Original Article

The inferior medial genicular artery and its vascularization of the pes anserinus superficialis
A cadaveric study

Lena Hirtler, Manuel Ederer[1], Mike Faber[1], Patrick Weninger[2]

Abstract

Background: A common method for reconstruction of the anterior cruciate ligament (ACL) is it's replacement by a free avascular graft, using the gracilis and/or semitendinosus tendons. These grafts pass a vulnerable phase in the ligamentization-process during the 1st year after reconstruction. The aims of this study were first to evaluate the vascularization of the pes anserinus superficialis (PAS) by the inferior medial genicular artery (IMGA) and second to develop a pedunculated surgical technique for ACL reconstruction, to preserve a maximal amount of natural vascularization of the tendons inserting at the PAS.
Materials and Methods: First, the vascularization of the PAS was assessed in 12 fresh-frozen lower extremities. The IMGA was identified at its origin at the popliteal artery and perfused with a methylene blue solution. Second, a pedunculated ACL reconstruction was performed in 5 fresh-frozen lower extremities under maintenance of the distal tendon insertion at PAS.
Results: The PAS is a highly vascularized structure. Vessels originate from the IMGA, running along the three tendons of the PAS in the paratendinous tissue. Histologically intratendinous vessels exist; however, perfusion of the inserting tendons through intratendinous vessels was not proven macroscopically. The pedunculated grafts could be positioned and fixed successfully into the bone tunnels in all knees.
Conclusion: Although intratendinous vascularization of the tendons of the PAS via the IMGA was not proven, this study indicates a new possibility of ACL reconstruction. The described operation technique can be conducive to shorten the vulnerable phase of the graft-ligamentization after ACL reconstruction.

Key words: Anterior cruciate ligament reconstruction, inferior medial genicular artery, pedunculated graft, pes anserinus superficialis, vascularization
MeSH terms: Anterior cruciate ligament reconstruction, grafts, knee injuries, arthroscopy

Introduction

Rupture of the anterior cruciate ligament (ACL) constitutes 2/3 of all ligamentous injuries of the knee joint, which are found in 40% of all clinically relevant traumas of the knee in general.[1,2] In the majority of cases, these injuries occur in athletic individuals. Surgical reconstruction must be performed in most patients in order to regain rotational stability and to prevent further damage to the cartilaginous tissues of the knee joint.

In ACL reconstruction, several different aspects must be taken into consideration: (1) Choice of tendon used for the plasty,[3] (2) localization of intraosseous tunnels,[4] (3) their orientation,[5] (4) the use of single- or double-bundle transplants,[5,6] (5) the fixation method,[7] as well as (6) the surgical approach via anteromedial, transtibial, or all-inside techniques.[8]

Division of Anatomy, Center for Anatomy and Cell Biology, Medical University of Vienna, [1]Center for Anatomy and Cell Biology, Medical University of Vienna, [2]Department of First Orthopedic, Orthopaedic Hospital Speising, Vienna, Austria

Address for correspondence: Mag. Dr. Lena Hirtler,
Division of Anatomy, Center for Anatomy and Cell Biology,
Medical University of Vienna, Währinger Straße 13, 1090 Vienna, Austria.
E-mail: lena.hirtler@meduniwien.ac.at

Access this article online	
Quick Response Code:	Website: www.ijoonline.com
	DOI: 10.4103/0019-5413.193476

How to cite this article: Hirtler L, Ederer M, Faber M, Weninger P. The inferior medial genicular artery and its vascularization of the pes anserinus superficialis: A cadaveric study. Indian J Orthop 2016;50:677-85.

These decisions are relevant for all ACL reconstructions regardless of the choice of tendon graft and have been well discussed in literature.

Recent discussions on to the surgical management of torn ACL focus on the postoperative treatment and on potential influences other than personal skill that surgeons might exert on postoperative ligamentization[9-15] and tendon-to-bone healing.[16,17] Besides, there exist several new approaches including therapeutic gene modulation[18] and the usage of platelet-derived growth-factor.[15]

The two aforementioned factors, postoperative ligamentization and tendon-to-bone healing, are mainly dependent on the choice of graft a surgeon makes for ACL reconstruction. Here, there are two main options in the modern ACL repair. The bone - patella tendon - bone graft with the central third of the patella tendon and bone blocks of the patella and the tibial tuberosity can be used,[19,20] as well as the tendons of the semitendinosus or gracilis muscle.[21,22] Both methods have in common that autogenous, free, avascular grafts are transplanted without any kind of vascularization.

