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ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TECHNIQUES

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Anatomical bases for minimizing sensory disturbance after arthroscopically-assisted anterior cruciate ligament reconstruction using medial hamstring tendons

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Abstract The aim of this study was to improve surgical techniques for arthroscopically-assisted anterior cruciate ligament (ACL) reconstruction with minimal sensory disturbance in the infrapatellar and anterior lower leg regions. Thirteen patients with sensory disturbance were examined neurologically, and 51 lower limbs of 26 adult cadavers were examined anatomically to investigate the nerve branches supplying the regions. The region of sensory disturbance was supplied by branches of the medial femoral cutaneous nerve and the saphenous nerve, and the nerves showed a complementary distribution area. After detailed investigation of the positional relationships between the nerve branches and the skin incisions of the operative procedure, it was found that at least one branch of both nerves ran across the longitudinal skin incision (80%) for tendon harvest in the above-mentioned reconstruction. The complicated anatomic variations of the nerve branches preclude their absolute avoidance in any surgical incision, and a completely safe zone could not be found in the present study. However, an oblique incision for the tendon harvest rather than the typical longitudinal incision should be considered to minimize the sensory disturbance.

Electronic Supplementary Material Supplementary material is available for this article if you access the article at http://dx.doi.org/10.1007/s00276-003-0130-1. A link in the frame on the left of that page takes you directly to the supplementary material.

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Bases anatomiques de la diminution des troubles sensitifs après reconstruction chirurgicale du ligament croisé antérieur par ligamentoplastie aux tendons ischio-jambiers sous arthroscopie

Résumé L'objectif de cette étude était d'améliorer les techniques chirurgicales assistées par arthroscopie pour la reconstruction du ligament croisé antérieur, en diminuant les troubles sensitifs de la région infra-patellaire ou de la jambe sous-jacente. 13 patients avec des troubles sensitifs ont fait l'objet d'un examen neurologique, et 51 membres inférieurs de 26 cadavres adultes ont été étudiés pour préciser les rameaux nerveux responsables des territoires sensitifs. Les troubles sensitifs étaient présents dans des territoires innervés par des branches du nerf cutané fémoral médial et du nerf saphène, et les nerfs montraient des aires de distribution complémentaires. Après une étude détaillée des rapports topographiques entre les rameaux nerveux et les incisions cutanées de la technique opératoire, il apparaissait qu'au moins une branche de chaque nerf traversait l'incision longitudinale (81%) pour le prélèvement des tendons. Les variations anatomiques compliquées des branches nerveuses ne permettaient pas d'éviter totalement leur lésion, quelle que soit l'incision chirurgicale, et une zone de sécurité complète n'a pu pu être mise en évidence dans cette étude. Cependant, une incision oblique pour le prélèvement tendineux plutôt que l'incision longitudinale typique semble pouvoir limiter la survenue de troubles sensitifs.

Keywords ACL reconstruction · Medial hamstring tendons · Sensory disturbance · Saphenous nerve · Medial femoral cutaneous nerve

Introduction

Recently the arthroscopically assisted anterior cruciate ligament (ACL) reconstruction technique has taken the place of open surgical techniques. The current inside-out technique allows the procedure to be performed with two small horizontal skin incisions for the arthroscopy portals and one longitudinal skin incision for tendon harvest of the semitendinosus muscle and/or the gracilis muscle.

The semitendinosus and gracilis tendons are commonly used as autografts in ligamentous reconstructions of the knee [6, 8, 13, 22, 23, 28, 29, 33, 39], and the bone–patellar tendon–bone graft has also been widely accepted as an autograft in ACL reconstruction [16, 18, 36]. Complications associated with ACL reconstruction using medial hamstring tendons are considered to be less common than those associated with bone–patellar tendon–bone graft. Harvesting a bone–patellar tendon–bone includes risks of patellar fracture, patellar tendinitis, anterior knee pain and sensory disturbance [7, 14, 19, 30, 32, 37]. In arthroscopically-assisted ACL reconstruction using medial hamstring tendons, there are few reports of complications. Pagnani et al. [29] pointed out the risk of the saphenous nerve damage by harvesting medial hamstring tendons at the pes anserinus, and in fact sensory disturbance has been recently reported [5, 27].

