Anatomical Study

Anatomy of the Infrapatellar Branch in Relation to Skin Incisions and as the Basis to Treat Neuropathic Pain by Percutaneous Cryodenervation

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Background: Neuropathic knee pain, particularly of the infrapatellar branch, is an important complication of knee replacement surgery, with an incidence as high as 70%. The increasing number of elderly patients requiring knee surgery, including total knee arthroplasty (TKA), has contributed to an increase in the number of patients with this pathology. Treatment includes neurectomy, infiltration therapy, and cryodenervation. Percutaneous cryodenervation of the infrapatellar branch is a promising option.

Objective: To provide the necessary anatomical analysis to optimize percutaneous cryodenervation of the infrapatellar branch by defining sections of the unbranched ramus infrapatellaris to demonstrate the risk of nerve injury through 3 different skin incisions typically used during TKA.

Study Design: Anatomical study.

Methods: Cadavers were used for assessment. Exclusion criteria were scars from knee surgery, deep wounds, and a flexion angle of no more than 90°. We compared 3 frequently used skin incisions with the course of the infrapatellar branch and identified sections of the unbranched nerves that were suitable for percutaneous cryodenervation.

Results: In total, 18 formalin-fixed cadavers (mean age, 78.9 years) contributed 30 knees (15 pairs) for dissection. We identified the following 4 anatomical variations of the ramus infrapatellaris in relation to the sartorius muscle: anterior, posterior, penetrating, and pes anserinus types. Sections were then found to treat the nerve branch types. The nerve sections were localized using the medial pole of the patella as a palpable landmark and varied in length between 15 mm and 40 mm. The medial parapatellar skin incision showed the highest risk of lesions to the infrapatellar branch (53.3%) followed by the midline skin incision (46.7%) and the lateral parapatellar skin incision (30.0%).

Limitations: This was an observational study, performed using a limited number of cadavers. This therefore precluded generalization and statistical analysis. Significantly more female (13) cadavers were examined compared to male (5). Further studies in human populations, and with larger samples, are necessary to confirm these results.

Conclusion: Based on our findings, the surgeon can localize the unbranched main nerve. Compared with the current practice, our approach should allow for a lower impact on tissues and should facilitate complete pain relief through a single cryodenervation. Furthermore, we propose that the lateral parapatellar skin incision is an acceptable alternative surgical approach in knee replacement surgery because it is associated with the lowest risk of damage to the infrapatellar branch.

Key words: Percutaneous cryodenervation, infrapatellar branch, neuropathic knee pain, knee surgery, skin incisions knee surgery, total knee arthroplasty

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The saphenous nerve is the longest cutaneous branch of the femoral nerve, and it arises from the anterior rami of the lumbar spinal nerves 2 – 4. Along its course down the leg, the saphenous nerve divides into an infrapatellar branch and a final branch that follows the great saphenous vein and continues to the medial side of the foot. The infrapatellar branch supplies the skin over the patellar ligament as well as the medial, anterior, and part of the lateral surface of the knee (1-3). Injury to the infrapatellar branch of the saphenous nerve is a well-known complication of several surgical interventions of the knee joint (4-7) and primarily results in anesthesia and paresthesia. The incidence of electrophysiological and clinical sensory defects are reported from < 1% to 70% (8-13).

Because of demographic changes in society and higher stress loads, we can anticipate that total knee arthroplasty (TKA) will be performed with increasing frequency and in increasingly younger patients (14-16). The rate of implantation of TKAs between 1980 and 2006 has increased by a factor of 130 for younger individuals (age, 30 – 59). Statistics for TKAs from 2009 (17), showed that 175,000 first TKAs were performed in Germany. The number of TKAs noted in the Organization for Economic Cooperation and Development has almost doubled between 2000 and 2009, from 63.1 to 118.3 per 100,000 population, respectively.

The increased use of knee surgery, particularly TKA, has led to an increased incidence of patients with severe pain syndromes in degenerative and osteoarthritic knee joints (18). Unfortunately, the optimal treatment modality for such neuropathic pain remains unclear. Although complete pain relief has been achieved using neurectomy of a painful neuroma of the infrapatellar branch (19), this was a single case report. Comparable results have also been achieved by Dellon et al (4) by partial denervation for persistent neuroma pain after TKA.

