the FT

In the distal part of the FT, the saphenous nerve and the FA and femoral vein are found between the sartorius, adductor longus, and medial vastus muscles (Figs. 2C, 5A). At this level, the nerve to the vastus medialis muscle lies between the sartorius and medial vastus muscles (Figs. 2C, 5A). The posterior branch of the medial femoral cutaneous nerve lies along the posterior side of the sartorius muscle and communicates with the saphenous nerve and the anterior branch of the obturator nerve forming the subsartorial plexus superficial to the VAM.[21–23] The posterior branch of the medial femoral cutaneous nerve continues subcutaneously on the medial side of the distal thigh and communicates with the

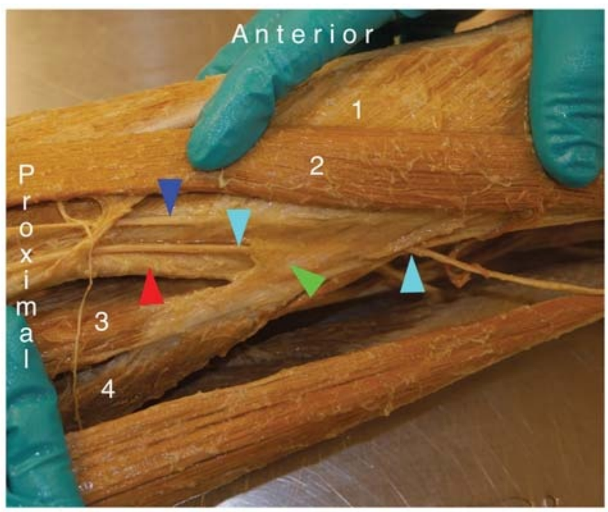

FIGURE 4. The figure shows how the VAM (green arrowhead) extends from the medial vastus muscle (1) under the sartorius (2) to the tendons of the adductors longus (3) and magnus (4). Saphenous nerve (cyan arrowhead); FA (red arrow); medial vastus nerve (blue arrowhead).

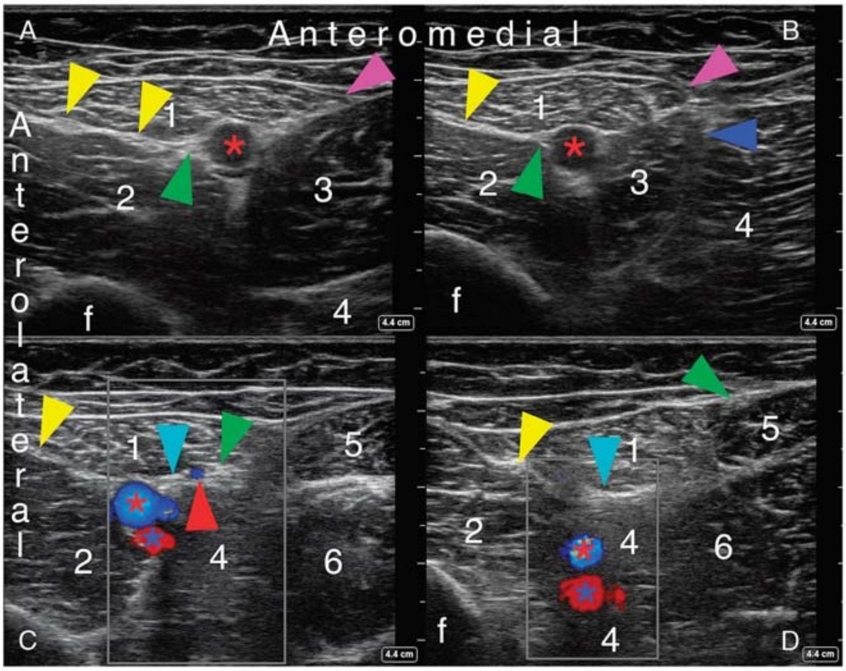

FIGURE 5. The figure shows the ultrasonographic visualization of the neurovascular bundle inside the FT and the AC. A, Femoral triangle midway between the ASIS and base of patella. B, Apex of FT (ie, proximal end of the AC, at the intersection of the medial margins of the sartorius and adductor longus muscles). C, Midway along the VAM where the saphenous nerve has penetrated the VAM and lies in the subsartorial space superficial to the VAM adjacent to the descending genicular artery. D, Distal end of the AC, where the femoral vessels pass through the adductor hiatus and become the popliteal vessels. Saphenous nerve (green arrowhead); medial vastus nerve and branches (yellow arrowheads); FA (red asterix); femoral vein (blue asterix); descending genicular artery (red arrowhead); VAM (cyan arrowhead); sartorius (1), medial vastus (2), adductor longus (3), adductor magnus (4), gracilis (5), and semimembranosus (6) muscles; femur (f). Medial border of sartorius (pink arrowhead); medial border of adductor longus (blue arrowhead).

