Pilot Study

Anatomical Variation of Infrapatellar Innervation Determines Clinical Risk of Infrapatellar Neuropathy

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Background: Infrapatellar neuropathy arises from traumatic, iatrogenic, or compression injury to the infrapatellar branch (IB) of the saphenous nerve. The risk of infrapatellar neuropathy has been shown to depend on the IB's anatomical course. The infrapatellar branch of the saphenous nerve (ISBN) has been discovered to take varying courses, and the IB can emerge directly from the femoral nerve. The variety of the IBSN's courses and the prevalence of cases involving the infrapatellar branch of the femoral nerve (IBFN) call the uniform IB course described in textbooks into question.

Objectives: In this study, we aim to identify sites of IB emergence and their anatomical relations and evaluate them for their risk of neuropathy.

Study Design: The study is an anatomical prospective pilot study.

Setting: The setting is a single-center cadaveric study performed at the anatomical institute of the Medical University of Vienna.

Methods: Twenty-two anatomical specimens were evaluated for the relationship of their IBs to anatomical risk sites. The subsartorial course, distal sartorial penetration, and the crossing of the medial femoral epicondyle were assessed. The measurements and relations of the IB were determined with callipers and assessed by computational modelling.

Results: Nine IBs originated from the saphenous nerve, 11 originated from the femoral nerve, and 2 originated from both. The subsartorial course was most frequent in IBs of saphenous origin. Penetrating and profound distal sartorial relations correlated moderately with emergence type and were highest in the saphenous group. The crossing of the medial femoral epicondyle was the most common relation of IBs that emerged femorally.

Limitations: The study's limitations were the low number of cadavers to examine and the confining of the exploration of knee extension to anatomical specimens that restricted an inferential analysis.

Conclusion: Infrapatellar innervation can emerge from the saphenous nerve, the femoral nerve, or a combination of both, and the origin of the innervation determines the clinical risk for infrapatellar neuropathy. While innervation from the IBSN may lead to compression at the subsartorial course, distal sartorial penetration, and the crossing of the medial femoral epicondyle, innervation from the IBFN carries reduced anatomical risk for infrapatellar neuropathy.

Key words: Infrapatellar neuropathy, anatomical variation, infrapatellar innervation, anterior knee pain syndrome, compression syndromes

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Infrapatellar neuropathy results from lesions of the infrapatellar branch (IB) of the saphenous nerve caused by compression syndrome (1-3), traumatic injuries (4,5), and iatrogenic injuries (6-10). This neuropathy is a mostly unidentified syndrome, associated with a habitually prolonged time without proper diagnosis or treatment and fundamentally under- and misdiagnosed (4). Often, physicians are confronted with imaging and test results that do not reflect the clinical presentation of anterior knee pain syndrome and still lack the pathophysiological correlate (10-12). Despite a unison anatomy textbook description of the infrapatellar branch of the saphenous nerve (IBSN), anatomical studies have identified a highly variant course of the IB that may influence the clinical risk of infrapatellar neuropathy (13-18). Therefore, further comprehension of the underlying anatomy involved in this type of neuropathy is required to broaden our understanding of the disease.

Variant Anatomy of Infrapatellar Innervation

The anatomical textbook course describes the IBSN as a sensory nerve branch that separates from the saphenous nerve branch of the femoral nerve either within the adductor canal or subcutaneously and then arches toward the anteromedial aspect of the knee proximal to the tibial tuberosity and distal to the patellar apex, where the branch usually terminates in several more branches that cross the patellar ligament superficially (3,9). Anatomical variations have been described for the height of the division, which can take place in the proximal, middle, or distal third of the femur, as well as before, in, or after the adductor canal (1,18).

As early as 1972, Lanz and Wachsmuth (19) described the IB's variable relationship to the sartorius muscle as 70% penetrating and 30% posterior (Fig. 1). In 1988, Arthornthurasook et al (13) classified the various relations to the sartorius muscle into 4 types: anterior, penetrating, posterior, and parallel (parallel type is no longer used). In a 2017 meta-analysis of 6 studies covering a total of 336 limbs, the penetrating type was the IB's most common sartorius relation at 42.9%, followed by the posterior type at 41.9% (17).

Anatomical Risk for Infrapatellar Neuropathy

The pathoethiologies of infrapatellar neuropathies differ in their anatomical risk sites despite their similar clinical presentation. In 1945, surgeons were already aware of the risk of iatrogenic injury to the IBSN during knee joint surgery (20). This problem has often been reported since during arthrotomy (6,7,21-27), arthroscopy (16,28-30), patellar tendon harvesting (31), hamstring tendon harvesting (30,32-35), and saphenous vein stripping (36,37). Despite physicians' efforts to define safe zones for incision (15,16,38), Kerver et al (39) have shown that any incision at the anteromedial aspect of the knee bears the risk of IB injury.

Anatomical risk sites for IB entrapment syndrome comprise the progression through the adductor canal (5,40), the crossing point above the medial femoral epicondyle (3,10), and the penetration of the sartorius muscle (3,41), which underlie the variant course of the IB. Several case reports even indicate divergent IB emergence. In anatomical studies, Arthornthurasook et al (13) described an IB variant that ran parallel to the sartorius muscle without crossing it. Ackman et al (6) reported that they found an "interesting variation" in which the infrapatellar skin was supplied by a long anterior cutaneous branch of the femoral nerve, while Esmer et al (42) specified that the medial cutaneous femoral nerve that innervated the infrapatellar region. Furthermore, in an ultrasound study, Henry et al (17) reported a limited prevalence of IB emergence in the saphenous nerve in 78% of 100 specimens and only 58% of 30 healthy volunteers, raising the question of how infrapatellar innervation originated in cases of IB emergence from somewhere other the saphenous nerve.

We aim to identify the innervation of the infrapatellar region and determine how the clinical risk of infrapatellar neuropathy depends on the anatomical relations of the site of IB emergence.

Material

Twenty-two fresh-frozen unpaired extended lower extremities (12 right, 10 left) originating from voluntary adult body donations (13 women, 9 men) to the Center of Anatomy and Cell Biology of the Medical University of Vienna, were examined. The specimens' mean age at death was 78 ± 10.6 years (range 59-95 years). Ethical approval was obtained from the institutional review board (1522/2020). Eligibility was determined by intact tissue configuration. Specimens were included if they featured intact lower extremities without signs of surgical interventions, trauma, or defects to the nervous or soft tissue. To ensure tissue preservation, specimens were stored upon arrival at the faculty at -20°C and thawed at 4°C for a maximum of 48 hours.

Dissection

The middle of the inguinal ligament, the patellar apex, and the tibial tuberosity were marked on each specimen's skin. Incision of the skin was conducted along the inguinal ligament, the posterior border of the gracilis muscle to a hand's width distal of the tibial tuberosity, from which a transverse incision departing to the anterolateral aspect of the lower leg was continued. Proximally, the femoral nerve was identified, and its saphenous and anterior cutaneous branches were pursued. Distally, a cutaneous skin flap was lifted delicately to identify the terminal nerve branches of the infrapatellar region.