Another technique, percutaneous cryodenervation, has been shown to be a promising therapy for post-thoracotomy neuralgia (20) and chronic postherniorrhaphy neuropathic pain (21). Following this procedure, 60% of patients with post-thoracotomy neuralgia (N = 43) were found to show significant pain relief. At the time of the study termination (3 months), 50% of these patients achieved a reduction in chronic thoracic pain. Patients (N = 10) included in the postherniorrhaphy study were found to show a mean pain reduction of 77.5% for a mean follow-up period of 8.2 months.

Furthermore, we identified a case report in by Trescot et al (22) describing the successful treatment of neuropathic knee pain by cryodenervation.

In the Department of Orthopedic and Trauma Surgery, St. Josefs-Hospital Bochum, Germany, percutaneous cryodenervation is currently used in patients with painful injury to the ramus infrapatellaris. Because of our own promising results with this treatment modality and the case report by Trescot et al, we aimed to investigate the course of the infrapatellar branch in the medial knee joint region to define sections of the unbranched ramus infrapatellaris that were optimally suited for cryodenervation. This enables a complete interruption of actions potentials from the more distally located branches by a single cryodenervation and a lower impact on tissue.

Methods

Formalin-fixed cadavers were selected for anatomic dissection from the Institute of Anatomy, Ruhr-Universität Bochum, Germany. A single knee was randomly chosen for the histological investigation. Cadavers with scars from knee surgery or deep wounds were excluded because the anatomy could have been altered. In addition, knees were excluded with a flexion angle greater than 90°.

Anatomic Dissections

All dissections were performed using standard instruments (i.e., scalpels and tweezers). A skin incision was made 100 mm proximal and distal to the lower and upper border of the patella and the skin in this area was removed. Next, the fat tissue of the subcutaneous layer was carefully removed to expose the fascia of the rectus femoris muscle. Following the fascia to the medial aspect of the leg, all vessels and nerves were excised to the great saphenous vein. A small incision was made into the fascia lata at the level of the sartorius muscle, and the nerves around this muscle were carefully traced in a distal direction by dissection of the surrounding connective tissue. This approach was used to identify the ramus infrapatellaris of the saphenous nerve in all cadavers.

To determine a suitable section for cryodenervation, "Line 0" was defined as a reference line and set at a right angle to the median plane of the leg, passing through the medial pole of the patella. We defined "Point 0" as the reference point where "Line 0" crossed the infrapatellar branches. Starting from this point, and moving in proximal and distal directions, the unbranched segments of the infrapatellar nerve were divided into 5 mm sections and their relative distances to the medial pole of the patella were measured (Fig. 1).

Points proximal and distal to the reference line were given positive and negative signs, respectively. Pins were inserted to delineate the nerve's course at 10-mm intervals. The most proximal pin was inserted into the infrapatellar nerve at the sartorius muscle and the most distal pin was located at the point before the first branch of the ramus infrapatellaris.

We compared 3 skin incisions frequently used during knee surgery against the course of the infrapatellar branch. For this we placed threads on the leg precisely along the course of the skin incisions to visualize the potential degree of surgical damage to the infrapatellar nerve. The skin incisions used were the medial parapatellar skin incision, midline skin incision, and lateral parapatellar skin incision.

Histological Analysis of the Saphenous Nerve and the Infrapatellar Region

A single knee was randomly selected. Specimens of the sural and infrapatellar nerves were dissected at the medial and infrapatellar region of the knee joint to expose both the topography of the nerves in situ and the nerve fiber spectrum. Paraffin and semithin sections were performed. The dissected specimens were post-fixed in 2% glutaraldehyde and then fixed for 2 hours in 2% osmium tetroxide, dehydrated and embedded in araldite. The cutting of the semi-thin sections was performed with an Ultracut E (Reichert Jung). Staining of the semi-thin sections (0.75 µm) was conducted with 1% toluidine blue and 1% borax.

The staining procedure of the paraffin sections were performed with Goldner, Elastica-van-Gieson, or Hematoxylin–Eosin and photo documented with an Olympus OM2 camera.