In our previous clinical studies [27], even when the skin incision was small, we still frequently observed regions of sensory disturbance in the anterior lower leg. Some new techniques in the bone–patellar tendon–bone autograft operative procedure using small skin incisions have reduced the sensory disturbance of the anterior knee region [18, 36]. According to the patient questionnaires of our previous clinical studies [27], the sensory disturbance in the anterior lower leg region does not severely affect daily living compared with the sensory disturbance after reconstruction using the bone–patellar tendon autograft; however, it is necessary to make efforts to minimize such complications. The aims of the present study were: (1) to investigate the precise area of the region of sensory disturbance, (2) to clarify anatomic details of the nerve branches distributed to the region of sensory disturbance, and (3) to provide a comprehensive anatomic basis to facilitate development of improved techniques to reduce sensory disturbance.

The branches which were distributed to the patellar region originated from the intermediate femoral cutaneous nerve proximally, the medial cutaneous femoral nerve medially and distally, and the branches of the lateral sural nerve laterally [4]. The distribution area of the medial and intermediate femoral cutaneous nerves [4] is considered to be similar to that of the anterior cutaneous branch of the femoral nerve [9]. There have been numerous reports on the nerve distribution patterns of the infrapatellar regions [2, 3, 11, 12, 15, 17, 26, 31, 34, 35, 38]. It is well known that the infrapatellar region and the anterior lower leg region are distributed by both the medial cutaneous nerve of the femoral nerve and the infrapatellar branch of the saphenous nerve [31, 34, 38]. von Lanz and Wachsmuth [38] reported the frequency of the main distributing nerves of the infrapatellar region: (1) the anterior cutaneous branch of the femoral nerve and the infrapatellar branch of the saphenous nerve (38%), (2) the anterior cutaneous branch of the femoral nerve (28%), and (3) the infrapatellar branch of the saphenous nerve (34%). The distribution of the anterior cutaneous branch of the femoral nerve and that of the infrapatellar branch of the saphenous nerve are in close proximity; further, there are many connections among peripheral branches [4, 9, 24]. In this study, we applied the description and terminology of the nerves to the infrapatellar region and the anterior lower leg region based on the classification in *Gray's Anatomy* as follows [9]. The saphenous nerve descends laterally along the femoral artery to enter the adductor canal, and leaves the artery at the distal end of the canal to proceed vertically along the medial side of the knee and runs between the sartorius and gracilis tendons. The medial femoral cutaneous nerve originates from the anterior cutaneous branches of the femoral nerve. The medial femoral cutaneous nerve runs laterally to the femoral artery, and crosses anterior to the artery at the apex of the femoral triangle to be distributed to the anteromedial thigh and the infrapatellar region. Branches of the medial femoral cutaneous nerve and the infrapatellar branch of the saphenous nerve connect with each other [31, 34, 37, 38], and form the subsartorial plexus in the infrapatellar region [4, 9].

Materials and methods

Operative procedure

We used three skin incisions for the ACL reconstruction. Two horizontal incisions were used for the arthroscopy portals, and one longitudinal incision (2.5–3 cm) at the pes anserinus was used for the tendon harvest and the tibial drill holes (Fig. 1). The medial hamstring tendons were harvested using a double open-looped tendon stripper (3M, St. Paul, Minn.) as described previously [24]. In the past, we harvested both tendons of the semitendinosus muscle and the gracilis muscle. However, we now harvest only the tendon of the semitendinosus muscle, because in most cases the semitendinosus tendon is long enough for the graft. Our tendon harvesting technique follows that described in previous reports with the knee flexed and hip externally rotated [10, 25, 29]. The longitudinal incision was also used for subsequent intra-articular placement of a graft through a tibial drill hole. EndoButton (Smith & Nephew Endoscopy, Andover, Mass.) was used for femoral fixation.