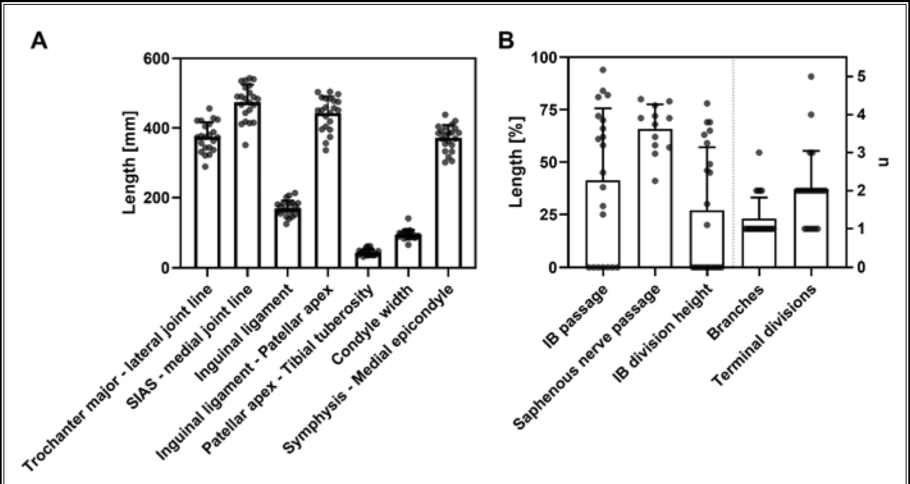

Fig. 1. *Measures depicted as mean + standard deviation and single data points. A) Anthropometric measures. B) Nerve measures normalized to the distance between the middle of the patellar ligament to the patellar apex.*
IB: infrapatellar nervous branch; SIAS: spina iliaca anterior superior (anterior superior iliac spine).

Documentation and Measurement

Prior to any measurement, the specimens' ages and genders and which side of each body was under examination were recorded. The following anthropometric linear measurements were obtained: major trochanter to lateral joint line, anterior superior iliac spine to medial joint line, middle of inguinal ligament to patellar apex, patellar apex to tibial tuberosity, symphysis to medial epicondyle, and bicondylar width. Specific measurements were the height of the division between the IB and the saphenous nerve, the height of the penetration of the fascia lata, and the number of terminal infrapatellar divisions. The specific measurements were related to the perforation point of the femoral nerve below the inguinal ligament. Measurements were taken with callipers (0.1 mm accuracy).

The relations of the IB were defined as the sartorial muscle (episartorial or subsartorial course; superficial, perforating, or profound distal relation), the medial femoral epicondyle (anterior, crossing, posterior) and the patellar apex and tibial tuberosity (proximal, traversing, distal). The course of the IB was recorded through sketches and scaled photo documentation.

Computational Modelling

For the development of the summative course model, data were transferred to a model of a right lower extremity generated by Paint.net (Version v4.0.9) in relation to the anthropometric measurements and scaled photographs. The data obtained from specimens' left lower extremities were therefore flipped horizontally for visualization (Supplemental Figs. 2 and 3).

Statistical Analysis

Groups were divided by the site of the IBs' emergence (the saphenous nerve, the femoral nerve, or the combination of both). Predefined endpoints were defined to exclude potential bias—namely, the height of the division between the saphenous nerve and its IB, the fascial penetration, the number of branches and terminal divisions, and the relation to the sartorial muscle, medial femoral epicondyle, patellar apex, and tibial tuberosity. Identified endpoints were the course's relation to the sartorial muscle (episartorial and subsartorial) and the cessation of anterior cutaneous branches. All metric data were described by mean, SD, and range. The correlation of IB emergence in the saphenous and femoral nerves was tested by Spearman rank correlation coefficient, which was considered weak at < 0.3, low between 0.3 and 0.5, moderate between 0.5 and 0.7, and strong between 0.7- and 1. The α-level of significance was set at 0.05.

Data were collected in Microsoft™ Excel™ (Office 365™ MSO-16.0.12624.20348), statistical testing was conducted by SPSS® (Version-X; SPSS), and graphs were arranged by GraphPad Prism® (V8.0.2 263).

Data integrity was ensured by photo documentation comparison.

Results

Topography & General Measures

The 22 lower extremities showed diverse anthropometric measures (Fig. 1, Supplemental Table 1). The specific nerve measures showed broad variation, with high SD and nonnormally distributed data. The infrapatellar branches had a mean division height of 107.5 ± 123.5 mm (0-282 mm) with a mean fascial passage of 181.0 ± 154.7 mm (0-450 mm), while the saphenous nerve had a mean fascial passage of 279.8 ± 69.2 mm (162-361 mm). The mean number of IB branches was 1.3 ± 0.6 (1-3) with mean terminal divisions of 2 ± 1 (1-5).

Course of the Infrapatellar Branch

Single-branch analysis revealed that the IB emerged from the saphenous nerve in 40.9% of cases (n = 11), from the femoral nerve in 50% of cases, and from both nerves in 9.1% of cases. The IB's course was episartorial in 40.9% of cases and subsartorial in 59.1%, while its distal sartorial relations were superficial in 56.1% of cases, perforating in 33.3%, and profound in 10.6%. The IB's relation to the medial femoral epicondyle was anterior in 12.9% of cases, crossing in 82.6% of cases, and posterior in 4.5% of cases. The IB crossed the patellar apex in 11.4% of cases and was proximal in 4.5% and distal in 84.1%. The relation to the tibial tuberosity was proximal in 97.6% of cases and crossing in 2.4% of cases. In 40.9% of cases, the infrapatellar branch ceased at the anterior cutaneous branches (Figs. 2 and 3, Supplemental Table 2).

Origin-Dependent Course

The intragroup ratios of IB emergence—IBSN (n = 9), IBFN (n = 11) and combined innervation through the IBSN and the infrapatellar branch of the femoral nerve (IBFN) (n = 2)—revealed that the episartorial course was most frequent in the IBFN group (16.67% [IBSN] vs. 63.64% [IBFN] vs. 25.00% [IBSN and IBFN]), the perforating distal sartorius relation was most frequent in cases of IBSN emergence (50.00% [IBSN] vs. 18.18% [IBFN] vs. 41.67% [IBSN and IBFN]) and the crossing medial femoral epicondyle relation was the most common in the IBFN group (66.67% [IBSN] vs. 100.00% [IBFN] vs. 58.33% [IBSN and IBFN]). In the majority of cases in all groups, the IB was distal to the patellar apex (93.75% [IBSN] vs. 81.82% [IBFN] vs. 75.00% [IBSN and IBFN]) and proximal to the tibial tuberosity (93.75% [IBSN] vs. 100.00% [IBFN] vs. 100.00% [IBSN and IBFN]). The IBFN-emergence group presented with the greatest number of departing anterior cutaneous branches (22.22% [IBSN] vs. 54.55% [IBFN] vs. 50% [IBSN and IBFN]) (Fig. 4A and Supplemental Table 3).