In the postoperative episode, the graft passes a remodeling process also called ligamentization, in which the implanted tendons transform into ligamentous structures. About 6 weeks after reconstruction there can be observed a regain of vascularization of the graft can be observed. In the remodeling episode, a neovascularization and a cellular repopulation with high levels of metabolism can be observed until approximately 1 year after reconstruction. During this time, the grafts remain in a vulnerable state with higher risk of failure or rerupture.[9,14]

Falconiero *et al*.[10] investigated in 1998 the revascularization of reconstructed ACLs and were able to show the importance of blood supply to the graft. Developing a possibility of a vascularized graft for ACL reconstruction should therefore improve the ligamentization of the inserted tendon.

Former studies evaluated the tendon insertion at the pes anserinus as highly vascularized structure. The perfusion of the area is effected through the network of arterial anastomoses around the joint (anatomical term: Rete arteriosum genus) and, in particular, the inferior medial genicular artery (IMGA), [Figure 1] and includes a retrograde perfusion of the peritendineum.[23,24] After previous work of Marcacci *et al*.[25-28] describing a method of intraarticular and extraarticular ACL reconstruction, Zaffagnini *et al*.[29] developed in 2013 their own surgical procedure for double-bundle reconstruction of the ACL leaving the tibial insertion of the tendons intact. Based on these studies, our hypothesis of a distally pedunculated and vascularized graft for ACL-single-bundle reconstruction was developed.

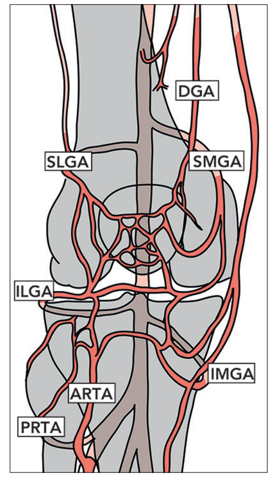

Figure 1: The rete arteriosum genus provides nutrition to the whole knee region. It consists of the superior medial genicular artery (SMGA) and superior lateral genicular artery (SLGA), the inferior medial genicular artery (IMGA) and inferior lateral genicular artery (ILGA), the descending genicular artery (DGA), the medial genicular artery (MGA) as well as the anterior recurrent tibial artery (ARTA), and posterior recurrent tibial artery (PRTA) recurrent tibial artery

Out of the currently available literature, the following hypothesis was formed: An operation technique with vascularized ACL grafts could accelerate the postoperative remodeling process and could therefore lead to an earlier regain of stability and a faster rehabilitation.

This study is aimed to: (1) Show the extent of the angiosome of the IMGA (2) evaluate the extent of perfusion of the tendons of the pes anserinus superficialis (PAS) through the IMGA (3) investigate intratendinous blood supply of the PAS and (4) evaluate and describe the technical possibility of a pedunculated ACL reconstruction, using single-bundle semitendinosus-gracilis grafts with a preserved vascularization through their distal insertion at the PAS.

Materials and Methods

17 fresh frozen lower extremities were obtained from our anatomical institute. Those specimen were obtained from voluntary donations to the institute and were randomly selected. Selection criteria were the sufficient quality of the specimen, no apparent evidence of surgical interventions in the area to be examined and severe arteriosclerosis of the blood vessels. There was no attempt to distinguish the gender nor the age of the donor.

An ethical approval for this study was obtained from the Ethics Board according to the Declaration of Helsinki.

For the first three aims, 12 fresh-frozen lower extremities were used. They were thawed at room temperature, and the arterial system flushed with a saline solution through the femoral artery until the venous outflow became clear. Then, the popliteal artery was dissected from a dorsal approach, and the IMGA was identified at its origin at the popliteal artery. Through an incision in the wall of the popliteal artery, a flexible cannula was inserted into the IMGA, and the artery was perfused with a methylene blue solution. Correct identification of the IMGA and correct placement of the cannula was controlled through the developing coloration of the respective angiosome. The skin coloration was documented photographically [Figure 2]. After skin incision, the arterial arch of the IMGA surrounding the PAS as described by Zaffagnini *et al.*[23] was documented photographically as well.

In the second step, the PAS and its inserting tendons were dissected carefully and without disturbing the peritendinous tissue. The extent of perfusion along the tendons in the peritendinous tissue was documented and measured as a distance from the insertion of the respective tendons.

