Surgical and Radiologic Anatomy (2019) 41:1461–1471
https://doi.org/10.1007/s00276-019-02291-y

ORIGINAL ARTICLE

Distribution of sensory nerves supplying the knee joint capsule and implications for genicular blockade and radiofrequency ablation: an anatomical study

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Received: 8 November 2018 / Accepted: 15 July 2019 / Published online: 23 July 2019

Abstract

Background Despite their emerging therapeutic relevance, there are many discrepancies in anatomical description and terminology of the articular nerves supplying the human knee capsule. This cadaveric study aimed to determine their origin, trajectory, relationship and landmarks for therapeutic purpose.

Methods We dissected 21 lower limbs from 21 cadavers, to investigate the anatomical distribution of all the articular nerves supplying the knee joint capsule. We identified constant genicular nerves according to their anatomical landmarks at their entering point to knee capsule and inserted Kirschner wires through the nerves in underlying bone at those target points. Measurements were taken, and both antero-posterior and lateral radiographs were obtained.

Results The nerve to vastus medialis, saphenous nerve, anterior branch of obturator nerve and a branch from sciatic nerve provide substantial innervation to the medial knee capsule and retinaculum. The sciatic nerve and the nerve to the vastus lateralis supply sensory innervation to the supero-lateral aspect of the knee joint while the fibular nerve supplies its inferolateral quadrant. Tibial nerve and posterior branch of obturator nerve supply posterior aspect of knee capsule. According to our findings, five constant genicular nerves with accurate landmarks could be targeted for therapeutic purpose.

Conclusion The pattern of distribution of sensitive nerves supplying the knee joint capsule allows accurate and safe targeting of five constant genicular nerves for therapeutic purpose. This study provides robust anatomical foundations for genicular nerve blockade and radiofrequency ablation.

Keywords Genicular nerve · Knee innervation · Anatomical landmarks · Genicular blockade · Radiofrequency ablation

Introduction

The sensory innervation of the human knee joint has increased the interest in the last decade due to the emergence of new tools to control severe chronic knee pain [2–5, 8, 21, 22, 26, 27]. These alternative procedures such as radiofrequency denervation, genicular blockade and cryoneurolysis are all based on the theory that cutting the nerve supply to a painful structure may alleviate pain and restore function [4, 23, 24]. Many studies have shown the relatively significant efficacy of this technique in several chronic knee pain conditions such as osteoarthritis and persistent pain after a total knee arthroplasty [4, 21, 23, 24]. However, a more precise anatomical knowledge of sensory nerve distribution and constant branches to the knee capsule, allowing more accurate treatment targets, would certainly lead to better analgesic effects [3, 8, 22].

Unfortunately, many discrepancies exist in the anatomic description and terminology of the nerves supplying the knee capsule. The term "genicular nerves" has been introduced by Choi et al. [4] to refer to the sensory nerves of the knee and, since then, this appellation is widely used. Despite

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the evidence that the technique described by Choi relieves chronic knee osteoarthritis pain to a certain amount, justifying the recent popularity of the genicular radiofrequency ablation, its anatomical foundations are somewhat inappropriate and confusing [8, 15]. Therefore, this anatomical basis that is currently used among interventional practitioners has to be evaluated and eventually revised.

Innervation of the human knee is complex and variable [8, 12, 13, 16, 18]. Although the nerves to the knee are known to originate from the lumbar (femoral and obturator nerve) and sacral (sciatic nerve) plexus, there is no consensus in the literature on the number, origin, trajectory, landmarks and importance of the nerve branches supplying the knee capsule [3, 4, 8, 13, 18, 22]. However, accurate anatomical description of the sensory innervation of the knee is mandatory regarding its emerging therapeutic relevance.

Therefore, we conducted this comprehensive cadaveric study to (1) investigate the distribution of nerves supplying the human knee capsule, (2) assess the constant branches that could be targeted during genicular nerve blocks (GNB) or radiofrequency ablation (RFA), and (3) define their anatomical landmarks and compare them with previous reports.

Materials and methods

We dissected 21 lower limbs (10 right and 11 left) from 21 cadavers (14 men and 7 women, aged 85.9 ± 15.6 years) donated to the Pole of Morphology of UCLouvain. This sample consisted of 20 fresh frozen limbs and a well-conserved embalmed (with zinc chloride solution) specimen donated during our study period. Specimens showed no sign of previous lower limb surgery or pathology. All dissections were performed using standard instruments.

Before dissection, a special preparation was performed in the first ten specimens:

- After flushing with lukewarm normal saline, red coloured latex was injected in the femoral artery under continuous manual pressure. This aimed to clearly discriminate small nerve branches from vessels, and to analyse whether the nerve distribution to the knee follows the vascular pattern. The dissection was performed after latex setting, 48 h after vascular injection.
- Intra-articular injection of 20 ml of 0.1% methylene blue was performed to highlight the knee capsule, and then to clearly identify the nerves reaching it.

In the femoral triangle, we first identified the femoral nerve and its branches. We carefully dissected each one of them to isolate the articular nerves penetrating the knee capsule. Second, we identified the anterior and posterior branches of the obturator nerve at the obturator foramen and followed their course distally to document any genicular branches. Then in prone position, we carefully dissected the sciatic nerve and its terminal branches (tibial and common fibular nerves) from the upper thigh to the upper leg to highlight all the articular branches to the knee.

The origin and course of each articular nerve were photographed and documented. Articular nerves whose distal anatomical trajectory, at their entry point to the knee capsule, followed the same pattern in all the specimens, were considered constant. We precisely identified their constant location on the periosteum just before their distribution to the knee capsule, which is theoretically admitted to be their best target area during GNB and RFA [4]. Then each constant nerve was fixed, at its target point, by a 1.5 mm Kirschner wire inserted through the nerve in the underlying bone. In a full extension position, measurements were taken from this target point to the articular line and surrounding anatomical bony landmarks using a sliding digital calliper to determine clinical landmarks (Table 1).