The IBSN group had a mean division height of 58.56% ± 14.00% (30-78%), whereas the IBFN group had a mean division height of 1.80% ± 5.69% (0-20%), and the combined-IB-innervation group had a mean of 22.78% ± 22.78% (0-46%) in relation to the distance between the middle of the inguinal ligament and the patellar apex. The fascial passage was higher in the IBSN group (62.31% ± 20.13%; range 0-84%) than in the IBFN (26.19% ± 31.86%; range 25-94%) or IBSN and IBFN (40.35% ± 40.35%, range 0-81%) groups (Fig. 4B).

The mean number of branches was highest in the combined-IBSN-and-IBFN group (2.5 ± 0.5, range 2-3), followed by the IBSN group (1.33 ± 0.47, range 1-2) and then the IBFN (1 ± 0, no range) group. The highest number of terminal divisions was observed in the IBSN-and-IBFN group (3.5 ± 1.5, range 2-5), followed by the IBSN group (2.11 ± 0.87, range 1-3) and finally the IBFN group (1.73 ± 0.62, range 1-4) (Fig. 4C).

Correlation of Nerve Origin to Anatomical Properties

The Spearman correlation of the nerve origin (IBSN vs. IBFN) to the anatomical properties of the IB presented a strong correlation of the division height (r = 0.92; *P* = 7*10-9) and weak correlation of the number of branches (r = 0.46; *P* = 0.039), fascial passage (r = 0.21; *P* = 0.031), and departure of anterior cutaneous branches (r = 0.33; *P* = 0.158). Meanwhile, the terminal divisions (r = 0.21; *P* = 0.366) and the patellar apex (r = 0.11; *P* = 0.662) and tibial tuberosity (r = 0.28; *P* = 0.252) relations showed no correlation.

The clinical risk group that showed a penetrating or profound distal sartorius relation (r = 0.50; *P* = 0.024) presented with moderate correlation, while the risk groups that showed a subsartorial course (r = 0.41; *P* = 0.069) and a crossing medial femoral epicondyle relation (r = 0.46; *P* = 0.039) presented with low correlation to the site of IB emergence (IBSN vs. IBFN) (Fig. 5).

Gender and Side Dependencies

Of the 22 preparations, 9 derived from female specimens and 13 from male specimens, and of the extremities, 12 were on the lower right side while 10

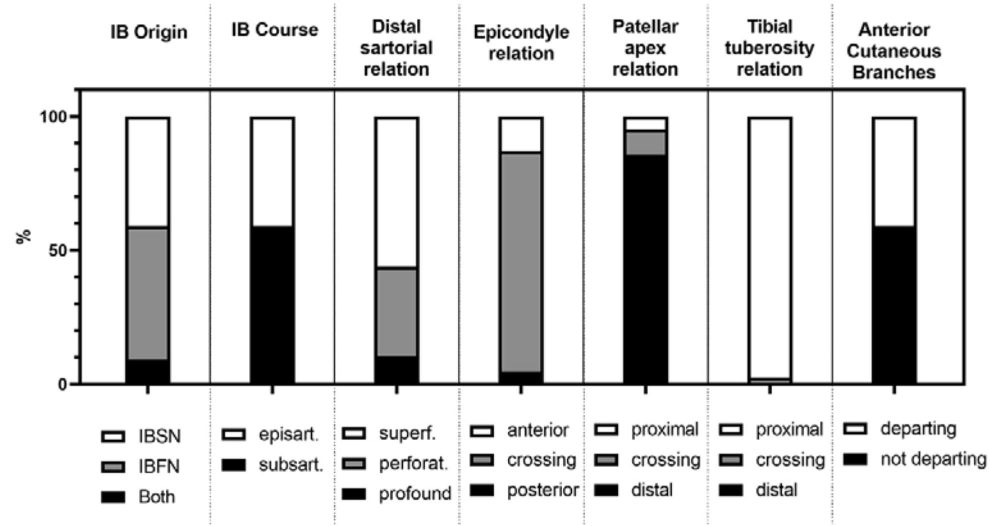

Fig. 2. ***Infrapatellar nervous branch emergence, relation, and course.***
IB: infrapatellar branch/es; IBSN: infrapatellar branch of saphenous nerve; IBFN: infrapatellar branch of femoral nerve; episart: episartorial; subsart: subsartorial; superf: superficial.

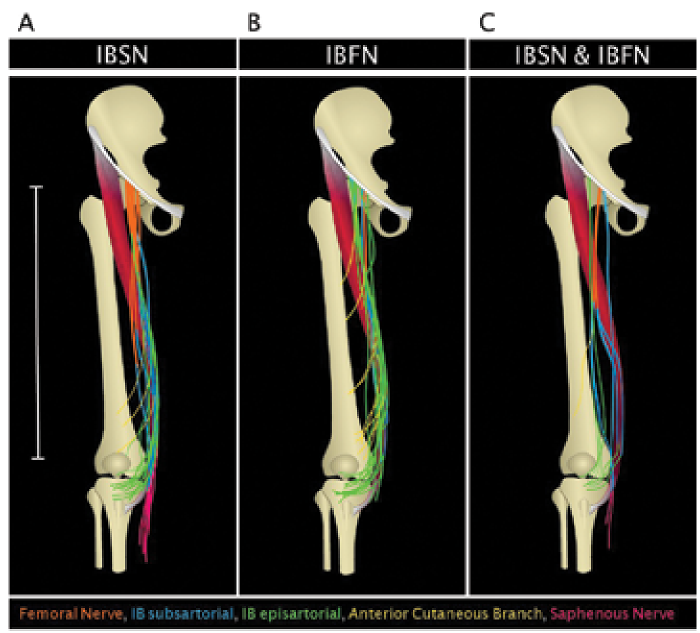

Fig. 3. ***Summative courses of variant IB innervation projected on a right lower limb model: (A) frequent distal division height, subsartorial course, less frequent departing anterior cutaneous branches or superficial distal sartorial relation; (B) frequent proximal division height, episartorial course, departure of anterior cutaneous branches and superficial distal sartorial relation; (C) combined emergence from saphenous and femoral nerve in each specimen. The reference line (middle of inguinal ligament to medial femoral epicondyle) was used to provide the overlay.***
IB: infrapatellar branch; IBSN: infrapatellar branch emerging from saphenous nerve; IBFN: infrapatellar branch emerging from femoral nerve.

were on the lower left side. There was no significant dependency (calculated with Fisher's exact test) between the site of IB emergence and the side (IBSN P = 1; IBFN P = 0.67; IBSN and IBFN P = 0.195) or the gender (IBSN P = 0.384; IBFN P = 0.387; IBSN and IBFN P = 1; Fig. 6). Furthermore, neither the gender nor the side presented a significant variation of means for the number of branches or divisions or the division height of the IBs (Supplemental Table 4).