Clinical examination

A total of 103 patients (49 males, 54 females) who had arthroscopically assisted ACL reconstructions using the medial hamstring tendons in Department of Orthopedics, University Hospital of Tokyo Medical and Dental University, from 1997 to 1999 were clinically examined to investigate the frequencies and areas of sensory disturbance. The average age at operation was 28.8 years (range 17–53 years). The clinical examination was on average 13.3 months (range 6–18 months) after the operation. We randomly selected 13 patients with sensory disturbance (5 males,

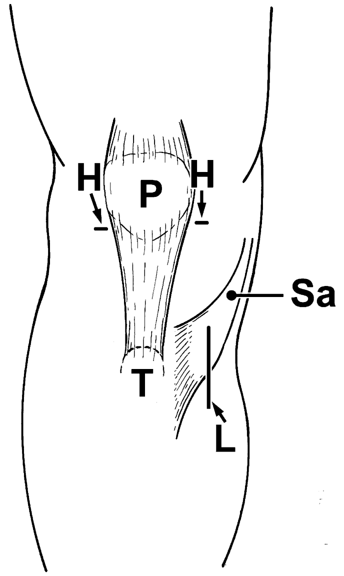

Fig. 1 Positions of the skin incisions. *H*, Horizontal skin incision for arthroscopy portal; *L*, longitudinal skin incision for tendon harvest; *P*, patella; *Sa*, sartorius muscle; *T*, tibial tuberosity

8 females; average age 27.6 years), and neurologically examined in detail the regions of sensory disturbance. The regions were marked and recorded by photographs.

Anatomic investigations

Fifty-one lower limbs of 26 adult cadavers (14 males, 12 females) were used in this study. The cadavers were fixed in 8% formalin and preserved in 30% ethanol. During dissection of the patellar, infrapatellar and anterior leg regions, cutaneous branches were carefully dissected, and the fasciae lata and cruris were removed to investigate the origin, course and distribution of the branches. In addition, we investigated the positional relationships between the nerve branches and the longitudinal skin incision of the operative procedure. The region of the longitudinal skin incision was classified into the following four zones: (1) proximal to the incision; (2) proximal half of the incision; (3) distal half of the incision; and (4) distal to the incision. The border between zones 2 and 3 was the intermediate line between the gracilis tendon and the semitendinosus tendon.

Results

Clinical evaluation of sensory disturbance

Sensory disturbance was detected on the anterior surface of the lower leg in 60 of 103 (58%) legs of postoperative patients. The regions of sensory disturbance were of various sizes and shapes. These regions were generally quadrilateral and located lateral to the longitudinal incision for tendon harvest and distal to the horizontal incisions for arthroscopy (Fig. 2). In the detailed neurologic examination, in 8 of 13 legs (62%), the region was very close to the longitudinal incision (Fig. 2A, B, C), and in the other 5 legs (38%) it was relatively distant (Fig. 2D). The region was lower than the superior end of the longitudinal incisions in 12 of 13 legs (92%); however, in one leg (8%) the region was close to the horizontal incisions (Fig. 2C). The region was located in the upper half of the lower leg in 10 legs (77%); however, in three legs (23%) the region was much more widespread (Fig. 2B).

Anatomic study of sensory supply

In the region mediodistal to the patella, the nerve branches pierced the fascia cruris in various patterns and ran on the outer surface of the fascia to supply the skin (Fig. 3). The nerve branches often connected with each other on the outer surface of the fascia. In the regions near the horizontal and longitudinal skin incision lines, the nerve branches ran on the outer surface of the fascia cruris in all legs.

After removal of the fasciae lata and cruris, the origin of the nerve branches was examined. The branches which were distributed to the anterior surface of the lower leg originated from the medial femoral cutaneous nerve proximally and from the saphenous nerve distally. The branches which were distributed to the patellar region originated from the intermediate femoral cutaneous