Then antero-posterior (A-P) and lateral radiographic images of the knees were made using a C-arm to highlight accurate geniculate landmarks under fluoroscopy, as it would customarily be used for the precise needle placement during an image-guided RFA procedure.

Results

Table 2 summarizes the nerves supplying the knee joint capsule.

Articular branches from the femoral nerve

We observed that the femoral nerve innervates the knee capsule through branches from the saphenous nerve (SN), the nerve to the vastus medialis (NVM), the nerve to the vastus lateralis (NVL) and the nerve to the vastus intermedius (NVI).

Articular branches from the saphenous nerve (SN)

We observed two articular branches from SN:

- The infra-patellar branch of saphenous nerve (IPBSN) was present in 100% of specimens. In most of them (18 of 21), it branched off distally, after the SN emerged from the adductor canal (AC) at the medial aspect of the distal third of the thigh (Fig. 1a). In three specimens, we observed an important variation of its origin: the IPBSN was detached from the SN in the proximal third of the thigh, above the AC and was running outside it (Fig. 1b). However, its distal trajectory at the level of the knee was constant. The IPBSN emerged

Table 1 Different parameters measured on each specimen for each constant genicular nerve

Genicular nerve	Axis of measurement	From target point of the genicular nerve to:
SMGN	Longitudinal	Medial femoral epicondyle
		Femoro-tibial articular space
IMGN	Longitudinal	Femoro-tibial articular space
	Transversal	Tibial tuberosity
ILGN	Longitudinal	Gerdy's tubercle
	Transversal	Tibial tuberosity
SLGN	Longitudinal	Lateral femoral epicondyle
		Femoro-tibial articular space
		Apex of the fibular head
IPBSN[a]	Transversal	Midpoint of the medial patellar margin
		Apex patellae

[a]We measured the transversal distance from the midpoint of the patella medial edge to the trunk of IPBSN. We also measured the transversal distance from the apex of the patella to the IPBSN

SMGN superior medial genicular nerve, *ILGN* inferior lateral genicular nerve, *IMGN* inferior medial genicular nerve, *SLGN* superior lateral genicular nerve, *IPBSN* infra-patellar branch of saphenous nerve

Table 2 Summary of the nerve supplying the knee joint capsule

Original nervous trunk	Branches from the original trunk carrying knee nerves	Nerves to the knee capsule (genicular nerves)	Constant landmarks for genicular blockade?	Supplied part of the knee capsule
Femoral	Nerve to the VM	1 Direct branch (SMGN)	Yes	Supero-medial
		0–3 Indirect branches (trans-muscular)	No	Superior medial
	Nerve to the VL	One or two branches	No	Supero-lateral
	Nerve to the VI	Intermedium GN	No	Anterior supra-patellar zone
	Saphenous nerve	IPBSN	Yes	Infero-medial
		One small branch in the AC	No	Supero-medial
Obturator	Anterior branch	One branch to the popliteal fossa via adductor hiatus	No	Postero-medial
	Posterior branch	1 Trans-muscular branch to the popliteal fossa	No	Posterior
Sciatic	SLGN	Superior lateral GN	Yes	Supero-lateral
	Posterior articular nerve	Infero-medial GN	Yes	Infero-medial
	Common fibular nerve	Lateral recurrent GN	No	Inferior lateral
		Inferior lateral GN	Yes	Inferior lateral
	Tibial nerve	1–2 Direct articular nerves	No	Posterior

VM vastus medialis muscle, *VL* vastus lateralis muscle, *VI* vastus intermedius muscle, *SMGN* superior medial genicular nerve, *SLGN* superior lateral genicular nerve, *IPBSN* infra-patellar branch of saphenous nerve, *GN* genicular nerve

variably in relation to the sartorius (anterior border, trans-muscular, or posterior border), curved in the subcutaneous layer from postero-medial to anterior, towards the infero-medial aspect of the knee. The main trunk of the IPBSN was located 58.2 ± 7.1 mm posterior to the midpoint of the medial patellar margin and 51.3 ± 7.3 mm medially to the apex patellae. It divided into one to four ending branches some of which were ascending towards the patella, some crossed towards the patellar ligament and others descended towards the tibial tuberosity (Fig. 1c, d). Some of these branches crossed the midline of the knee to innervate its antero-lateral aspect.

- In four specimens, a small branch from the SN detached within the AC and joined the descending genicular artery and, a few centimetres lower, the articular nerve from the NVM. They ran together towards the medial aspect of the knee capsule.