Results

Patients

In total, 18 formalin-fixed cadavers (mean age at death, 79.8 years; range, 60 – 95 years; women 13; men, 5) were examined. Fifteen pairs of knees were selected, providing 30 knees. We chose one knee (age at death, 75 years; male; right knee) for the histological investigation.

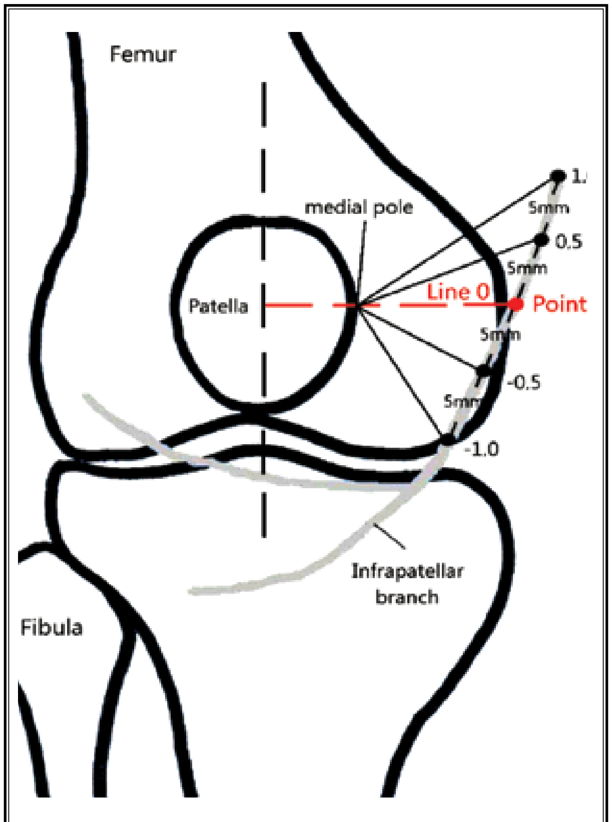

Fig. 1. *Anterior view of the right knee joint with a schematic representation of the ramus infrapatellaris. The figure illustrates the reference line "Line 0" and the reference point "Point 0" to determine the section for cryodenervation. Distances between the medial pole of the patella and nerve were measured.*

Anatomic Dissections

Common Anatomical Variations of the Ramus Infrapatellaris

The ramus infrapatellaris curved in the subcutaneous layer from medial to anterior, supplying the proximal skin on the medial, ventral, and lateral aspects of the lower leg.

We identified 4 anatomical variations of the ramus infrapatellaris using the topography of the nerve in relation to the sartorius muscle to define the type. In the "anterior type" (Fig. 2A), the infrapatellar nerve emerged from the anterior border of the sartorius