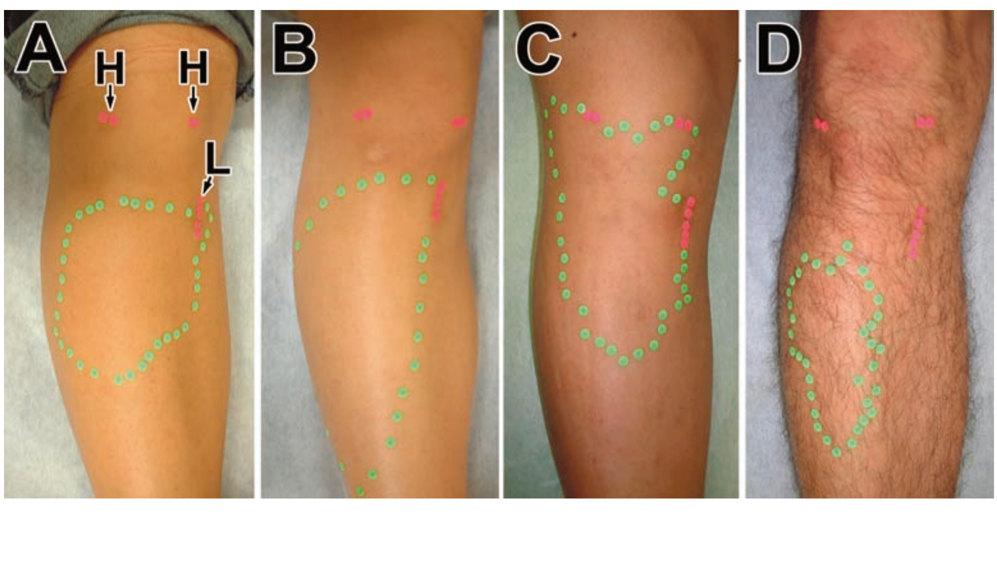

Fig. 2A–D Examples of cases of sensory disturbance in 13 legs. *Red dots* indicate the skin incision line, and *green dots* indicate the sensory disturbance region. **A** Four legs (31%); **B** 3 legs (23%); **C** 1 leg (8%); **D** 5 legs (38%). *H*, Horizontal skin incision for arthroscopy portal; *L*, longitudinal skin incision for tendon harvest

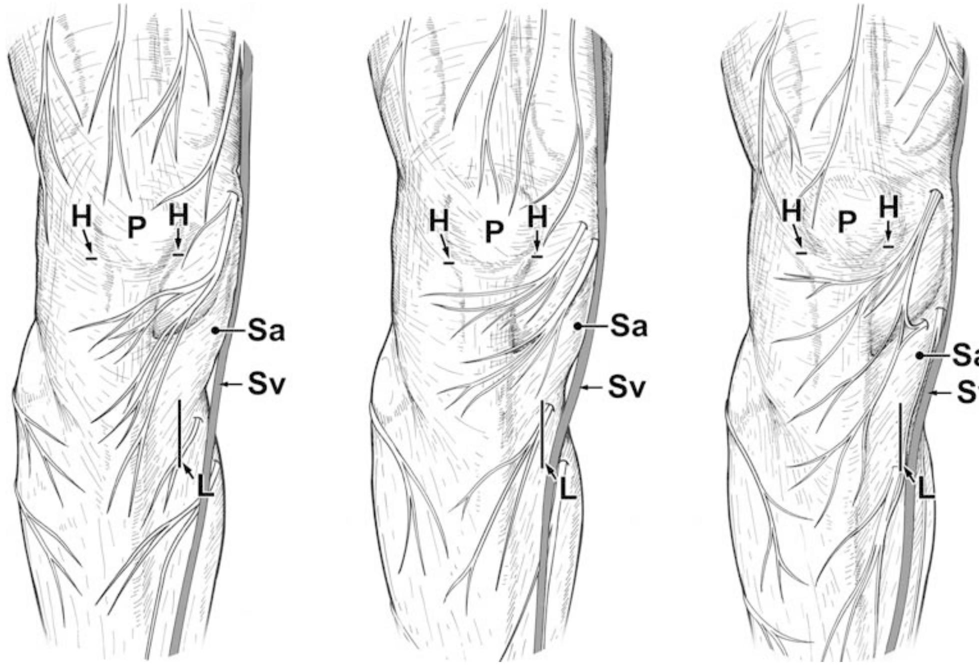

Fig. 3 Examples of the distribution of the nerve branches on the fasciae lata and cruris. The nerve branches connected in various ways in the medial infrapatellar region. Some nerve branches pass through the longitudinal skin incision line. *H*, Horizontal skin incision for arthroscopy portal; *L*, longitudinal skin incision for tendon harvest; *P*, patella; *Sa*, sartorius muscle covered by fasciae; *Sv*, greater saphenous vein