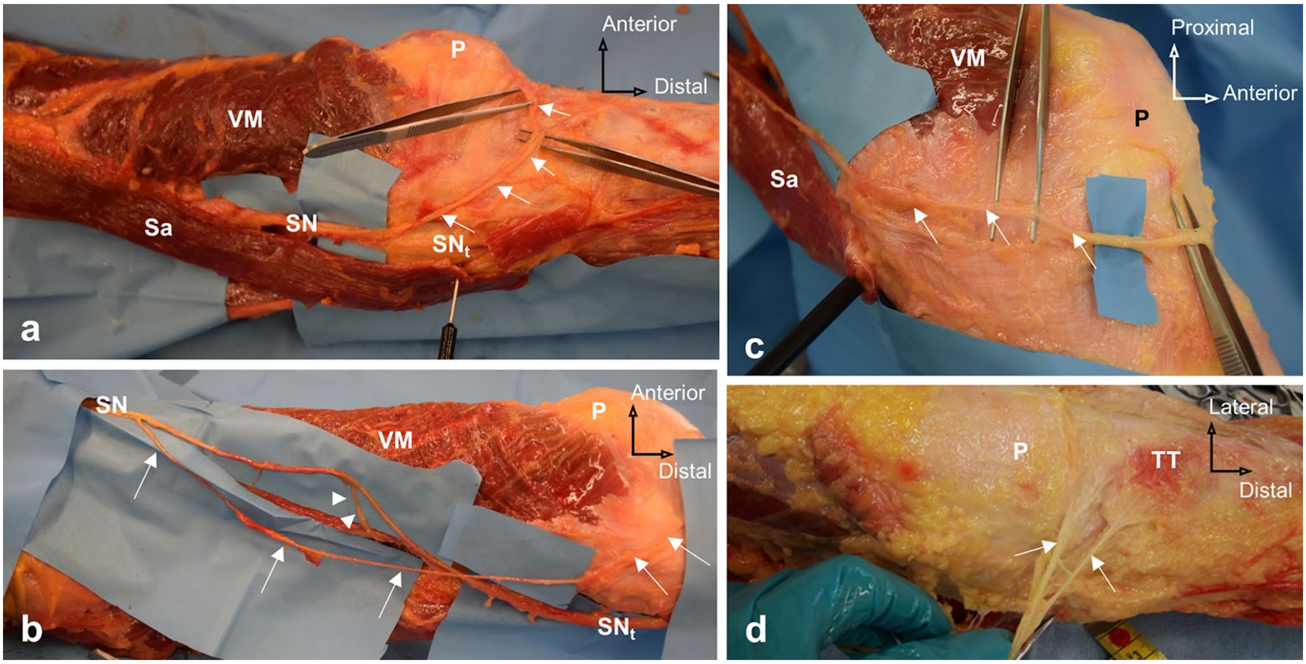

Fig. 1 Articular branches of the saphenous nerve. **a** Infra-patellar branch of saphenous nerve (IPBSN) detached distally after the emergence of SN from the adductor canal. **b** Important anatomical variation of the origin of the IPBSN, detached proximally to the adductor canal (opened). **c**, **d** Ending branches of IPBSN penetrating the knee capsule. *SN* saphenous nerve, *Thin arrows* IPBSN, *Arrowheads* posterior branch of SN, SN_t tibial branch of the saphenous nerve running towards the medial aspect of the leg, *Sa* sartorius muscle, *VM* vastus medialis muscle, *P* patella, *TT* tibial tuberosity

Articular branches from the nerve to the vastus medialis (NVM)

The NVM was found running in a short distance with the SN in the proximal third of the thigh, and then pierced the fascia of the VM muscle to continue its course between the muscle and its fascia. The NVM was not found within the adductor canal. It divided into three to five muscular rami and one constant articular branch. We observed two types of articular branches from the NVM:

- A constant direct (intra-fascial) articular branch that was present in all specimens (Fig. 2a, b): the supero-medial genicular nerve (SMGN). This was the distal branch of the NVM, originating at the union between the middle and distal third of the thigh. After a short distance, it entered a tunnel within the fascia of the VM and ran in this intra-fascial trajectory for 5–8 cm. Then it joined the descending geniculate artery and they descended together in the same bundle on the adductor magnus tendon towards the adductor tubercle. Just in front of the adductor tubercle, this nerve established a bony contact with the medial condyle 48.4 ± 8.9 mm above the femoro-tibial (FT) space; it divided into three or more branches entering the knee capsule.

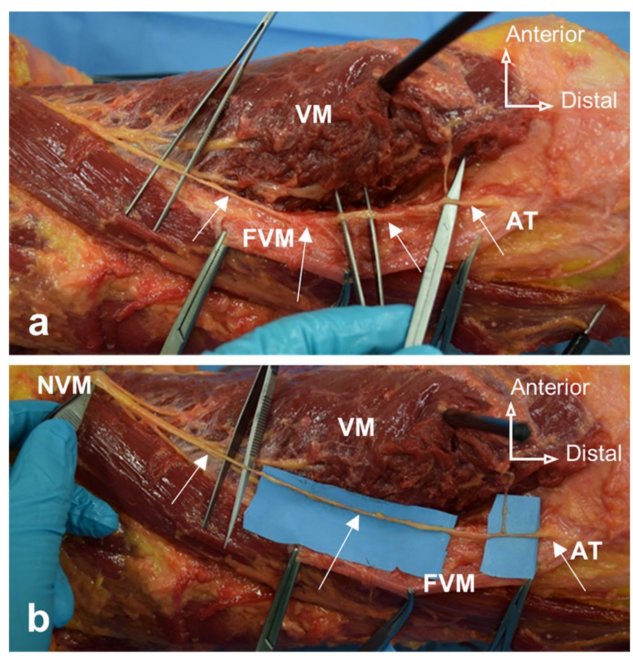

Fig. 2 Supero-medial genicular nerve (SMGN) from the nerve to the vastus medialis (NVM). **a** Trajectory of the SMGN in a fascial tunnel (partially dissected) in the thick vastus medialis fascia which belongs to the medial intermuscular septum. **b** Complete view of the SMGN after delicate dissection from the fascial tunnel. *Thin arrows* SMGN, *NVM* nerve to the vastus medialis, *FVM* fascia of the vastus medialis muscle, *AT* adductor tubercle, *VM* vastus medialis muscle)

- Indirect (trans-muscular) branches: after ramifying into the VM, some muscular branches of the NVM ended in the supero-medial aspect of the anterior knee capsule. They were inconstant in number (zero to three) and anatomic location.

Articular branch of the nerve to the vastus lateralis (NVL)

After giving off all the muscular branches, the NVL was found at the deep surface of the distal third of this muscle and ran obliquely close to the periosteum near the metaphysis towards the antero-lateral aspect of the knee (Fig. 3). It ended by giving one or two articular branches: a superficial retinacular branch running transversally forward and a deep capsular branch descending longitudinally. The anatomical location of this nerve was variable in our specimens.

Articular branch of the nerve to the vastus intermedius (NVI)

The ending branch of the NVI was found at the anterior aspect of distal femur, deep to the VI muscle, running towards the supra-patellar pouch of the knee capsule (Fig. 4).

Articular branches of the obturator nerve

The obturator nerve emerges from the pelvis by the obturator canal and divides into two branches that descend together between the obturator externus and the pectineus muscles.