infrapatellar branch of the saphenous nerve. Together with the middle femoral cutaneous branches of the femoral nerve, the anterior branch of the medial femoral cutaneous nerve, and the lateral femoral cutaneous nerve, they form the patellar plexus, which supplies the skin anterior to the patella. The anterior branch of the medial femoral cutaneous nerve descends across the anterior surface of the sartorius muscle, and innervates the integument down to the medial side of the patella, where it ends in the patellar plexus.

An FT (syn: Scarpa triangle) block is a subsartorial injection anterolateral to the FA proximal to the apex of the FT (Figs. 1, 2C, 5A), which blocks the saphenous nerve, the nerve to the vastus medialis muscle, and the medial femoral cutaneous nerve. These 3 nerves are likely responsible for post TKA pain but their individual roles have not been scientifically proven. It would be a challenge to anesthetize one nerve and not the other. The FT block is expected to anesthetize the vastus medialis muscle nerve but not the femoral nerve branches to the rectus femoris, vastus intermedialis, and vastus lateralis muscles unless a large volume of local anesthetic injection spreads proximally inside the FT. The degree of motor paralysis and ambulation impairment will be limited with a small volume FT block. A subsartorial FT injection with a large volume of local anesthetic can also be speculated to spread into the AC. That would only be clinically relevant with consistent spread via the most distal part of the AC through the adductor hiatus and into the popliteal fossa with anesthesia of the posterior branch of the obturator nerve and maybe even the entire popliteal plexus. However, that is speculative and not evidence based.

Blockade of Femoral Nerve Branches Inside and Around the AC

At the apex of the FT, the saphenous nerve as well as the FA and femoral vein dives into the AC (Figs. 2D, 5B, C). The saphenous nerve, the only nerve that consistently runs inside the AC for a variable extent, crosses anterior to the FA from anterolateral to anteromedial and pierces the VAM together with the saphenous branch of the descending genicular artery (Fig. 5C). The infrapatellar branch is the primary articular afferent of the saphenous nerve.[11] Most often, it branches off deep to the sartorius muscle before the saphenous nerve penetrates the fascia lata between the sartorius and gracilis muscles (Fig. 6). However, the infrapatellar branch may also run medial, lateral, or even through the sartorius muscle.[11,24]

The medial retinacular nerve from the medial vastus nerve dives into a fascial tunnel proximal to the entrance of the AC between the medial vastus muscle and the adductor longus muscle outside the AC in 90% of human subjects.[25] In the remaining 10%, the nerve is superficial to the medial vastus muscle fascia and descends inside the AC. The medial retinacular nerve lies adjacent to the medial recurrent geniculate artery and vein and runs deep to the medial retinaculum after it emerges from the inferior margin of the medial vastus muscle.[11]

In some anatomical textbook, it is stated that the medial vastus nerve lies inside the AC.[21–23] A recent dissection study claimed the same course concerning the medial vastus nerve.[26] However, other dissection studies have found that the medial vastus nerve lies inside a duplicature of the fascia covering the

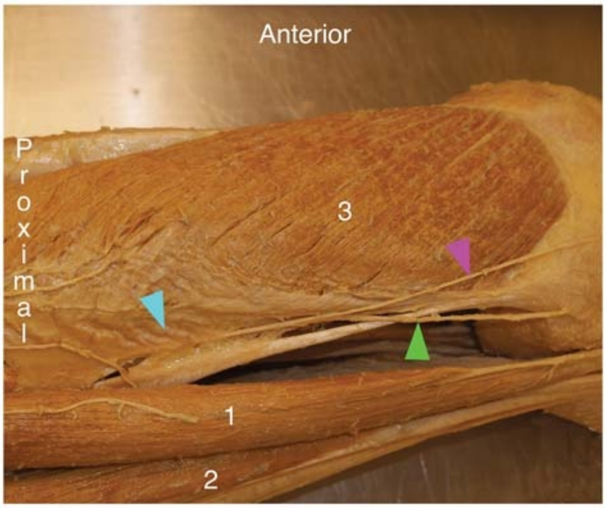

FIGURE 6. The figure shows how the saphenous nerve (green arrowhead) penetrates the VAM (cyan arrow) before the infrapatellar branch (pink arrowhead) ramifies and innervates the anteromedial part of the knee. Sartorius (retracted, 1), gracilis (2), medial vastus (3) muscles.