nerve proximally, the medial cutaneous nerve medially and distally, and the branches of the lateral sural nerve laterally. The anterior surface of the lower leg was distributed by branches of the medial femoral cutaneous nerve proximally and by branches of the saphenous nerve distally. In addition, the patellar region was distributed by branches of the intermediate femoral cutaneous nerve superiorly and by branches of the medial femoral cutaneous nerve medially and inferiorly.

According to a comparison of the detailed clinical examinations and the present anatomic findings, the regions of sensory disturbance in the postoperative patients were considered to correspond with the regions supplied by branches of the medial femoral cutaneous and saphenous nerves.

The infrapatellar region and the anterior surface of the lower leg were distributed by branches of the medial femoral cutaneous nerve proximally and those of the saphenous nerve distally (Fig. 4). In 33 of 51 legs (65%; Fig. 4A, B), the infrapatellar branch of the saphenous nerve ran posteriorly to the inferior border of the sartorius muscle. The infrapatellar branch of the saphenous nerve pierced the distal part of the sartorius muscle in 16 of 51 legs (31%; Fig. 4C). In two legs (4%; Fig. 4D), the branch of the saphenous nerve emerged from the anterior border of the sartorius muscle, and ran lateralward horizontally. The infrapatellar region and the anterior region of the lower leg were generally supplied by branches of both the medial femoral cutaneous nerve and the saphenous nerve in various patterns. Branches of these nerves and their connections were distributed to the region around the insertion of the sartorius muscle (Fig. 4B, C). However, branches of the medial femoral cutaneous nerve were also distributed to the anterior surface of the leg in 8 legs (16%; Fig. 4A), and branches of the saphenous nerve were also observed to supply the infrapatellar region in two legs (4%; Fig. 4D). Therefore, the branches of these two nerves showed a complementary distribution, and a broad transitional zone.

In general, the branches in the infrapatellar region ran lateralward horizontally, and the branches in the anterior region of the lower leg ran obliquely laterodistalward. Therefore, the branches located more distal from the patella ran more obliquely laterodistalward.

We investigated the positional relationships between the branches of the saphenous nerve and the line of the longitudinal skin incision (Fig. 5A; Table 1). In two legs (4%), the branches passed superior to the line (zone 1). In 41 of 51 legs (80%), at least one branch of the saphenous nerve or a communicating branch between the saphenous and medial femoral cutaneous nerves ran across the line (zones 2, 3). Although in 10 legs (20%) no branch of the saphenous nerve ran across the line, in these cases branches of the medial femoral cutaneous nerve ran across the line. We divided the line into an upper part (zone 2) and a lower part (zone 3) according to the border between the tendons of the gracilis and semitendinosus muscles. Branches of the saphenous nerve passed through the upper part in 21 of 51 legs (41%), and the lower part in 24 of 51 legs (47%). The branches that ran across the incision line were classified into branches that ran parallel to the tendons of the gracilis and semitendinosus muscles (40 in 66 branches, 61%; Fig. 5B) and those that ran obliquely across these two tendons (26 branches, 39%; Fig. 5C). In the 10 legs in which no saphenous branch crossed the line and the saphenous nerve was only distributed to the region inferior to the line (zone 4), branches of the medial femoral cutaneous nerve were distributed to this region, and they supplied the anterior surface of the lower leg.