- The anterior branch: descended between the adductor longus and brevis muscles, then on the posterior side of the adductor longus. It turned round anteriorly along the free edge of the adductor longus muscle, pierced the vastoadductor membrane (VAM) to enter the AC. It ran in a short distance in the proximal part of the AC and gave two branches. One branch anastomosed with a posterior branch from the SN and pierced the VAM to exit from the AC above the emergence of the SN, and descended between the sartorius and gracilis muscles to innervate superficially the medial aspect of the knee and distal thigh (Fig. 5a). The second branch joined a thin descending artery in the AC and entered in the adductor hiatus with the femoral vessels towards the popliteal fossa (Fig. 5b).
- The posterior branch of the obturator nerve was found running between the external obturator and the pectineus muscles, then between the adductor brevis and the adductor magnus muscles (AM). It divided proximally into many muscular branches supplying the AM. One of those branches pierced obliquely through the AM and emerged at its posterior surface to enter the popliteal fossa. We were not able to follow the distribution of this branch to the posterior capsule of the knee, as we could not demonstrate its participation in a popliteal plexus innervating the knee capsule like previously described.

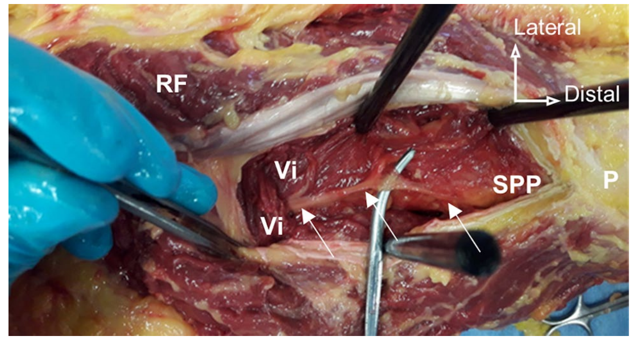

Fig. 4 Anterior view of the supra-patellar region, with the rectus femoris and the vastus intermedius muscles dissected and retracted. See the middle genicular nerve (MGN), terminal branch of the nerve to the vastus intermedius, running towards the supra-patellar pouch. *Thin arrows* indicate MGN emerging at the deep surface of the Vi muscle, *Vi* vastus intermedius muscle, *P* patella, *RF* rectus femoris muscle, *SPP* supra-patellar pouch

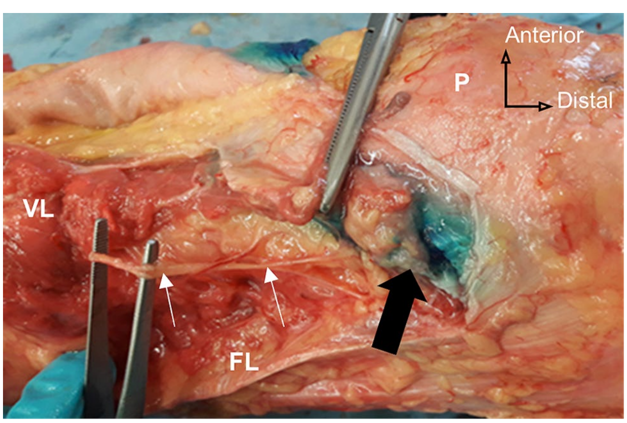

Fig. 3 Articular branch from the nerve to the vastus lateralis penetrating the knee capsule. The knee capsule is highlighted (*thick arrows*) due to infiltration of methylene blue in the knee joint before dissection (*thin arrows* indicate articular branch from the nerve to the vastus lateralis at the deep aspect of the VL muscle, *VL* vastus lateralis muscle (retracted), *FL* fascia lata, *P* patella)

Articular branches of the sciatic nerve

We observed that the sciatic nerve gives two constant branches to the knee capsule before its bifurcation:

- The supero-lateral genicular nerve (SLGN) detached from the sciatic nerve in 19 specimens. It ran down laterally under the biceps femoris muscle towards the postero-superior angle of the lateral femoral condyle where it reached the periosteum (Fig. 6), 40.1 ± 10.7 mm above

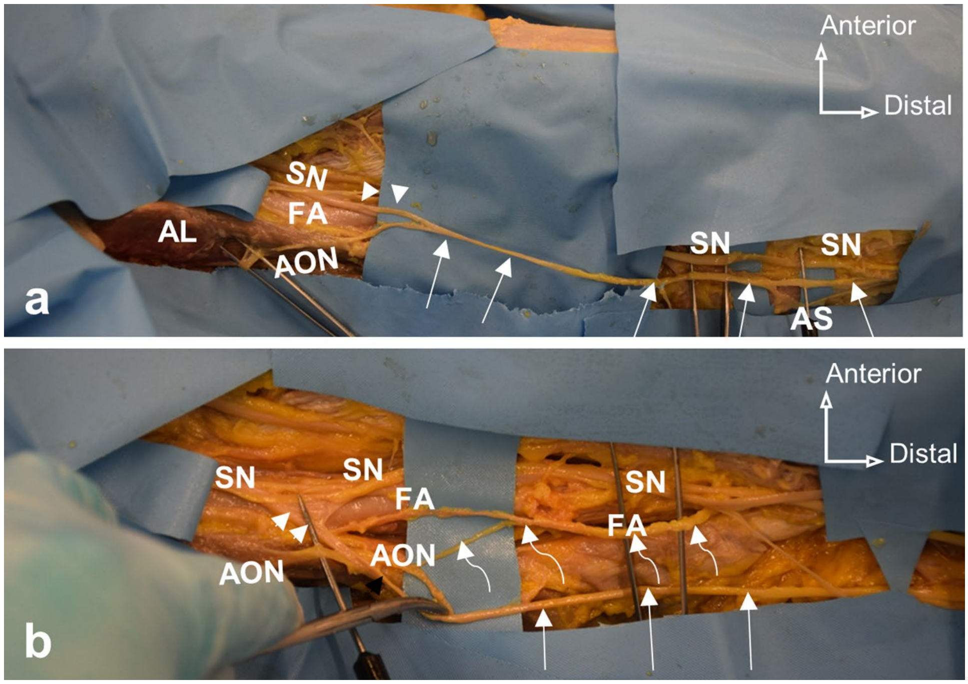

Fig. 5 Branches of the obturator nerve running towards the knee. **a** Anterior branch (AON) turning around the medial edge of adductor longus (AL) and branches with a branch (arrowhead) of saphenous nerve in the adductor canal (opened) to supply the medial aspect of the distal thigh and the knee. **b** Bifurcation of AON in the adductor canal, one branch joins a branch of SN like described above (thin arrow), the second branch (spiral arrow) joins a small vessel and enters the adductor hiatus with femoral vessels. *AON* anterior branch of the obturator nerve, *SN* saphenous nerve, *Arrowhead* branch from saphenous nerve anastomosing with a branch of AON, *Thin arrows* ending branch from the AON and SN running to the knee, *Spiral arrow* ending branch of AON penetrating the adductor hiatus with the femoral vessels, *AL* adductor longus muscle, *AS* articular (femoro-tibial) interspace (black tip inserted into)