medial vastus muscle outside the AC. The medial vastus nerve lies deep to the sartorius muscle and superficial to the roof of the AC, outside the AC.[25,27]

We have performed dissections of the AC in 4 cadavers at the Division of Clinical and Functional Anatomy, Medical University of Innsbruck, Austria, to solve this paradox. All 8 dissections showed that the medial vastus nerve lies outside the AC in a separate fascial tunnel on the medial vastus muscle (Fig. 7, A–D). The apparent incongruence is probably due to different dissection techniques. If the fascia of the medial vastus muscle is removed, it is not possible to identify that the medial vastus nerve lies inside a separate intrafascial tunnel in the fascia of the medial vastus muscle and superficial to the VAM.

Adductor Canal Block

Injection of local anesthetic midway along the VAM into the true AC reliably anesthetizes the saphenous nerve,[28] maybe the medial retinacular nerve in 10% of the cases (as previously mentioned) and the posterior branch of the obturator nerve in some few cases. A true AC block does not produce motor paralysis.

If a small volume of local anesthetic is injected periarterially into the most distal part of the AC, it may not spread sufficiently proximal to anesthetize even the saphenous nerve before it penetrates the VAM and exits the AC (Figs. 5C, 6).

Subsartorial Compartment Block

A subsartorial compartment block performed under ultrasound guidance involves injection of local anesthetic into the subsartorial compartment superficial to the VAM to surround the saphenous nerve adjacent to the saphenous branch of the descending genicular artery.[29,30] The subsartorial compartment extends beyond the distal margin of the VAM. This block aims to anesthetize the saphenous nerve after it has penetrated the VAM. When done properly, this block does not produce motor paralysis. The descending genicular artery can be visualized as a proxy marker of the saphenous nerve with ultrasound (Fig. 5C). The subsartorial compartment block will likely produce analgesia equivalent to an injection directly into the AC after TKA, as both techniques frequently would only block the saphenous nerve and not the medial vastus nerve.

Infrapatellar Nerve Block

An infrapatellar nerve block aims to selectively deposit a small volume of local anesthetic around the infrapatellar branch without spread to the saphenous nerve itself. Under ultrasound guidance, the block targets the infrapatellar branch immediately after it emerges on either side of the sartorius muscle or as it pierces this muscle.[31]

Medial Retinacular Nerve Block

A medial retinacular nerve block selectively blocks the medial retinacular nerve inside the fascial tunnel containing the nerve

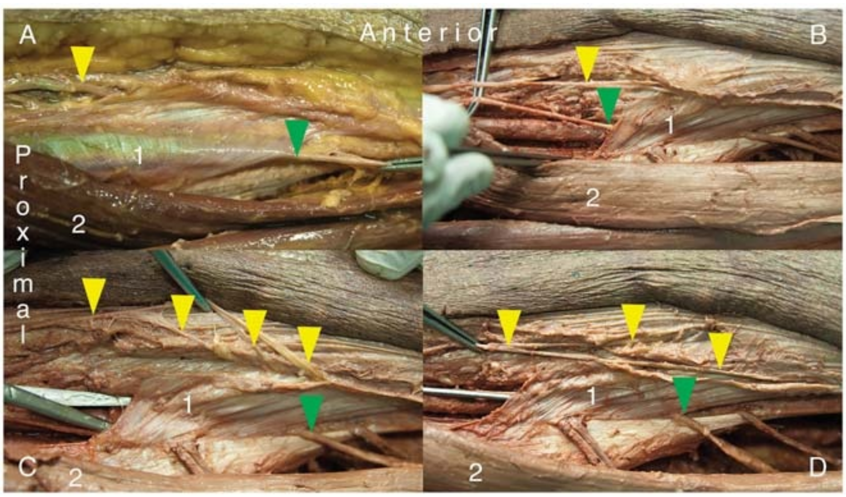

FIGURE 7. The saphenous nerve (green arrowhead) penetrates (A) the distal end of the VAM (1). In (B), the saphenous nerve dives into the proximal end of the AC. The medial vastus nerve (yellow arrowheads, A–D) enters a separate fascial tunnel (A–B) in the fascia covering the medial vastus muscle and superficial to the VAM. When this fascial tunnel is opened (C–D), it can be seen that the entire tunnel is superficial to the VAM. The sartorius muscle (2) is retracted to visualize the VAM.

between the sartorius muscle and the medial vastus muscle (Fig. 5, C and D). This block is not anticipated to produce any motor blockade but its contribution to pain relief after TKA has not been described in the literature.