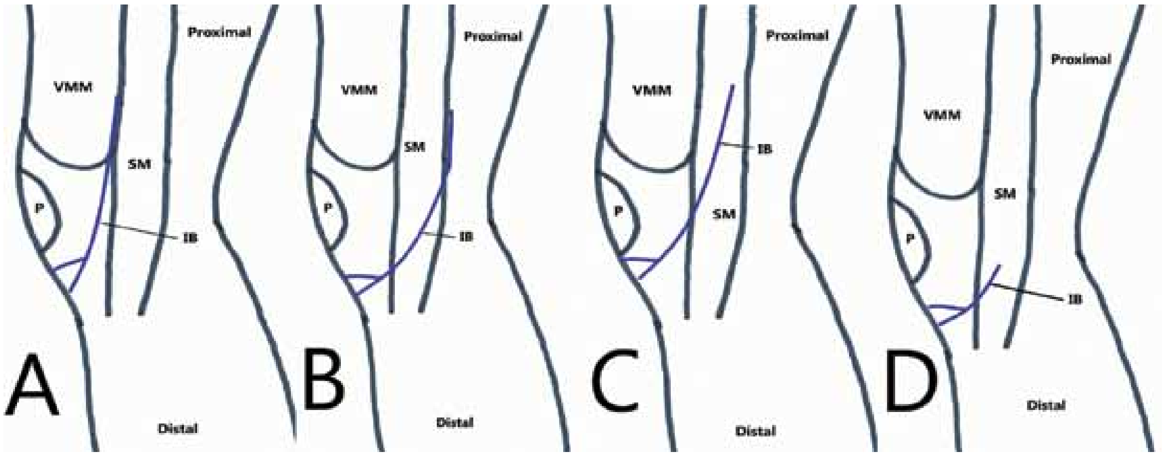

Fig. 2. *Medial views of right knee joints. Anatomical variations of the infraptellar branch (IB) in relation to the sartorius muscle (SM) are shown. A. Anterior type: the IB emerges from the anterior border of the SM. B. Posterior type: the IB emerges from the posterior border of the SM. C. Penetrating type: the IB penetrates the belly of the SM. D. Pes anserinus type: the IB penetrates the tendon of the SM close to the superficial pes anserinus. VMM, Vastus medialis muscle; P, Patella*

Table 1. *Frequency distribution of the infrapatellar branches in relation to the sartorius muscle*

Type	Total	Right knees	Left knees
Anterior type (%)	8 (26.7)	3 (20.0)	5 (33.3)
Penetrating type (%)	11 (36.7)	7 (46.7)	4 (26.7)
Posterior type (%)	7 (23.3)	2 (13.3)	5 (33.3)
Pes anserinus type (%)	4 (13.3)	3 (20.0)	1 (6.7)

muscle. In the "posterior type" (Fig. 2B), the infrapatellar nerve emerged from the posterior border of the sartorius muscle. The "penetrating type" (Fig. 2C) described the infrapatellar nerve penetrating the belly of the sartorius muscle. Finally, the "pes anserinus type" (Fig. 2D) described a situation where the infrapatellar nerve penetrated the tendon of the sartorius muscle close to the superficial pes anserinus. "Line 0" was used as a reference to differentiate between the last 2 types, i.e., nerves proximal to this line were associated with the penetrating type and those distal to "Line 0" were associated with the pes anserinus type.

The "type" of infrapatellar nerve in all our dissections differed between right and left legs. The most common (Table 1) was the penetrating type (36.7%) followed by the anterior (26.7%), posterior (23.3%), and pes anserinus types (13.3%). The penetrating type was also most common in the right knee, accounting for 7 cases (46.7%), while the anterior and posterior types were most common in the left knees, each accounting for 5 cases (33.3% each).

Association of Nerve Course with Common Clinical Incisions

The medial parapatellar skin incision most frequently passed over the underlying infrapatellar branch (53.3% of cases), followed by the midline skin incision (46.7% of cases). The course of the lateral parapatellar incision passed over the underlying nerve in only 30% of cases (Table 2). Anatomic examination of 30 knees from cadavers revealed that there was no difference between the right and left knees in terms of the likelihood of a given skin incision passing over the infrapatellar branch.

Nerve Segments Suitable for Cryodenervation

Concerning the nerve segments for cryodenervation, we determined that each type has a common length. The longest occurred with the anterior type (40 mm), followed by the penetrating (30 mm), posterior (20 mm), and pes anserinus types (15 mm).

The common segment for the anterior type (Fig. 3A) was located between points "0" and "4.0." The average distance (Table 3) to the medial pole of the patella was 61.8 mm (range, 39 – 76 mm) for point "0" and 79.8 mm (range, 72 – 86 mm) for point "4.0." The defined section (Fig. 3B) for the penetrating type was between the points "–1.0" (average, 66.4 mm; range, 40 – 96 mm) distally and "2.0" (average, 78.0 mm; range, 51 – 114 mm) proximally in the leg. For the posterior type, the common segment (Fig. 3C) was located between the points "0" (average, 88.9 mm; range, 60 – 125 mm) and

Table 2. *Frequency of crossings over between the skin incisions compared to the course of the nerve fibers.*