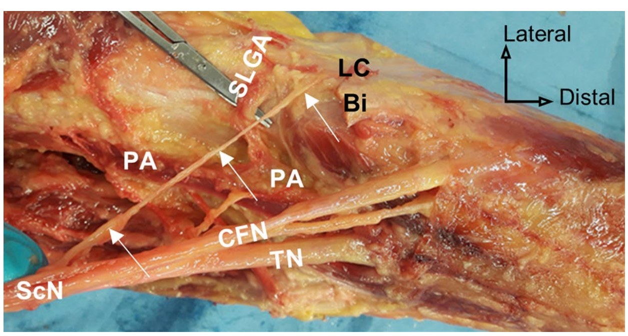

Fig. 6 Articular branches from sciatic nerve: supero-lateral genicular nerve (SLGN). Postero-lateral view of the knee, biceps femoris (Bi) removed. Note that the SLGN (thin arrows) does not run in the same bundle with SLGA. *Thin arrows* SLGN, *ScN* sciatic nerve, *TN* tibial nerve, *CFN* common fibular nerve, *SLGA* supero-lateral genicular artery from popliteal artery (*PA*); *Bi* biceps femoris tendon (sectioned); *LC* lateral femoral condyle

the FT space. It then divided into two branches: a transversal branch running forward to the lateral retinaculum (lateral retinacular nerve) and a longitudinal branch descending towards the FT space.

- The posterior articular nerve detached from the tibial part of the sciatic nerve before its bifurcation in 19 of the specimens. It descended towards the popliteal vessels and divided into two branches. The distal branch passed between the popliteal artery and vein, crossed obliquely the deep surface of the popliteal artery and joined the infero-medial genicular vessels (Fig. 7a, b). Both turned around the medial tibial condyle, from posterior to anterior, following a recurrent trajectory. They coursed beneath the deep surface of the collateral tibial ligament, and then ascended anteriorly towards the antero-medial part of the knee capsule. We found this nerve constant in 100% of specimens and it corresponded to the infero-medial genicular nerve (IMGN).

Articular branches from the tibial nerve (after bifurcation)

The tibial nerve released inconstantly one to two branches, which dived towards the posterior knee capsule. In the two specimens with proximal sciatic bifurcation, the posterior articular nerve was detached directly from the tibial nerve, and the SLGN detached from the common fibular nerve (CFN). In 11 specimens, we did not identify any articular branch directly arising from the tibial nerve.

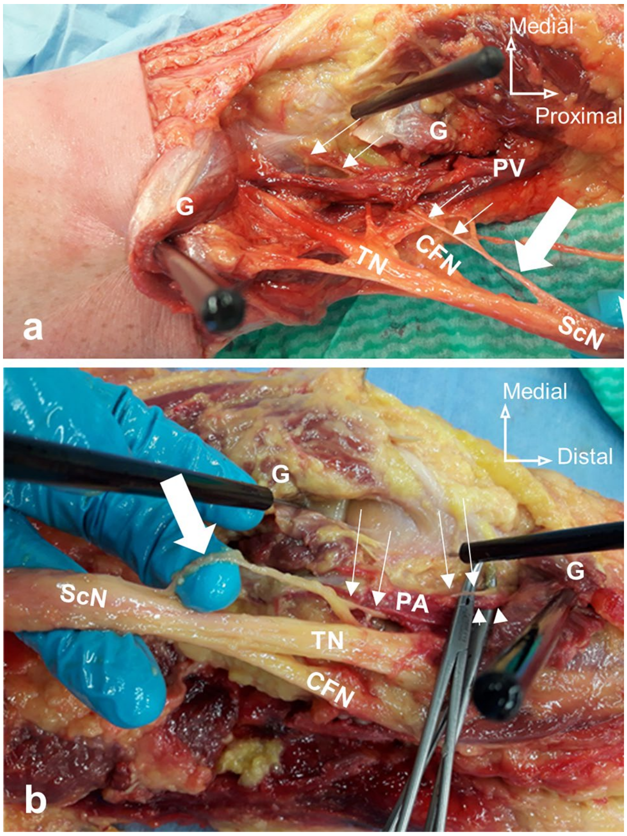

Fig. 7 Articular branch from sciatic nerve: posterior articular nerve (thick arrow). Posterior view of the knee joint, gastrocnemius muscle cut and reflected. **a** Trajectory of the infero-medial genicular nerve (IMGN, thin arrow) passing between the popliteal vessels (PV) and penetrating the knee capsule. **b** IMGN (thin arrows) running with the infero-medial genicular artery (arrowhead) at the posterior aspect of the knee, towards its antero-medial aspect. *Thick arrow* posterior articular nerve, *Thin arrows* IMGN, *G* gastrocnemius muscle (cut and reflected), *ScN* sciatic nerve, *TN* tibial nerve, *CFN* common fibular nerve

Articular branches of the common fibular nerve (CFN)

We observed two constant articular branches detaching from the common fibular nerve, just before its bifurcation.