Discussion

In this anatomical study, the variable origins and courses of the IBs were identified and described. Infrapatellar innervation may be provided by a branch

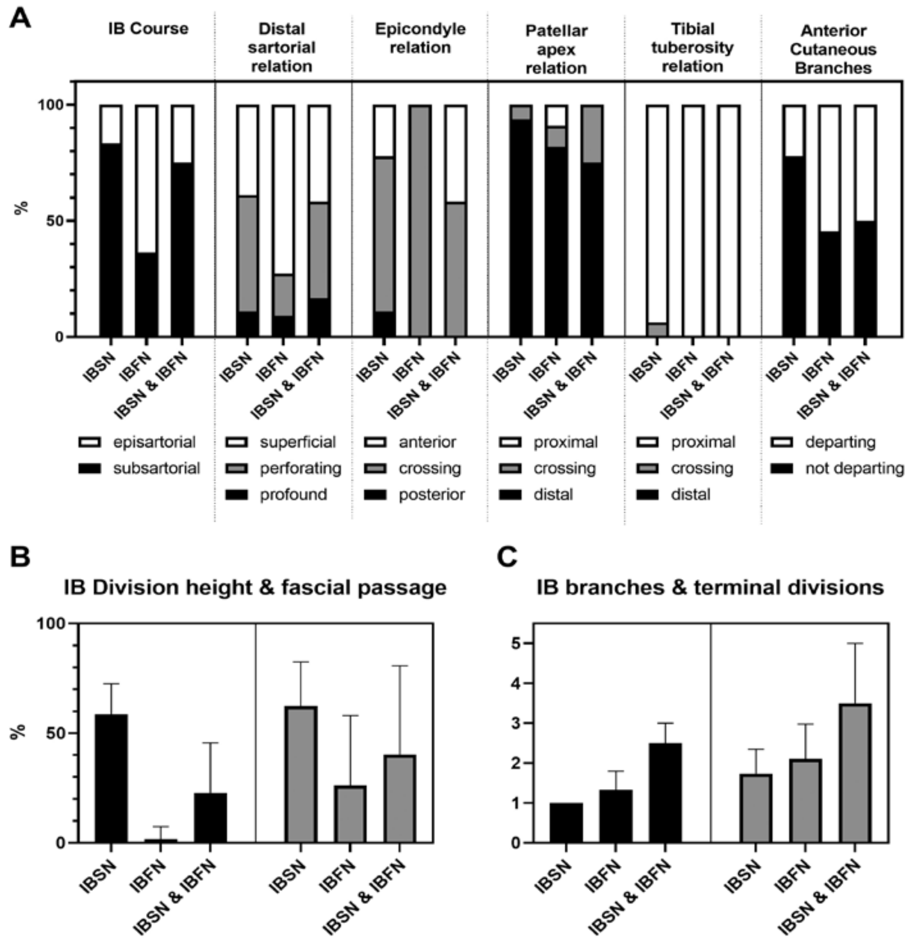

Fig. 4. *Relations of variant infrapatellar branch emergence: (A) intra ratios of anatomical variations within each group (IBSN n = 9, IBFN n = 11, IBSN and IBFN n = 2); (B) IB division height & fascial passage (mean + SD); (C) IB branches and terminal divisions (mean + SD).*
IB: infrapatellar branch; IBSN: infrapatellar branch of saphenous nerve; IBFN: infrapatellar branch of femoral nerve.

originating from either the saphenous nerve or the femoral nerve, or by a combination of branches from both nerves. This branching pattern and the nerves' respective course then determine the clinical risk for infrapatellar neuropathy. While innervation from the IBSN may lead to compression at the subsartorial course, distal sartorial penetration, and the crossing of the medial femoral epicondyle, innervation from the IBFN carries reduced anatomical risk for infrapatellar neuropathy.

Rationale for Alternating Emergence

The cutaneous innervation pattern is a highly variant system that depends on embryological development. The cutaneous innervation of the anterior knee region is supplied exclusively by the lumbar plexus's spinal segments L3 and L4 through a complementary pattern that runs among the anterior cutaneous femoral branches proximally, the IBSN distally, the lateral femoral cutaneous nerve laterally, and the branches of the common peroneal nerve both laterally and distally (19). In some cases, a distribution of the obturator nerve to the cutaneous innervation and knee joint can be found (43). This complementary innervation pattern forms communicating anastomoses among its nerves, composing the infrapatellar plexus (19,38,44).

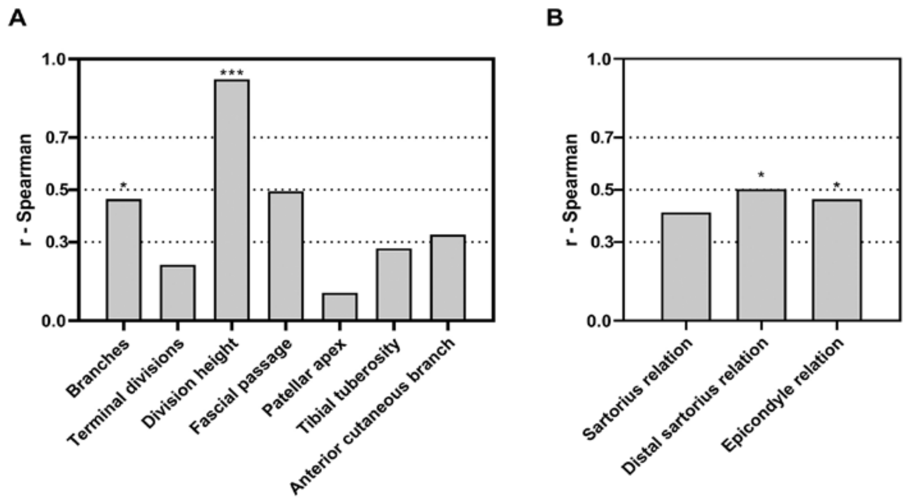

Fig. 5. *Correlation of infrapatellar branch origin to anatomical relations: Spearman correlation coefficient r in absolute values: r-values are considered weak if below 0.3, low if between 0.3 and 0.5, moderate if between 0.5 and 0.7, and strong if between 0.7 and 1.0. Data on innervation by saphenous and femoral nerve combined are excluded. (A) Correlation of nerve origin (infrapatellar branch of saphenous or femoral nerve origin) to anatomical variations (IBSN vs. IBFN, exclusion of combined innervation); (B) Correlation of nerve origin (infrapatellar branch of saphenous or femoral nerve origin) to risk groups: sartorius relation (subsartorial), distal sartorius relation (penetrating, profound), epicondyle relation (crossing) (IBSN vs. IBFN, exclusion of combined innervation).*

IB: infrapatellar branch; IBSN: infrapatellar branch of saphenous nerve; IBFN: infrapatellar branch of femoral nerve.

*P < 0.05; **P < 0.01; ***P < 0.001.