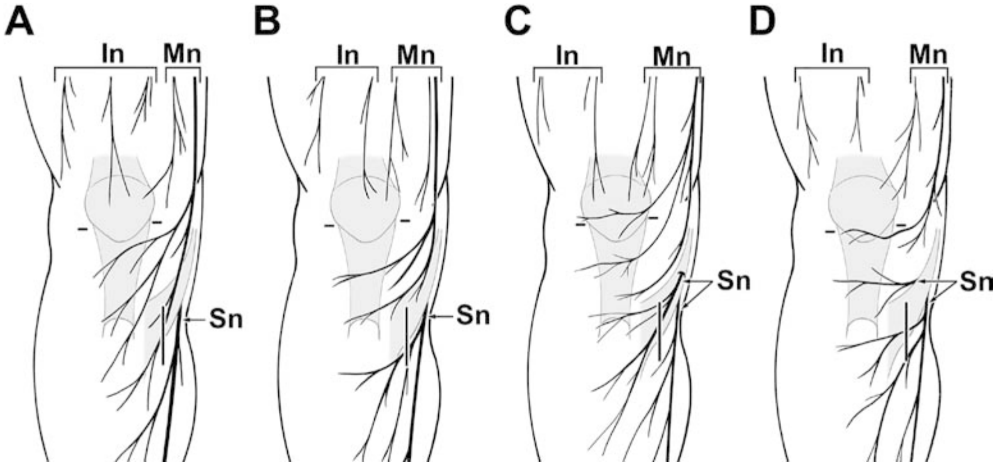

Fig. 4A–D Four patterns of the distribution of the nerve branches based on findings in 51 legs. **A** Branches of the medial femoral cutaneous nerve are distributed to the anterior leg region (8 legs, 16%). **B** Branches of the medial femoral cutaneous nerve are distributed to the infrapatellar region, and branches of the saphenous nerve are distributed to the anterior leg region (25 legs, 49%). **C** Infrapatellar branch of the saphenous nerve pierces the sartorius muscle and is distributed to the infrapatellar region (16 legs, 31%). **D** Infrapatellar branch of the saphenous nerve emerges from the anterior border of the sartorius muscle, and is distributed to the infrapatellar region (2 legs, 4%). *In*, intermediate femoral cutaneous nerve; *Mn*, medial femoral cutaneous nerve; *Sn*, saphenous nerve

In addition, in 4 of these 10 legs the branches of the medial femoral cutaneous nerve ran across the line obliquely. The branches of both the saphenous nerve and the medial femoral cutaneous nerve running near the longitudinal incision (zones 2, 3) in each leg were classified into three types: (1) parallel type (29 in 51 legs, 57%), (2) oblique type (14 legs, 27%) and (3) mixed type (2 legs, 4%). In 6 of 51 legs (12%), no branches ran across the line. Therefore, at least one or more branches of a nerve ran across the line of incision in 45 of 51 legs (88%). The number of saphenous nerve branches which ran across the longitudinal incision (zones 2, 3) was zero (10 in 51 legs, 20%), one (26 legs, 51%), two (13 legs, 25%) or three (2 branches, 4%).

Fig. 5A–C Classifications used in this study regarding the nerve branches passing through the longitudinal skin incision. **A** The region of the longitudinal skin incision is divided into the following four zones: *1*, proximal to the incision; *2*, proximal half of the incision; *3*, distal half of the incision; *4*, distal to the incision. The borderline between zones 2 and 3 is the intermediate line between the gracilis tendon and the semitendinosus tendon. **B** The branches passing through the incision run parallel to the tendons of the gracilis muscle and the semitendinosus muscle (40/66, 61%). **C** The branches run obliquely across both tendons (26/66, 39%). *Gr*, gracilis tendon; *P*, patella; *Sa*, sartorius muscle; *St*, semitendinosus tendon

Discussion

Numerous clinical anatomic studies have discussed the nerve distribution patterns of the infrapatellar region [2, 3, 11, 12, 15, 17, 26, 32, 34]. In most of these studies, the nerve branches supplying the skin of the medial inferior region of the patella are recognized as the infrapatellar branch of the saphenous nerve. However, according to the present study and standard anatomy textbooks [4, 9, 21], branches of the saphenous nerve and the medial femoral cutaneous nerve, which originates from the anterior cutaneous branches of the femoral nerve, are distributed to this region. The two nerves have a complementary distribution, and the branches of the medial femoral cutaneous nerve sometimes extend to the anterior lower leg region. Interestingly, while the two nerves have clearly distinguishable origins, it is very difficult to find the border between their distribution territories due to their numerous connections.