Knees	Skin incisions	Crossed over	Did not cross over
Total	Lateral parapatellar (%)	9 (30.0)	21 (70.0)
	Medial parapatellar (%)	16 (53.3)	14 (46.7)
	Midline (%)	14 (46.7)	16 (53.3)
Right	Lateral parapatellar (%)	5 (33.3)	10 (66.7)
	Medial parapatellar (%)	8 (53.3)	7 (46.7)
	Midline (%)	7 (46.7)	8 (53.3)
Left	Lateral parapatellar (%)	4 (26.7)	11 (73.3)
	Medial parapatellar (%)	8 (53.3)	7 (46.7)
	Midline (%)	7 (46.7)	8 (53.3)

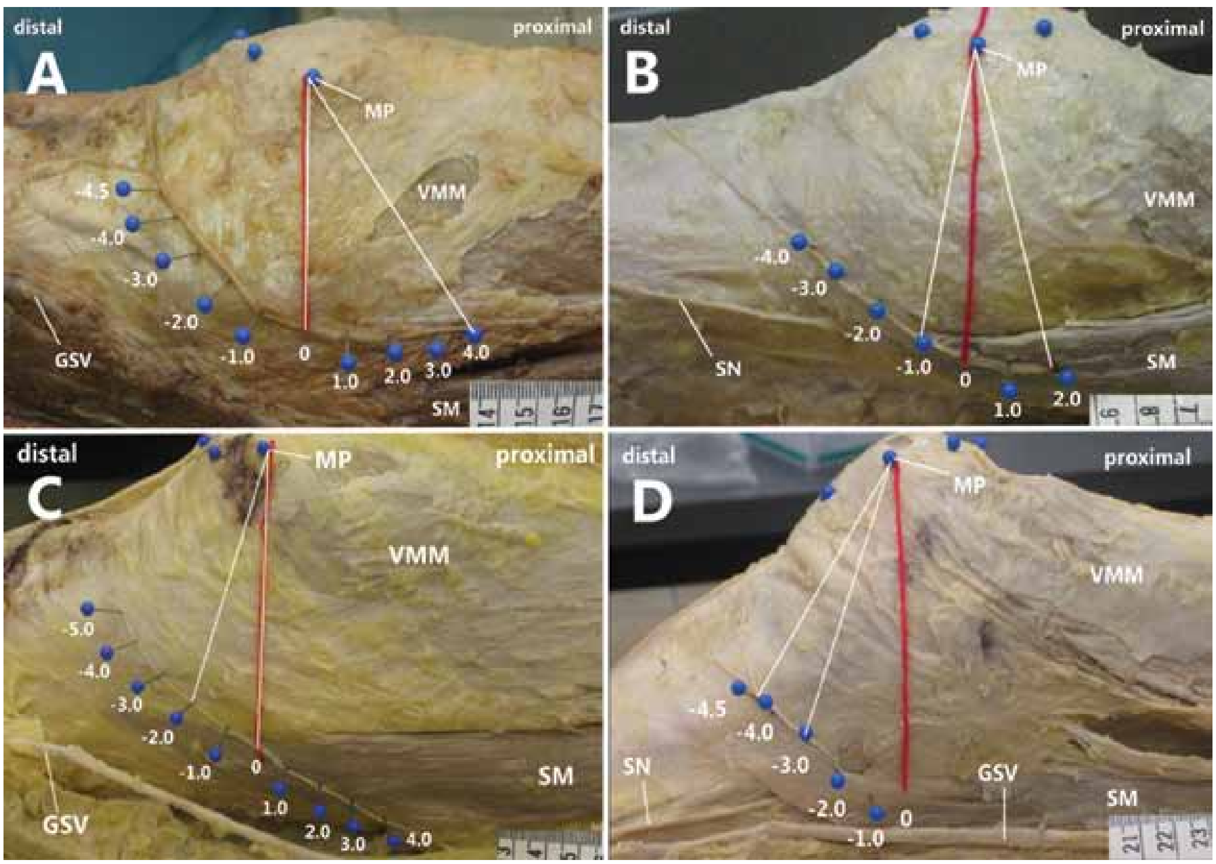

Fig 3. *Medial knee joint views. Anatomical dissection of the cadavers: white lines represent the distal and proximal limits of the defined sections for cryodenervation. The red thread represents the reference line "Line 0" between the medial pole of the patella (MP) and the reference point "Point 0" on the infrapatellar branch. A. Left knee (anterior type; figure is mirrored): the defined section for cryodenervation is between the points "0" in a distal direction and "4.0" in a proximal direction of the leg. B. Right knee (penetrating type): the defined section for cryodenervation is between the points "−1.0" and "2.0." C. Right knee (posterior type): the defined section for cryodenervation is between the points "−2.0" and "0." D. Right knee (pes anserinus type): the defined section for cryodenervation is between the points "−4.5" and "−3.0."*
GSV, Great saphenous vein; VMM, Vastus medialis muscle; SM, Sartorius muscle; SN, Saphenous nerve