- The lateral recurrent genicular nerve was the first branch arising at the level of the fibula neck and destined to the proximal tibiofibular joint.
- The infero-lateral genicular nerve (ILGN) was the second branch (Fig. 8). It detached at the level of the fibular neck and descended forward giving off many muscular collaterals. Then the terminal branch emerged at the deep surface of the anterior tibial muscle and joined the lateral recurrent genicular vessels at the junction of the lateral condyle and the shaft of the tibia. They ascended together on the periosteum towards the infero-lateral aspect of the anterior knee capsule, passing between the tibial tuberosity and Gerdy's tubercle.

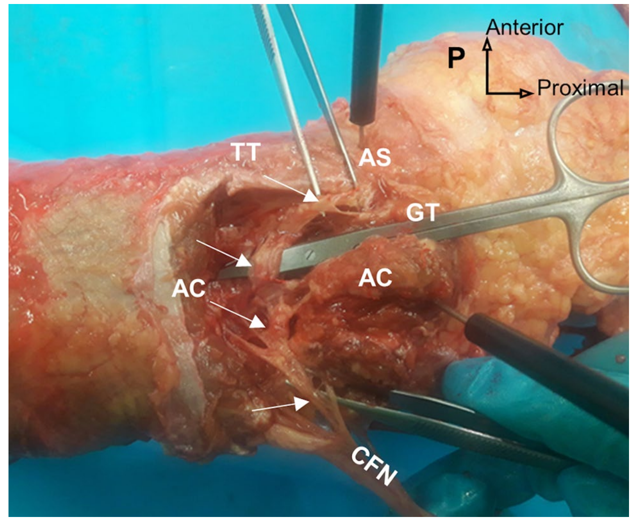

Fig. 8 Infero-lateral genicular nerve (ILGN) from the common fibular nerve (CFN). *Thin arrows* ILGN, *TT* tibial tuberosity, *GT* Gerdy's tubercle, *AC* anterior compartment muscles, *AS* articular (femoro-tibial) space (black tip inserted into), *P* patella

Constant genicular nerves and anatomical landmarks for genicular nerve blockade and radiofrequency ablation

Based on this comprehensive cadaveric dissection, we have selected five constant articular branches that are potential targets during these emerging therapeutic procedures. The measurements from the anatomical landmarks are presented in Table 3.

1. *Supero-medial genicular nerve* It was a branch from the NVM in all specimens. Under fluoroscopy, the target point was located in front of the adductor tubercle, at the superior edge of the medial femoral condyle on the antero-posterior (AP) view (Fig. 9a). On the lateral view, it was located at the posterior third of the condylar width (Fig. 9b), and not at the middle.
2. *Supero-lateral genicular nerve* It was a direct branch from the sciatic nerve. Under fluoroscopy, the target point was located at the postero-superior angle of the lateral condyle on the lateral view, corresponding to the upper edge of the lateral condyle height on AP view (Fig. 9).
3. *Infero-medial genicular nerve* Originating from the posterior articular nerve, which branches off from the sciatic nerve. It was found at the tibial metaphysis, beneath the deep surface of the tibial collateral ligament. Under fluoroscopy, the target point was located at the junction

Table 3 Measurements from the target point of each constant genicular nerve to the surrounding anatomical landmarks

Nerve	Origin	Quadrant of the knee capsule	From the targeted location of the nerve to:	Mean (± standard deviation) distance (mm)
SMGN	Nerve to vastus medialis	Supero-medial	Femoro-tibial interspace	48.4 ± 8.9
			Medial epicondyle	21.9 ± 3.2
SLGN	Sciatic nerve	Supero-lateral	Femoro-tibial interspace	40.1 ± 10.7
			Top of the fibula head	59.9 ± 9.6
			Lateral epicondyle	19.5 ± 5.15
IMGN	Posterior articular nerve (from sciatic nerve)	Inferior medial	Femoro-tibial interspace	38.0 ± 3.9
			Tibial tuberosity	43.9 ± 6.5
ILGN	Common fibular nerve	Inferior lateral	Gerdy's tubercle	16.8 ± 3.3
			Tibial tuberosity	22.6 ± 5.6
IPBSN	Saphenous nerve	Inferior medial	Midpoint of the medial edge of the patella	58.2 ± 7.1
			Tip of the patella	51.3 ± 7.3

SMGN superior medial genicular nerve, *ILGN* inferior lateral genicular nerve, *IMGN* inferior medial genicular nerve, *SLGN* superior lateral genicular nerve, *IPBSN* infra-patellar branch of saphenous nerve

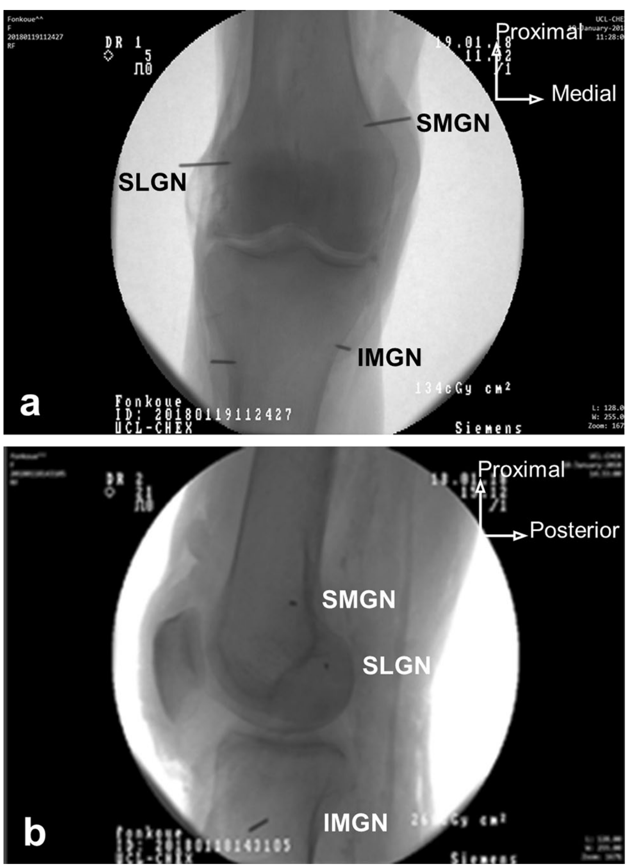

Fig. 9 Landmarks proposed for fluoroscopic-guided genicular nerve blockade of the SMGN, SLGN and IMGN (during dissection, Kirschner wires have been inserted through the constant genicular nerves in the underlying bone at their target point, before radiographs have been done). **a** Antero-posterior incidence, **b** lateral incidence. *SMGN* supero-medial genicular nerve, *SLGN* supero-lateral GN, *IMGN* infero-medial *GN*

of the tibial shaft and medial condyle on the AP view, while on the lateral view, it was located at the middle of the tibial width (Fig. 9).