Obturator Nerve Block

The posterior branch of the obturator nerve exits the obturator canal and may or may not pierce the external obturator muscle and descends a short distance between the external obturator and pectineus muscles before it dives between the adductor brevis and magnus muscles (Fig. 8, A and B). Then, it pierces obliquely through the adductor magnus muscle (Fig. 8C) and emerges from the posterior surface of the muscle (Fig. 8D) to enter the popliteal fossa, where it joins the popliteal vessels.[10] This was already described 177 years ago by Ellis in 1839.[32]

In some instances, it emerges from the anterior surface of the adductor magnus muscle to join the FA in the distal part of the AC. The posterior branch of the obturator nerve joins branches from the tibial nerve in the popliteal plexus, which innervate the intra-articular structures of the knee joint.[10] Sometimes the posterior obturator branch also innervates the anteromedial knee capsule together with the saphenous nerve and the medial vastus nerve.[10]

The anterior branch of the obturator nerve typically exits the obturator canal anterior to the origin of the obturator externus muscle and descends a short distance between the obturator externus and pectineus muscles together with the posterior branch of the obturator nerve, before the anterior branch descends between the adductors longus and brevis muscles (Fig. 8, A and B). It crosses the lower margin of the adductor longus muscle and supplies branches to the subsartorial plexus superficial to the roof of the VAM (Fig. 2D). At this point, a vascular branch from the anterior branch of the obturator nerve descends a bit further distal on the posterior wall of the AC and reaches the FA in the adductor hiatus. Occasionally, the contribution from the obturator nerve to the popliteal plexus is from this vascular branch from the anterior branch of the obturator nerve, when the posterior obturator nerve branch is absent.[10]

A cutaneous branch from the anterior branch of the obturator nerve sometimes emerges between the adductor longus and gracilis muscles and innervates the inferomedial side of the thigh.[1] An accessory obturator nerve branch is present in 10% to 30% of human beings.[27] It sometimes innervates the adductor muscle via a communication with the anterior branch of the obturator nerve, but it does not innervate the knee.[33]

The anterior and posterior obturator nerve branches can be blocked concomitantly with an ultrasound-guided subpectineal approach between the pectineus and external obturator muscles proximal to the adductor brevis muscle (Fig. 8, A and B).[34–36] The posterior branch of the obturator nerve can be blocked selectively in the subinguinal region between the adductor brevis and magnus muscles.[37,38] The anterior branch of the obturator nerve can be blocked selectively in the subinguinal region between the adductor brevis and longus muscles.[37]

An FT block with a modest volume of local anesthetic will most likely not anesthetize the posterior branch of the obturator nerve. On the other hand, a properly executed AC block may anesthetize the posterior branch of the obturator nerve in some few patients when the nerve emerges from the anterior side of the adductor magnus muscle. Local anesthetic injection around the popliteal plexus anterior to the popliteal artery and vein will also probably block the posterior branch of the obturator nerve.