In our hospital, after arthroscopically-assisted ACL reconstruction using medial hamstring tendons, sensory disturbance was observed in 58% of cases. However, to date there are few reports of sensory disturbance in the

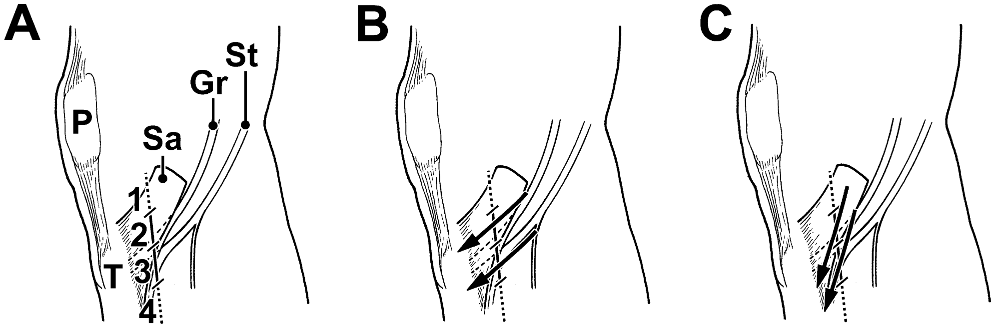

Table 1 Positional relationships between the longitudinal incision and the nerve branches of the medial femoral cutaneous nerve and the saphenous nerve. The zones are defined in Fig. 5A. *M*, Branches of the medial femoral cutaneous nerve mainly pass through the zone; *S*, branches of the saphenous nerve mainly pass through the zone. –, no branch passes through the zone

Type		Zone 1	Zone 2	Zone 3	Zone 4	No. of legs		
Medial femoral cutaneous nerve dominant type	1	M	M	M	S	3 (6%)	4 (8%)	51 (100%)
	2	M	M	–	S	1 (2%)		
Saphenous nerve dominant type	3	M	–	S	S	14 (28%)	41 (80%)	
	4	M	S	–	S	10 (20%)		
	5	M	S	S	S	15 (29%)		
	6	M + S	–	S	S	1 (2%)		
	7	M + S	S	S	S	1 (2%)		
	8	M	–	–	S	6 (12%)		
No. of legs in which the branches of the saphenous nerve pass through each zone		2 (3.9%)	30 (41%)	24 (47%)	51 (100%)			
			45 (88%)					

anterior lower leg region after this operative procedure. According to the present anatomic findings, the region of sensory disturbance corresponds to the distribution area of the branches of the medial femoral cutaneous nerve and the saphenous nerve. During our operative procedure we made three skin incisions: two horizontal incisions for the arthroscopy portals and one longitudinal incision for the harvest of the tendons of the semitendinosus muscle and/or gracilis muscle. On the basis of the detailed clinical investigations and the present nerve distribution findings, the sensory disturbance is considered to be closely related to the skin incisions. Nerve injury due to the horizontal incisions used for arthroscopy portals as well as the related anatomic findings has been reported [26, 35]. In the findings of the clinical examinations, the sensory disturbance region was located in close proximity to the horizontal incisions in only one case (Fig. 6). According to the present anatomic investigations, the branch of the medial femoral cutaneous nerve might have been injured by the anteromedial arthroscopy portal. In this case, the area of sensory disturbance also extended to the lower anterior leg region. Since the infrapatellar branch of the medial femoral cutaneous nerve is distributed to this region in 28% of cases [38], such horizontal skin incisions might cause broad sensory disturbance.

There have been few reports on nerve injuries related to the longitudinal incision for tendon harvest [5]. According to the present anatomic investigations, the line of the longitudinal incision ran across the nerve branches which were distributed to the infrapatellar region and the anterior lower leg region. These branches originated from the medial femoral cutaneous nerve and the saphenous nerve. On the basis of the origin, course and distribution of the nerves, at least one or more branches of the nerve ran across the line of the incision in 88% of cases, and a true safety zone could not be found around the incision area (Fig. 6). The line of the longitudinal incision is directed almost perpendicular to the tendons of the gracilis muscle and the semitendinosus muscle. To avoid nerve injuries, it seems essential to make a shorter incision. However, since the longitudinal incision is also used for making the tibial drill hole for the grafted tendon as well as for the tendon harvest, it must be sufficiently long. It might be preferable to change the direction of the incision for the tendon harvest to an oblique direction, parallel to the tendons in this region, rather than perpendicular to the tendons. In some patients, the region of sensory disturbance is not adjacent to the longitudinal skin incision. These cases might be explained by the various patterns of the connections and the overlapping distribution territories of the saphenous nerve and the medial femoral cutaneous nerve.