4. *Infero-lateral genicular nerve* Branched off from the CFN. The target point was located at the distal part of this nerve, just before entering the knee capsule, far away from the CFN, and after the muscular branches had been given off. This point was located at the intersection between the longitudinal line passing through Gerdy's tubercle and the transversal line passing through the top of tibial tuberosity.
5. *Infra-patellar branch of saphenous nerve* The target of IPBSN was found to be a line, like recently described by Hu et al. [14], with a slight modification. The landmark is the longitudinal line connecting the transversal lines passing through the apex patellae and tibial tuberosity, 4 cm medially to the apex patellae. In our study, this line crossed all the terminal branches of the IPBSN in 20 out of 21 specimens (95% of accuracy).

Discussion

The knee's sensory innervation has been described to be complex with a high degree of anatomical variability [2, 3, 8, 9, 13, 18]. However, a precise knowledge of the distribution pattern of nerves supplying the knee makes some of them accessible to percutaneous denervation for the treatment of chronic knee pain. In this comprehensive cadaveric study, we dissected the three nerves of the lower limb from their origin, and we rigorously traced each of their branches to its termination to systematically check all of the articular nerves supplying the knee capsule. We have found that nerve supply to the medial aspect of the knee capsule originates from the saphenous nerve, the SMGN from the nerve to the VM, the IMGN from the sciatic nerve, and to some extent, the anterior branch of the obturator nerve. The lateral aspect of the knee is innervated by the nerve to the VL, the SLGN from the sciatic nerve, the lateral recurrent nerve and the ILGN from the common fibular nerve. The supra-patellar area is supplied by the median intermediate genicular nerve from the nerve to the vastus intermedius. The tibial nerve and the posterior branch of the obturator nerve supply the posterior aspect of the knee. Some of these nerves were accompanied by small vessels (SMGN, IMGN, ILGN, IPBSN), but it did not appear that the nerve course is scheduled to follow the genicular artery distribution.

Despite the anatomical variability of sensory nerves supplying the knee, we found more constant nerve branches with therapeutic significance than those used for genicular nerve blocks and radiofrequency ablation [4]. The success of genicular blocks or RF denervation depends on the target nerve being included within the volume of thermocoagulated tissue or immersed in anaesthetic [4, 21, 23]. Several research groups have focused on optimizing this technique, but we found that the anatomical description of the genicular nerves given by Choi and colleagues, on which these therapeutic procedures are based, is somewhat inaccurate concerning their origin and targets used. We selected five genicular nerves whose distal course was found to be consistent, despite some variations in their proximal trajectory: the SMGN, IMGN, IPBSN, SLGN and ILGN.

The NVM seems to play a much greater role as previously suggested by Burckett [3]. Almost all the authors since Gardner [9] described the trans-muscular branches of the NVM supplying the antero-medial aspect of the knee capsule following Hilton's law [11], but most of them failed to describe the only constant direct branch of the NVM to the medial joint capsule, which has the most important therapeutic interest. This might be because the trajectory of this thin nerve, hidden in a fascial tunnel, does not facilitate its dissection and identification. Additionally, if the fascia of the vastus medialis muscle is removed or damaged during dissection, it would no longer be possible to identify this nerve, which lies within it. We found that this intra-fascial direct branch, observed in all the specimens, running in front of the adductor tubercle and supplying the supero-medial quadrant of the knee capsule, corresponds to the SMGN. Recently, Burckett et al. [3] described an extra-muscular branch of the NVM, found in only 7 specimens out of 20, but 3 other very recent studies [2, 22, 26] described this branch (intra-fascial) in all their specimens, in accordance with our findings. We found like all these recent studies that the SMGN is not a branch of the tibial nerve like previously described since Gardner [9]. However, there remain some discrepancies concerning the origin of this nerve and the therapeutic target point. Unlike Tran et al. [26] who suggested that this nerve originates directly from the femoral nerve, we clearly found (and illustrated) that it is a branch of NVM (Fig. 2a, b), in accordance with Orduna-valls [22] and Bendsten [2]. Curiously, when looking carefully at Fig. 4c provided by Tran, we observed that the SMGN seems to be directly detached from the NVM. Another important difference we found is that, although most of the authors (including anatomical textbooks) state that the NVM lies within the adductor canal [3, 22], it was found outside the AC in our specimens. This finding is in accordance with Bendtsen et al. [2] and Elabad [7] who found the NVM out of the AC in all of their specimens. This anatomic detail could be of relevant clinical interest, especially concerning adductor canal blockade.

This study shows that the combination of the SN and the NVM provides the substantial innervation to the antero-medial aspect of the knee joint (capsule and retinaculum). They should be the primordial therapeutic targets in medial knee pain. Contrary to Burckett [3] who found the contribution of the SN to knee joint innervation to be relatively modest with an inconsistent infra-patellar branch (11 specimens out of 25), we found this IPBSN in all specimens, in accordance with most of the studies [1, 10, 17, 19]. We observed an anatomical variation of great clinical importance for pain physicians: in three of our specimens, because the IPBSN emerged proximally to the AC and coursed outside it, an AC blockade would have theoretically been less efficient for suppression of the afferent nerve influx from the IPBSN than a distal blockade at the level of the knee. In a recent study, Koch et al. [19] did not observe this proximal origin of the IPBSN. This might be due to the fact that, contrary to those authors who started the dissection of SN at its emergence from the AC, we dissected the entire thigh to trace the SN from its origin.