Table 3. Average distances between the medial pole of the patella and the unbranched ramus infraptellaris for the anterior type, the penetrating type and the posterior type. Figs. 3. A – C. are used to illustrate.

	Point	-2.0	-1.5	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Anterior type	Mean (mm)					61.8	63.8	65.8	68.0	69.7	72.1	74.1	77.1	79.8
	SD (mm)					13.2	11.8	9,8	8.4	7.5	6.3	5.7	5.2	4.9
	Range (mm)					37	33	27	22	19	17	15	12	14
Pene-trating type	Mean (mm)			66.4	67,1	68.1	71.0	73.6	75.9	78.0				
	SD (mm)			15.4	14.3	13.7	14.7	16.7	17.2	17.2				
	Range (mm)			56	52	51	53	61	63	63				
Posterior type	Mean (mm)	82.0	84.4	87.4	88,1	88.9								
	SD (mm)	20.5	24.3	22.7	22.8	22.7								
	Range (mm)	57	59	63	64	65								

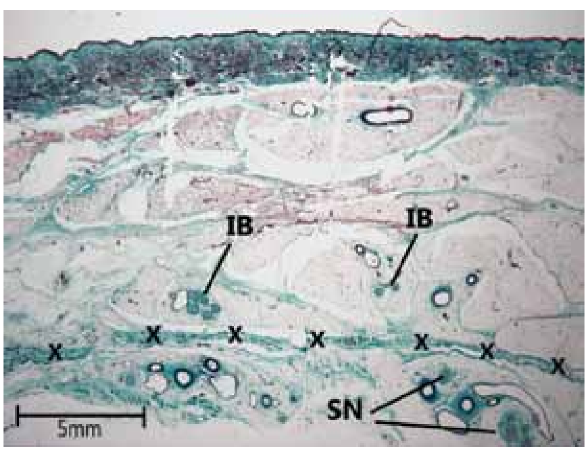

Fig. 4. *Histological section of the medial region of the knee with the branches of the infrapatellar nerve (IB) in the subcutaneous layer. The saphenous nerve (SN) below the fascia lata (X). Paraffin section, Goldner staining; male, age 75 years.*

“−2.0” (average, 82.0 mm; range, 59 – 116 mm).

The pes anserinus type (Table 4) had an average length of 94.5 mm (range, 82 – 109 mm) between the medial pole of the patella and point “0.” All nerves were concealed by the sartorius muscle at this point. The first common point where all unbranched nerves ran on the body of the muscle was point “−3.0” (average, 87.3 mm; range, 73 – 92 mm). The cryodenervation segment (Fig. 3D) started at point “−3.0” and extended distally to point “−4.5” (average, 82.3 mm; range, 70 – 96 mm).

Histological Analysis of the Saphenous Nerve and the Infrapatellar Region

Under the Goldner stain, the histological section showed that the course of the closest nerve trunk to the skin surface was located 7 mm into the subcutaneous tissue of the medial knee region. The infrapatellar branch was located above the fascia lata and the saphenous nerve below the fascia lata (Fig. 4).

Histological analysis of the semithin sections using toluidine blue revealed that the branches in the infrapatellar region and medial aspect of the knee joint had the typical histological structure of a cutaneous nerve. The thickness of the nerve trunks differed between the 2 tissue samples but had the same structure in the endoneurium, perineurium, and epineurium.

Tissue from the infrapatellar region containing the infrapatellar branch showed 3 nerve trunks with 12 fascicles, with each nerve trunk surrounded by its own fat tissue lobule. Most of the nerve fibers of these nerve trunks were small and unmyelinated. Less than a third of all the nerve fibers had a thick myelin sheath (Fig. 5). We also identified a third group of small thin myelinated fibers between the other fibers.