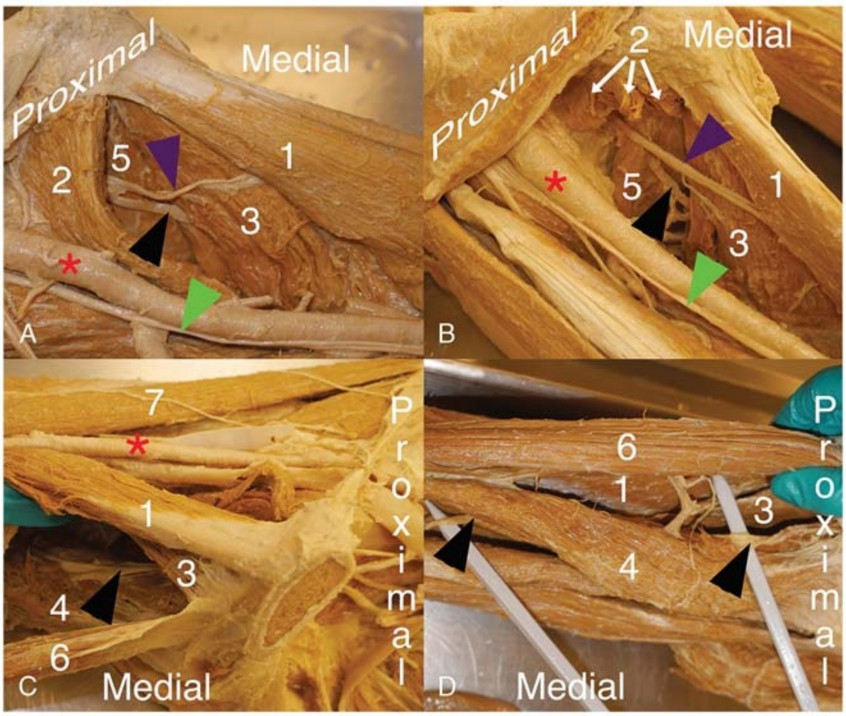

FIGURE 8. The anterior branch of the obturator nerve (purple arrowhead) emerges from the obturator canal (A) and descends between the adductors brevis (3) and longus (1) (B). The posterior branch of the obturator nerve (black arrowhead) also emerges from the obturator canal and pierces the external obturator muscle (5) (A–B). Subsequently, the posterior branch of the obturator nerve penetrates (C–D) the adductor magnus muscle (4) and typically emerges from the distal posterior surface of the muscle (D) to contribute to the popliteal plexus. The pectineus muscle (2) is retracted in (A) and cut away in (B). Gracilis (6) and sartorius (7) muscles.

Infiltration of the posterior genicular capsule as part of local infiltration analgesia (LIA) will anesthetize the capsular branches from the popliteal plexus. Selective blockade of the popliteal plexus as a perivascular approach or infiltration between the popliteal vessels and the posterior knee capsule to block the genicular contribution from the obturator and tibial nerves has not been described in the literature. However, trials are ongoing, exploring the effect of combined FT block and local anesthetic infiltration of the interspace between the popliteal artery and the capsule of the posterior knee—coined the "iPACK" principle by its originator Sanjay Sinha (personal communication).

Sciatic Nerve Block

The sciatic nerve originates from the sacral plexus and emerges from the pelvis through the greater sciatic foramen deep to the piriformis muscle and descends vertically in the thigh and ends in the popliteal fossa with the bifurcation into the tibial and common peroneal nerves. The single main tibial branch which typically branches off the sciatic nerve 10 to 25 cm proximal to the genicular joint line has a variable number of smaller branches that form the popliteal plexus together with the posterior obturator nerve branch.[10] The common peroneal nerve typically provides articular branches to the anterolateral knee capsule, which is not relevant for a medial parapatellar arthrotomy.

Sacral plexus block, the most proximal approach to block the sciatic nerve, can be carried out under ultrasound guidance using the parasacral parallel shift approach. With this technique, the sacral plexus is easily visualized in long axis view deep to the piriformis muscle.[39] The sacral plexus blockade is expected to impede ambulation due to motor paralysis of the hip muscles, hamstrings, and leg muscles. The sciatic nerve can also be approached transgluteally and infragluteally in the proximal thigh.[40] Because the transgluteal approach is anticipated to anesthetize branches of the sciatic nerve to the hamstrings muscles and the infragluteal or proximal thigh approach will affect branches to the short head of the biceps femoris muscle, these approaches will also likely compromise ability to ambulate. A popliteal sciatic nerve block is not expected to anesthetize the tibial genicular nerve branch to the popliteal plexus, as it typically branches off the sciatic part of the tibial nerve proximal to the popliteal fossa. However, the relative importance of sciatic nerve contribution to genicular nociception via the popliteal plexus compared with the contribution from the obturator nerve has not been clarified by evidence. Contribution from the obturator nerve may be more important than previously thought.