Although it is well admitted that the ON participates in the innervation of the knee capsule, there is no consensus on the patterns of distribution of the ON branches to the knee [2, 9, 12, 22]. Burckett [3] found no terminal branches of the ON that directly innervates the capsule of the knee joint. Horner and Dellon [13] found ON contribution to knee innervation in only 11% of specimens. We found that the anterior branch of the obturator nerve enters the AC and contributes to the sensory innervation of the knee joint, through a plexus with the SN, and potentially through the branch penetrating the adductor hiatus with the femoral vessels (Fig. 5). The small branches that anastomosed with branches of the SN in the AC were named as subsartorial plexus in an old study by Druner [6]. A branch of the posterior ON perforates the adductor magnus muscle to penetrate the popliteal fossa and might contribute to the posterior innervation of the knee capsule via a popliteal plexus, as suggested in the literature. However, no authors have illustrated this, and we could not identify a macroscopically customizable branch penetrating the posterior knee capsule or anastomosing with the tibial nerve branches. Moreover, unlike most descriptions since Gardner [9], we highlighted that the anterior branch of the ON, and not the posterior one, lies in the AC and penetrates the adductor hiatus. Nevertheless, the importance of the ON to the sensory innervation of the knee capsule is reinforced by clinical studies suggesting that ON blocks contribute to knee analgesia [20].

The contribution of the sciatic nerve to the knee innervation is well established, but the anatomical description of the specific nerves that enter the knee capsule is somewhat inappropriate. We found that the sciatic nerve gives two constant nerves for the knee capsule. The SLGN, constant in its origin and trajectory, is found in 100% of our specimens, as recently described by Sutaria [25]. This nerve could be an important therapeutic target for postero-lateral knee pain. Surprisingly, most of the authors [2, 3, 8, 27] wrongly describe the SLGN as a branch of the NVL or the common fibular nerve. The second nerve, the posterior articular nerve, was first described by Gardner [9] as a branch of the tibial nerve. However, it emerges from the tibial part of the sciatic nerve, before the bifurcation. We were able to demonstrate that in all the specimens, it gives a small branch that joins the infero-medial geniculate vessels and innervate the infero-medial aspect of the knee capsule. We did not find that specific trajectory description and illustration in the literature.

The anatomic references supporting the genicular RF therapeutic procedure suggests that the tibial nerve gives off the SMGN and the IMGN [4]. We found this description inaccurate, in accordance with Orduna et al. [22] in a recent cadaveric study, who were unable to determine a consistent pattern of the tibial nerve sensory branches. Contrary to the wide spread anatomical description, the SMGN and the IMGN are not direct branches of the tibial nerve. Many authors [2, 3, 13, 18] cited a popliteal plexus made of branches of obturator nerve and tibial nerve, which we did not specifically observe. We did not find a single illustration of this plexus in the literature.

The importance of the sensory branches from the common fibular nerve was described by Gardner [9] and subsequently confirmed by Horner [13]. The close proximity of the ILGN (recurrent fibular nerve for some authors [8, 26]) to the CFN has precluded radiofrequency as a therapeutic option [4, 22]. Then to avoid accidental damage to the CFN trunk while targeting ILGN, all the authors strongly countermanded the blockade of the ILGN. This is right if we consider the target point at the origin of the ILGN on the fibular neck, just after it detached from the CFN. However, we found that this nerve could safely be targeted in its distal trajectory, before it enters the knee capsule, far away from the CFN. More interesting, as the IPBSN, our proposed landmarks for targeting the ILGN does not require the absolute use of imaging devices, but just the palpation of the superficial bony landmarks. To our knowledge, this is the first description of a potentially safe target point of the ILGN for RFA.

Radiographic landmarks improve the likelihood of successful inclusion of a segment of the relevant genicular nerve within the tissue volume, thermocoagulated or immersed, providing better clinical response [8]. The originality of our method to determine the radiological landmark is that, after identifying the bony target point of a constant genicular nerve, a Kirschner wire was directly inserted through the nerve in the underlying bone, exactly at its target point, under direct visual observation. Then true A-P and lateral radiographic images allowed us to determine the target point of each nerve under fluoroscopic guidance and to verify the consistency of their radiological landmarks in all specimens. The solid fixation of Kirschner wires in bone through the targeted nerve prevents any displacement during closure and handling for radiography, contrary to the method used by Franco [8] who just placed slender stainless steel wires along the course of the genicular nerves. Our study showed some significant differences in radiological landmarks of the genicular nerve from those widely used for RFA since their description by Choi et al. [4]. This advocates a clinical study to compare the therapeutic relevance of our proposed landmarks to that of the classical ones currently used for RFA.

Conclusion

This study was designed to revisit the sensory innervation of the human knee capsule and to re-examine the anatomical basis for the therapeutic selective denervation of the knee capsule that has been widely used since the description of Choi et al. Our results show that they failed to accurately determine the origin of some of the genicular nerves on one hand, and some of their recommended target points are not accurate on the other hand. The NVM, saphenous nerve, anterior branch of the ON and IMGN from sciatic nerve provide substantial innervation to the medial knee capsule and retinaculum. The sciatic nerve and the NVL supply sensory innervation to the supero-lateral quadrant of the knee joint, while the CFN supplies its infero-lateral side. Tibial nerve and posterior branch of the obturator nerve supply the posterior aspect of the knee capsule. According to our study, five constant genicular nerves with accurate landmarks could be targeted for therapeutic purpose. These findings warrant further clinical studies using these modified anatomical target points to compare their therapeutic efficacy with the current standard of art.

Acknowledgements The authors thank the donors of the cadavers used in this study and their families.

Author contributions LF: protocol development, data collection, data analysis, manuscript writing. CB: protocol development, data analysis, manuscript revision. J-EKK: data collection, manuscript revision. MC: manuscript revision. CD: manuscript revision. ET: manuscript revision. OC: project development, data analysis, manuscript revision.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights This article does not contain any study with human participants performed by any of the authors, but it involved human cadavers.

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