Many reports on infrapatellar innervation focus on the variant course of the IBSN and its implications for knee surgery without considering alternative innervation patterns (6,30,31,38,39,45-47). However, some anatomical investigations report an inconsistent prevalence of the IBSN at various anatomical levels without providing the alternating innervating nerve (17,48). To our knowledge, among numerous anatomy textbooks, only an applied anatomy book from 1972 (19) reports alternate innervation of the infrapatellar region through either a branch of the saphenous nerve or a direct branch of the femoral nerve. The authors of this book describe the distribution of the infrapatellar innervation as 1) sole innervation through the IBSN in 34% of cases, 2) sole innervation through the IBFN in 28% of cases, and 3) combined innervation through the IBSN and IBFN in 38% of cases (19), a distribution that has not been considered in anatomical textbooks. Individual findings of femoral infrapatellar innervation have again indicated variation (6,42). Only Mochizuki et al (8), in their investigation of 51 lower extremities, confirmed the complementary distribution and a broad transitional zone between the infrapatellar branches of the femoral nerve and saphenous nerve.

Despite clear evidence of alternative IB emergence—namely, the limited prevalence of the IBSN and reports of femoral emergence—most studies that have investigated the IB's course for its clinical risk of IB lesion have not followed these findings. Similarly, the unison presentation used in anatomy textbooks, which have adopted descriptions of the IB without re-examining them, limits clinicians' basic anatomical knowledge and thus understanding of infrapatellar neuropathy.

Clinical Implications

Predilection Sites of IB Compression

The course through the adductor or Hunter's canal, which is described as a risk site for compression of the IB (5,40), is primarily relevant to the IBSN. We found the course to be subsartorial in 83.88% of those cases. By contrast, in the IBFN variation, the course was primarily episartorial, at 63.64% (Fig. 7, Marking 1). The penetration of the sartorius muscle and its tendon appears to be an origin-dependent risk factor for IB compression, since sartorial penetration occurred in 50% of the IBSN cases, 18.18% of the IBFN cases, and 41.67% of the combined-emergence cases in our data. The medial

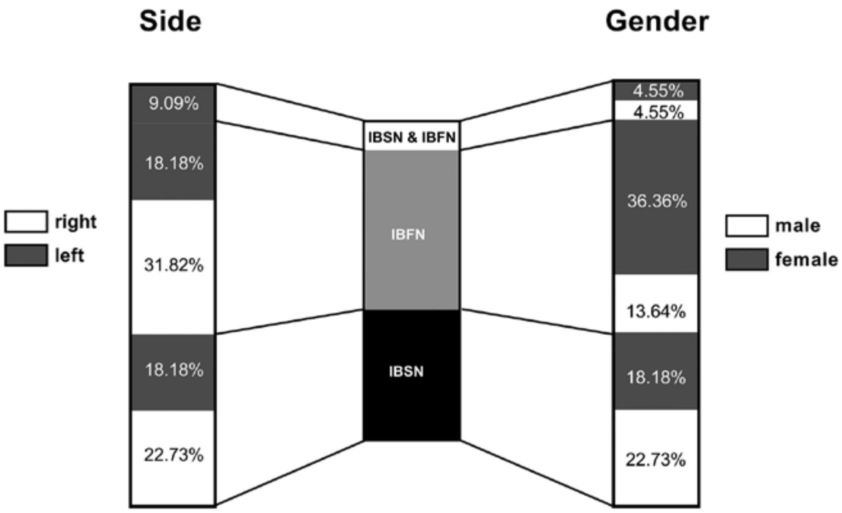

Fig. 6. *Gender and side dependencies: The infrapatellar branch emergence had no significant dependency on the side or gender.* IBSN: infrapatellar branch of saphenous nerve; IBFN: infrapatellar branch of femoral nerve

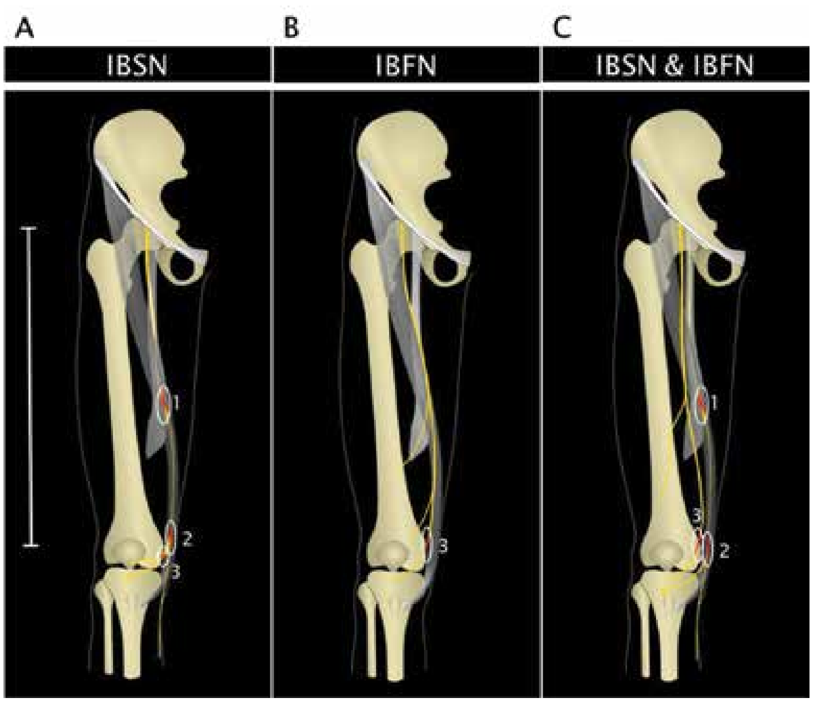

Fig. 7. *Anatomical predilection sites of IB compression: Identified anatomical risk sites were the subsartorial course (1), the perforating or profound course at the distal sartorius (2), and the crossing of the medial femoral epicondyle (3). A) The IBSN had a subsartorial course through the adductor canal in the highest percentage of cases (83.88%), perforated the sartorius muscle in 50% of cases, and crossed the medial femoral epicondyle in 66.67% of cases, while in 77.78% of cases, no anterior cutaneous branches departed. B) The IBFN was episartorial in 63.64% of cases, traversed the sartorius muscle superficially in 72.73% cases, and crossed the medial femoral epicondyle in 100% of cases, while anterior cutaneous branches departed in 54.55% of cases. C) Combined innervation by the IBSN and IBFN took a subsartorial course in 75% in cases, perforated the sartorius muscle in 41.67% of cases, and crossed the medial femoral epicondyle in 58.33% of cases, while anterior cutaneous branches were involved in 50% of cases. The reference line (from the middle of the inguinal ligament to the medial femoral epicondyle) was used to depict the nerve course in relation to the landmarks of the anatomical specimen.* IB: infrapatellar branch; IBSN: infrapatellar branch of the saphenous nerve; IBFN: infrapatellar branch of the femoral nerve.

femoral epicondyle is, in our data, a comparable predilection site of IB compression, since 82.6% of all IBs crossed it independently of neural origin (Fig. 7, Marking 3).