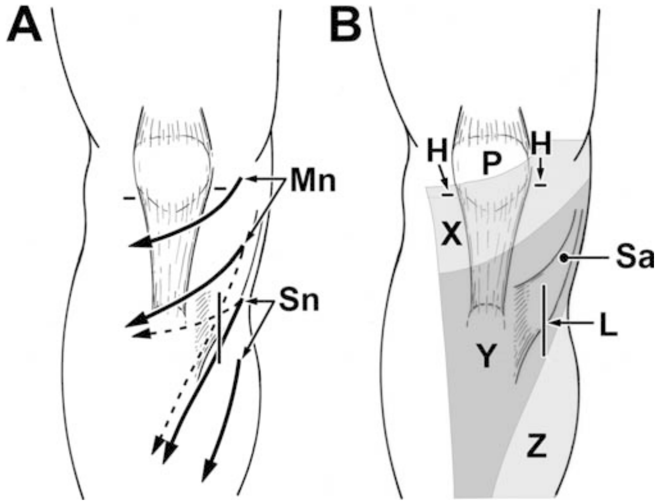

Fig. 6A, B Schematic drawings of the nerve distribution in the infrapatellar region and the anterior leg region. **A** The branches of the medial femoral cutaneous nerve are distributed to the proximal part of the infrapatellar region, and the branches of the saphenous nerve are distributed to the mediodistal part of the anterior leg region. In these two parts, the branches of the medial femoral cutaneous nerve and the saphenous nerve show a compensatory distribution. It is possible for branches of both nerves to pass through the longitudinal skin incision. **B** The regions of the infrapatellar region and the anterior lower leg region are divided into three regions based on the distribution of the nervous branches: *X*, the region distributed by the medial femoral cutaneous nerve; *Y*, transitional zone between the regions *X* and *Z*; *Z*, the region distributed by the saphenous nerve. *H*, Horizontal skin incision for arthroscopy portal; *L*, longitudinal skin incision for tendon harvest; *Mn*, branches of the medial femoral cutaneous nerve; *P*, patella; *Sa*, sartorius muscle; *Sn*, branches of the saphenous nerve

The possibility of nerve injury during harvesting of the semitendinosus tendon with a tendon stripper cannot be overlooked. The main trunk of the saphenous nerve runs distally on the medial (outer) surfaces of the tendons of the gracilis and semitendinosus muscles to the longitudinal incision along the medial collateral ligament. Since the region of sensory disturbance was located lateral to the longitudinal incision line in all patients, tendon harvest using a tendon stripper could not be the main reason for the sensory disturbance. Injury or entrapment of the main trunk of the saphenous nerve has been reported [1, 20], and the region of sensory disturbance due to such injury is much wider than that of the present study. If the tendon stripper causes the nerve injury, the main trunk of the saphenous nerve could be damaged as well as the branches of the nerve, as previously pointed out by Pagnani et al. [29]. Therefore, special attention should be paid to the main trunk of the saphenous nerve due to its close positional relationship to the tendons.

The complicated anatomic variations of the nerve branches in the infrapatellar region and the anterior lower leg region preclude their absolute avoidance in any surgical knee incision, and a completely safe zone could not be found in the present study. Ebrahein and Mekhail [11] described a safety zone to avoid injury of the infrapatellar branch of the saphenous nerve. However, their zone must be supplied by the branches of the medial femoral cutaneous nerve, and thus it is very difficult to identify a completely safe zone. Nevertheless, it is necessary to minimize nerve injuries. On the basis of the anatomic findings of nerve distribution, an oblique rather longitudinal incision for the tendon harvest could be a technique worth investigating to minimize the area of sensory disturbance.

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