Table 4. *Average distances between the medial pole of the patella and the unbranched ramus infraptellaris for the pes anserinus type. Fig. 3D. is used to illustrate.*

Point	-4.5	-4.0	-3.5	-3.0	-2.5*	-2.0*	-1.5*	-1.0*	-0.5*	0*
Mean (mm)	82.3	83.8	85.5	87.3	88.5*	90.0*	91.8*	93.8*	94.0*	94.5*
SD (mm)	9.8	9.5	9.6	9.6	9.2	8.5	9.1	10.0	10.4	10.1
Range (mm)	26	26	26	26	25	23	24	26	27	27

* Nerves were concealed by the sartorius muscle or the distances were not relevant for the cryodenervation distance, but necessary for orientation.

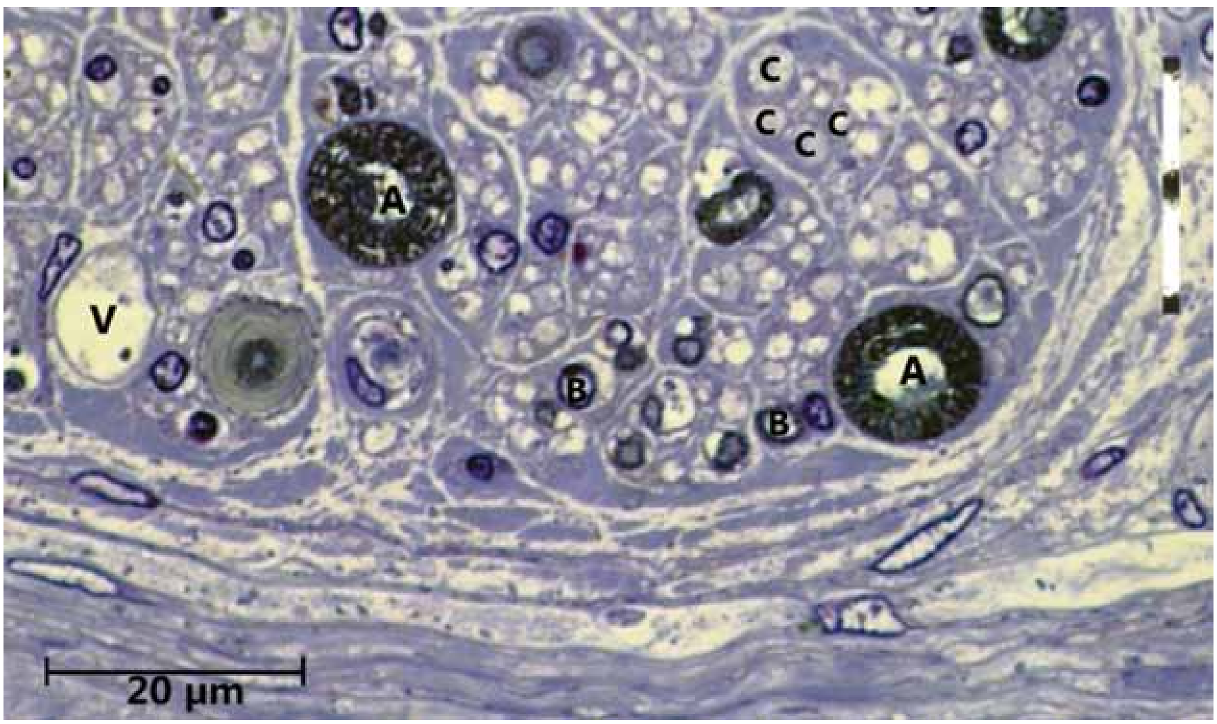

Fig. 5. *Detail of the endoneural compartment of the infrapatellar nerve fiber of the medial side of the knee. Most of the nerve fibers are of the unmyelinated type. Thick myelinated axon (A), thin myelinated axon (B), and unmyelinated axon (C) are shown. Venule (V) of the vasa nervorum; perineural sheath (PS); Semithin section, Toluidinblue staining; male, age 75 years.*