Implications for Diagnostic Workflow

When taking the histories of and conducting physical examinations on patients with infrapatellar neuropathy, physicians should know about the alternating innervation patterns and therefore consider pain or altered sensations (an-, hyp-, dys-, or para-esthesia) in the femoral triangle and the anterior thigh region as indications that the femoral nerve is involved. In cases of IB emergence from the femoral nerve (Table 1), traumatological or iatrogenic injuries to the inguinal region may elicit pain in the infrapatellar region. If the patient has anterior knee pain, careful palpation should include not only the knee and sartorial region but also the groin and femoral triangle, where careful percussion of pain trigger points may elicit the Hoffmann-Tinel sign, with radiation to the anterior knee aspect in IBFN course types. The origin of the IB's emergence may be detected clinically by applying von Frey filament testing to determine the region of the altered sensation. Furthermore, the reverse Lasègue's sign (triggering pain in the thigh by prone hip extension) may be positive for patients whose IBs have emerged in the femoral nerve, while pain triggered after additional knee flexion may indicate a classic saphenous nerve origin for the IB (10,49). Also, electrodiagnostic examinations, which are already utilized for diagnosing infrapatellar neuropathy (50-53), may facilitate differentiation between IBSN and IBFN cases (Table 1).

Palpation of the anatomical predilection sites (adductor canal, medial femoral epicondyle, and sartorius insertion) might trigger pain and indicate an entrapment syndrome of the IB, in which surgical nerve translocation or neurolysis may result in pain relief (3). High-resolution ultrasonography (US) can be utilized by an experienced examiner to identify the location and course of the nerve lesion, marked by swelling, hourglass phenomena (thinning at the site of lesion accompanied by a proximal and distal intraneural edema), neuroma, or disruption. US imaging further shows the topography and blood flow of the adjacent tissue. With high-frequency US, 86% to 100% of the branches may be identified, providing high diagnostic sensitivity (54). When used for interventions, US visualizes the exact localization of a neuroma before removal or imaging-guided nerve blockage (2,17,55,56). The use of the adductor canal block for diagnosis or anesthesia during anterior knee interventions was investigated by Anagnostopoulou et al (1), who stated that the IB always ran within the adductor canal. This observation must be reconsidered in view of the IB's alternative episartorial course and demonstrated possible emergence from the femoral nerve (Table 2).

Implications for Treatment

When physicians treat anterior knee pain conditions, especially infrapatellar neuropathies, the alternative innervation patterns and variant IB courses must be considered. Surgical exploration of the adductor canal may be unsuccessful in episartorial nerve courses that arise mainly in the IBFN innervation type. Innervation of the anterior knee region is highly complementary, and the expression of a classic IBSN course may not exclude the presence of alternative nerve courses, such as those found in combined-IB innervation. To avoid surgical exploration or therapeutic infiltration of a nerve that innervates the painful region but does not cause the pain, identifying the pathophysiological correlate is crucial. Furthermore, differential diagnosis must be conducted to exclude pathologies involving the musculoskeletal system of the knee, such as knee-joint pathologies, meniscopathies, sartorius tendinitis, and pes anserinus bursitis (3,10). If infrapatellar neuropathy is the likeliest clinical diagnosis but physical examination and imaging techniques fail to distinguish the lesioned nerve, diagnostic infiltration by local anesthetics and corticosteroids can be effective. In addition, the latter technique is assumed to stop the spontaneous activity of injured C-fibers and therefore the pain cycle in chronic compressions (53).

Limitations

Even the limited number of specimens in this study

Table 1. *Clinical discrimination of infrapatellar innervation in infrapatellar neuropathy.*

Sign	Saphenous type	Femoral type
Trauma site	Knee, adductor canal	Knee, inguinal region
Pain, altered sensation, radiation	Medial lower leg	Femoral triangle,anterior thigh
Pain triggering	Knee flexion	Reverse Lasègue's sign
Electroneurography	Saphenous nerve	Femoral nerve
Sonography	Saphenous nerve	Femoral nerve
Diagnostic nerve blockage	Saphenous nerve	Femoral nerve

Table 2. *Diagnostic signs of infrapatellar neuropathy.*

Diagnostic Signs of Infrapatellar Neuropathy		
History	Onset	Knee trauma, knee surgery
	Quality	Neuropathic pain (burning, stinging), Altered sensation (an-, hyp-, par-, or dysesthesia)
	Severity	Visual analog scale 1-10
	Radiation	Thigh, groin, hip, femoral triangle, lower leg
	Temporal progression	Acute-subacute (trauma, iatrogenic), chronic (compression syndrome)
	Provocation, palliation	Knee flexion/extension, kneeling
Examination	Sensation	Hofmann-Tinel sign, Von-Frey filament testing, reverse Lasègue's sign
	Entrapment points	Adductor canal, medial femoral epicondyle, sartorius insertion
	Pain triggering	Reverse Lasègue's sign, knee flexion
Apparative diagnostics	Electroneurography	Reduced somatosensory evoked potentials
	Sonography	Nerve lesion, hourglass phenomena, neuroma

may demonstrate a clear anatomical variation that has been overlooked by replicated textbook descriptions. For a broad inferential analysis, a larger sample size and a cross section of diverse ethnicities are required. Furthermore, the relation to the anatomical landmarks was observed only in extended knees. Future studies are necessary to assess the influence of knee flexion and to observe the effects within a larger sample size.

Conclusion

The numerous underlying pathoethiologies and varying clinical presentation of the IB challenge the clinician in finding the correct diagnosis and providing sufficient therapy. Here, we provide an extensive description of the anatomical variations of infrapatellar innervation, the risk they pose of causing compression syndromes, and those variations' clinical implications for diagnostic and therapeutic measures.

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Supplemental Table 1. ***Anthropometrical measurements: standardized measurements with bone landmarks for reconstruction in computational modeling and relative interspecimen comparison.***

Anthropometrical Measurements			
Origin	**Fine**	**Mean**	**Range**
Major femoral trochanter	Lateral joint line	374.5 ± 42.1 mm	289 - 456 mm
Anterior superior iliac spine	Medial joint line	474.5 ± 50.4 mm	351 - 543 mm
Anterior superior iliac spine	Symphysis	169.0 ± 22.1 mm	124 - 213 mm
Middle of inguinal ligament	Patellar apex	442.7 ± 48.4 mm	336 - 504 mm
Patellar apex	Tibial tuberosity	42.1 ± 9.1 mm	30 - 60 mm
Lateral femoral condyle	Medial femoral condyle	93.7 ± 14.1 mm	64 - 140 mm
Symphysis	Medial femoral epicondyle	371.7 ± 336.9 mm	301 - 438 mm

Supplemental Table 2. ***Course of the infrapatellar nervous branch: single-branch analysis—the sum of all branches of a specimen equals 1. Therefore, if a specimen has 2 branches, their value is 0.5 each; absolute numbers in brackets.***