The Optimal Analgesic Nerve Block After TKA

Strategy to Block Knee Pain From the Anterior Nerve Group

Hitherto, no studies have clearly defined the contributions of the infrapatellar branch of the saphenous nerve, the medial retinacular nerve, and the medial femoral cutaneous nerve to post TKA pain with a medial parapatellar arthrotomy. The clinical relevance is that paralysis of the medial vastus nerve with the FT block may reduce the ability to ambulate to some extent. Perhaps, the retinacular nerve is more responsible than the saphenous nerve for pain after TKA? This has never been investigated. The alternative hypothetical scenario would be that future research demonstrates that the retinacular nerve is negligible for pain after TKA. In that case, the saphenous nerve could be blocked inside the AC proper or superficial to the roof of the VAM and the medial vastus nerve could be spared. These important research questions have never been clarified by evidence.

If the infrapatellar branch of the saphenous nerve, the retinacular nerve of the medial vastus nerve, and the medial femoral cutaneous nerves were all important for analgesia after TKA, then the FT block would be the most suitable block to alleviate pain after a medial parapatellar arthrotomy. Current study evidence indicates that injection lateral to the FA proximal to the AC guided by ultrasound or midway between the ASIS and the base of the patella using anatomical landmarks is as effective as a femoral nerve block for post TKA pain as part of an effective multimodal analgesia regimen.[41]

If the surgeon makes a lateral parapatellar arthrotomy, the FT block would not alleviate any pain from the incision.

Combined femoral and sciatic nerve blockade reduces pain and morphine consumption after primary TKA compared to femoral nerve block in patients with multimodal analgesia.[42–47] However, both femoral and sciatic nerve blocks impede ambulation, which makes these blocks unsuitable for analgesia after TKA.

Strategy to Block Knee Pain From the Posterior Nerve Group

It is not well established whether LIA of the posterior knee capsule is superior to sciatic nerve block regarding morphine consumption and pain scores when combined with femoral nerve block and multimodal analgesia after TKA.[48,49] Pain from the posterior knee region after TKA is probably not from the posterior part of the knee capsule, because it is not intersected during surgery. It is rather referred pain from the intra-articular innervation. On the other hand, some patients have hamstring muscle contracture when they present for surgery. If surgical debridement is performed to release the contracture, these patients will have pain from hamstring muscles that is mediated by the sciatic nerve.

In most patients, the contribution to the posterior nerve complex of the knee from the obturator nerve is from the posterior branch of the obturator nerve, but not always. Maybe it is more effective to block both branches of the obturator nerve rather than blocking the posterior branch selectively. It is not likely that even a large volume of local anesthetic injected with an FT block will block the posterior obturator nerve consistently.

Studies from the pre-ultrasound era present ambiguous results regarding the effectiveness of obturator nerve block for TKA.[50–53] A new study has compared the analgesic effect and opioid consumption of combined ultrasound-guided FT and subpectineal obturator nerve block versus FT block alone versus LIA in patients treated with multimodal analgesia after TKA.[36] The total intravenous morphine consumption during the first 24 postoperative hours showed a very large and significant reduction in the combined obturator nerve and FT blocks group compared to the other 2 groups—as well as reduced pain, nausea, and vomiting. The ambulation tests showed no difference between the groups.

CONCLUSIONS

Femoral triangle block guided by internal anatomical structures visible with ultrasonography or midway between the ASIS and the base of patella provides effective analgesia after medial parapatellar arthrotomy through the integument and the extra-articular retinaculum of the medial part of the knee. However, it does not alleviate pain deriving from the popliteal nerve branches innervating the intra-articular excision component of TKA. Supplemental blockade of the popliteal plexus by an obturator nerve block or local anesthetic infiltration of the posterior genicular capsule or local infiltration of the interspace between the popliteal artery and the capsule of the posterior knee is required.

What is the optimal analgesic block for TKA? An answer based on strong evidence requires further randomized controlled trials (RCTs) addressing important research questions. Examples of such questions are as follows:

–Is analgesia after TKA improved by adding medial retinacular and medial femoral cutaneous (anterior branch) nerve blockade to saphenous nerve blockade after TKA? (RCT comparison of low volume FT-obturator vs AC-obturator blockade).
–Does sparing of the anterior obturator nerve improve ability to ambulate after TKA? (RCT comparison of FT-obturator nerve (subpectineal) vs FT-obturator nerve (anterior branch) blockade).
–Does the tibial nerve nociception contribute significantly to pain after TKA? (RCT comparison of FT-obturator vs FT-obturator-tibial nerve blockade).

Future RCTs are needed to answer these important research questions and provide more evidence.

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