Discussion

It was apparent that the medial parapatellar skin incision was associated with the highest risk of damaging the infrapatellar branch because the incision passed over the nerve in 53.3% of cases. This was followed by the midline skin incision, where the midline nerve fibers in our specimens crossed or reached the patellar tendon to the tibial tuberosity in 46.7% of cases. This is comparable to the findings of Ebraheim et al (23), where 36% of the nerve fibers crossed to the lateral border of the patellar tendon. However, in our study, the lowest risk of nerve damage was associated with the lateral parapatellar skin incision, in which only 30% crossed over. This concurs with the clinical observation of Laffosse et al (24) who found that the area of hypesthesia was less using this incision compared with the midline incision.

Several other clinical observations (25-28) discuss the relationship between different skin incisions used during knee surgery and injury to the infrapatellar branch. On the basis of our anatomical results, we propose that the lateral parapatellar access is an acceptable alternative skin incision in knee replacement surgery. Although the medial parapatellar incision and the midline incision provide excellent surgical exposures and the length of incision has decreased (29), both incisions run through the skin region innervated by the ramus infrapatellaris.

Our anatomic dissection showed 4 clear anatomical variations of the ramus infrapatellaris in relation to the sartorius muscle; however, with the low magnification power used in this study, it is not clear that there are only 4 variations. Combining the present investigation with the results of Arthornthurasook and Gaew-Im (30) provides a case sample of 67 investigated knees. Our posterior type can be combined with the parallel type and with the posterior type described by Arthornthurasook and Gaew-Im and constitute 52.2% (35) of these knees. The anterior and penetrating types were comparable in both examinations, providing 13.4% (9) and 28.4% (19), respectively. The pes anserinus type was only described in our investigation and provided 6.0% (4) of the cases.

We defined the optimal treatment sections for cryodenervation of the unbranched ramus infrapatellaris according to type; no common section could be universally applied. This implies that in daily clinical practice, the surgeon has to first define the anatomical variant or type, as we propose. Indeed, our investigations showed the wide divergence in distances between the medial pole of the patella and the nerve's course and the high variability of the infrapatellar branch in the subcutaneous layer. Considering this, the relation of the nerve to the sartorius muscle should be identified and localized by ultrasound to allow for the optimal choice of section for cryodenervation. Our own experiences, combined with those of Le Corroller et al (31), have found that, despite the thinness of the nerve, the infrapatellar branch can be clearly depicted by ultrasound. Using both ultrasound and "Line 0" for orientation, "Point 0" can be located in each type to optimize cryodenervation. Further clinical studies are essential to confirm whether these anatomical results are applicable to clinical practice and whether they will provide a meaningful clinical benefit for patients. The major limitation of our study is that it was an observational study and did not use any statistical analysis. This is primarily because the number of dissected cadavers was too few.

Another option for the treatment of postoperative neuropathic pain is pharmacological therapy. Prior to the invasive procedure of percutaneous cryodenervation, this treatment method should be attempted. Medical therapy can be performed using first-line drugs (such as tricyclic antidepressants or dual reuptake inhibitors of serotonin and norepinephrine), second-line (such as opioid analgesics), and third-line drugs (such as topical lidocaine) (32). Previous randomized, controlled trials have shown that pharmacological relief of neuropathic pain is often insufficient, and that in patients receiving these therapies, only an optimum pain relief of 50% could be achieved (33). Further possibility for achieving pain relief includes physical therapy such as superficial or deep heat agents or neurostimulation techniques; however, these are also insufficient when applied alone (34).

These examples illustrate the extreme complexity of therapy of postoperative neuropathic pain; therefore, in this study, we hope to provide an anatomical basis for a novel approach.

We found one interesting variation in our anatomical dissection, where the skin of the infrapatellar region was supplied by a long anterior cutaneous branch of the femoral nerve. This branch was also crossed by the course of the medial parapatellar skin incision and the midline skin incision. The course of the lateral parapatellar skin incision did not cross the nerve because the infrapatellar branch did not extend that far laterally. Its course was completely different to all others, and it emphasized the importance of keeping anatomical variations in mind, particularly when the clinical outcome is not as expected.

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