Course of the Infrapatellar Nervous Branch			
Origin	saphenous nerve	femoral nerve	both
	40.9 % (9)	50% (11)	9.1 % (2)
Course	episartorial	subsartorial	
	40.9 % (9)	59.1 % (13)	
Distal sartorius relation	superficial	perforating	profound
	56.1 % (12.3)	33.3 % (7.3)	10.6 % (2.3)
Medial femoral epicondyle	anterior	crossing	posterior
	12.9 % (2.8)	82.6 % (18.2)	4.5 % (1)
Patellar apex	proximal	crossing	distal
	4.5% (1)	11.4 % (2.5)	84.1 % (18.5)
Tibial tuberosity	proximal	crossing	distal
	97.6 % (20.5)	2.4 % (0.5)	0
Anterior cutaneous branches	departing	not departing	
	40.9 % (9)	59.1 % (13)	

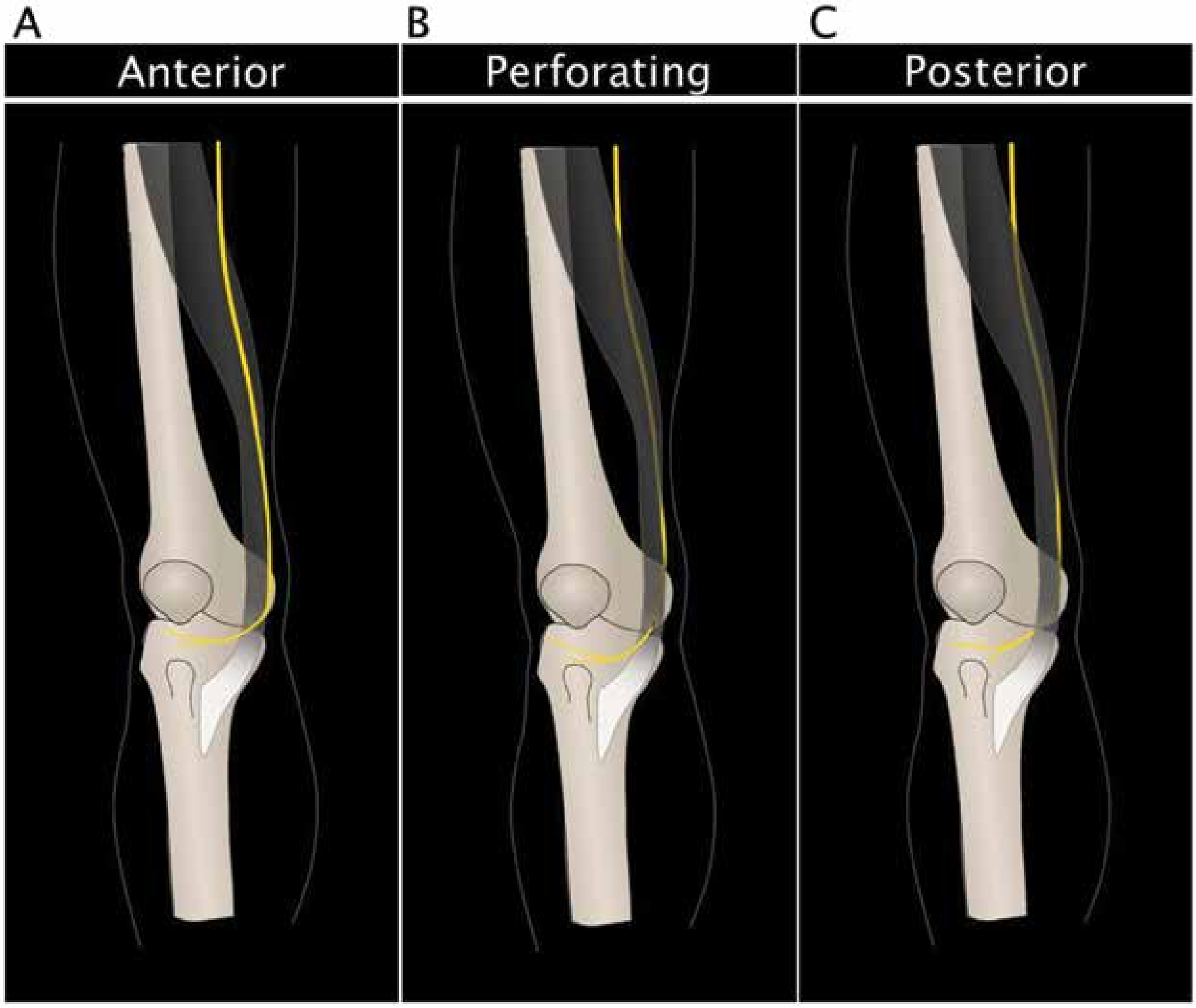
Supplemental Table 3. ***Percent of nervous branches per group, absolute numbers of branches per subjects as parenthetical numbers.***

Relations of the Infrapatellar Nervous Branch As They Pertain to Nerve Origin				
		IBSN	**IBFN**	**IBSN and IBFN**
Course				
	Episartorial	16.67% (1.5)	63.64% (7)	25.00% (0.5)
	Subsartorial	83.33% (7.5)	36.36% (4)	75.00% (1.5)
Distal sartorial relation				
	Superficial	38.89% (3.5)	72.73% (8)	41.67% (0.83)
	Perforating	50.00% (4.5)	18.18% (2)	41.67% (0.83)
	Posterior	11.11% (1)	9.09% (1)	16.67% (0.33)
Medial femoral epicondyle relation				
	Anterior	22.22% (2)	0.00%	41.67% (0.83)
	Crossing	66.67% (6)	100.00% (11)	58.33% (1.17)
	Posterior	11.11% (1)	0.00%	0.00%
Patellar apex relation				
	Proximal	0.00%	9.09% (1)	0.00%
	Crossing	6.25% (0.5)	9.09% (1)	25.00% (0.5)
	Distal	93.75% (7.5)	81.82% (9)	75.00% (1.5)
Tibial tuberosity relation				
	Proximal	93.75% (7.5)	100.00% (11)	100.00% (2)
	Crossing	6.25% (0.5)	0.00%	0.00%
	Distal	0.00%	0.00%	0.00%
Anterior cutaneous branch				
	Departing	22.22% (2)	54.55% (6)	50% (1)
	Not departing	77.78% (7)	45.45% (5)	50% (1)

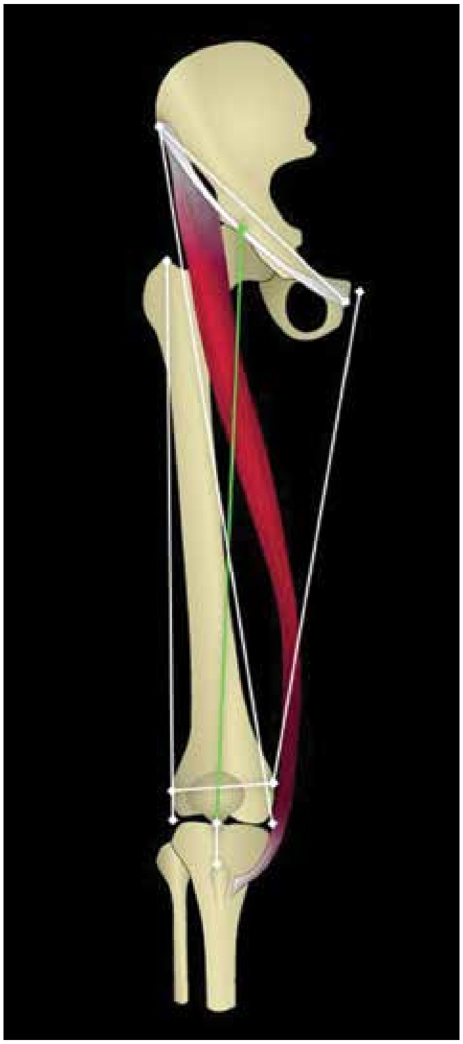
Supplemental Table 4. ***Gender- and side-specific dependencies: unpaired Student's t-test; nerve measurements normalized to the distance between the middle of the patellar ligament and the patellar apex.***

Gender- and Side-Specific Dependencies					
		Branches	**Divisions**	**Relative SN Perforation Height**	**Relative IB Division Height**
Gender	mean difference	0.1	0.11	-7%	-13%
	SEM	0.24	0.44	0.15	0.13
	significance	0.678	0.805	0.646	0.334
Side	mean difference	-0.23	-0.65	-0.19	-0.12
	SEM	0.24	0.41	0.15	0.13
	significance	0.334	0.132	0.224	0.358

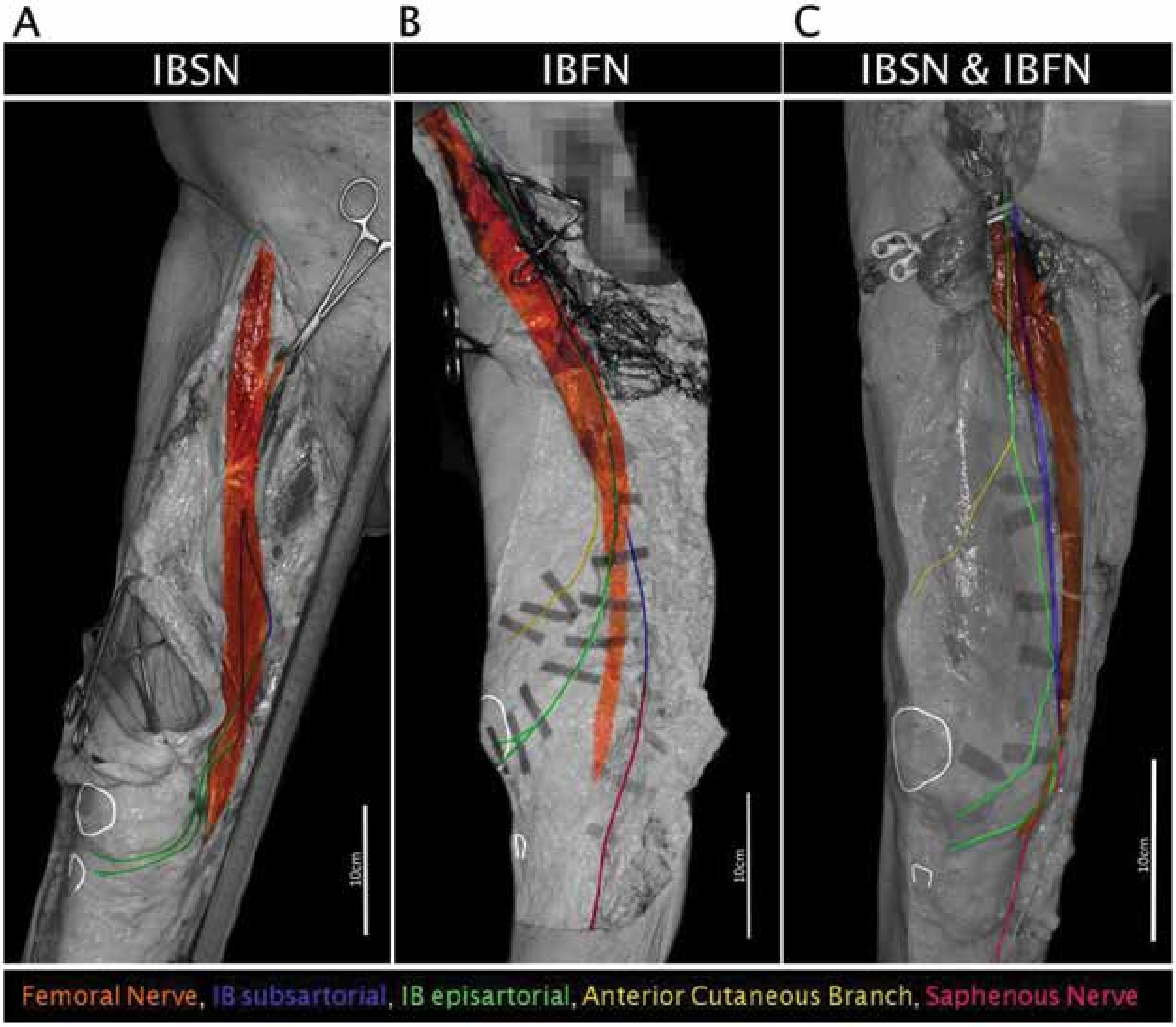
IB: infrapatellar branch; IBSN: infrapatellar branch emergence from saphenous nerve; IBFN: infrapatellar branch emergence from femoral nerve; SN: saphenous nerve; SEM: standard error of mean.



Supplemental Fig. 1. *Variation of infrapatellar branch course: The infrapatellar branch varies in its relation to the sartorius muscle (depicted transparently) either in an anterior (A), perforating (B) or posterior (C) manner.*



Supplemental Fig. 2.
Computational modelling: Blank anatomical model of a right lower limb, sartorius muscle and illustrated measures (white lines) for data transfer. The course of the infrapatellar branch was transposed to the scaled measures in relation to the middle of the inguinal ligament to the patellar apex (green). Measures from proximal to distal: Inguinal ligament, anterior superior iliac spine to medial joint line, Middle of patellar ligament to patellar apex, symphysis to medial femoral epicondyle, major femoral trochanter to lateral joint line, condyle width, patellar apex to tibial tuberosity. [print in colour]



Supplemental Fig. 3. *Exemplary photographs of variant infrapatellar branch (IB) emergence, patellar apex and tibial tuberosity projections marked in white: (A) infrapatellar branch emerging from saphenous nerve (IBSN): 2 IB in subsartorial course emerging from saphenous nerve, superficial and perforating relation to distal sartorius and 3 terminal divisions (B) infrapatellar branch emerging from femoral nerve (IBFN): IB with episartorial course, emerging from femoral nerve under inguinal ligament, departing anterior cutaneous branch, superficial distal sartorial relation, 2 terminal divisions and no relation to saphenous nerve (C) combined emergence from saphenous & femoral nerve: first IB with episartorial course emerging under the inguinal ligament form the femoral nerve, departing anterior cutaneous branch and superficial distal sartorial relation, second IB with subsartorial course from saphenous nerve, perforating the sartorial muscle.*