In the third step, the tendons of the PAS were evaluated for intratendinous vessels. This was first performed through transsections through the tendons at a distance of 1 cm and by evaluation of the cross section by operating microscope. Then, the tendons were also evaluated histologically. For this purpose, sections of each tendon of the PAS were selected and prepared for histological staining. As this evaluation was just to confirm the existence of intratendinous vessels, simple hematoxylin and eosin staining were applied to facilitate identifying the blood vessels.

For the development of the surgical procedure, the remaining five fresh-frozen lower extremities were used. Their arterial system was also flushed with a saline solution through the femoral artery until the venous outflow became clear. Then the specimen was mounted in a custom-built clasp to mimic the leg's position during arthroscopic surgery. Each surgical step was documented photographically. Afterward, the arterial perfusion of the PAS footprint was checked by methylene blue solution.

Results

Vascularity of the pes anserinus superficialis

The PAS constitutes a highly vascularized structure. In all 12 specimens, sufficient perfusion of the angiosome of the IMGA was achieved. The angiosome, however, varied significantly in size. This can be seen clearly in the summarized graphical representation of the angiosomes of all specimens [Figure 3]. Immediately after perfusion of the IMGA, retrograde perfusion of the descending genicular artery (DGA) through its saphenous branch was observed in all specimen. This is due to permanent anastomoses of the vascular network between the IMGA, the superior medial genicular artery (SMGA), and the DGA [Figures 1 and 4]. This then was used as an additional sign of successful identification and perfusion of the IMGA.

After skin removal, the branching of the subcutaneous blood vessels of the IMGA was clearly discernible in the subcutaneous fat tissue. Completing the removal of the subcutaneous fat, an arching artery on the crural fascia surrounding approximately the footprint of the inserting tendons of the PAS was observed [Figure 5]. The subfascial course of the blood vessels, which originated from the previously described arterial arch, was radial toward distal, lateral, and also proximal. In addition, originating from this arterial arch were branches following the tendons of the PAS toward proximally, thereby entering the peritendineum and supplying the distal parts of the tendons.

The extent of the peritendinous perfusion varied depending on the different muscles (sartorius, gracilis, and

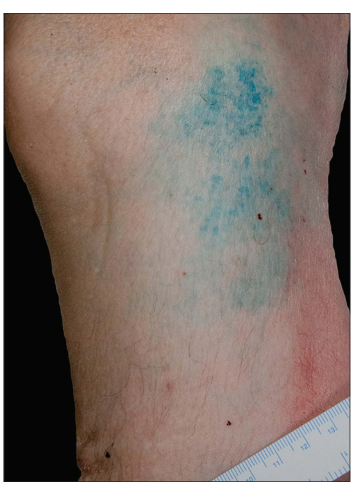

Figure 2: Clinical photograph showing perfusion after successful methylene blue injection into the inferior medial genicular artery in the right knee

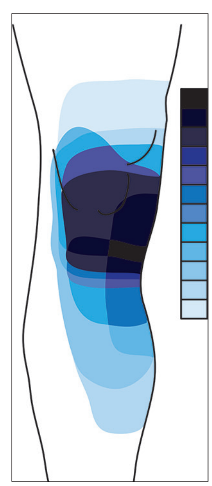

Figure 3: Graphic representation of the extent of the angiosomes of the inferior medial genicular artery of each specimen showed exemplary in the right leg

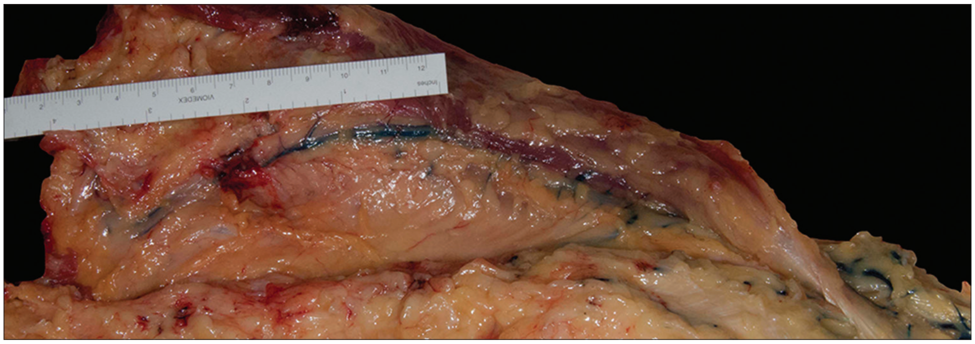

Figure 4: The arrows point at the dyed saphenous branch of the descending genicular artery as a sign of the anastomoses between the branches of the inferior medial genicular artery, the superior medial genicular artery, and the descending genicular artery

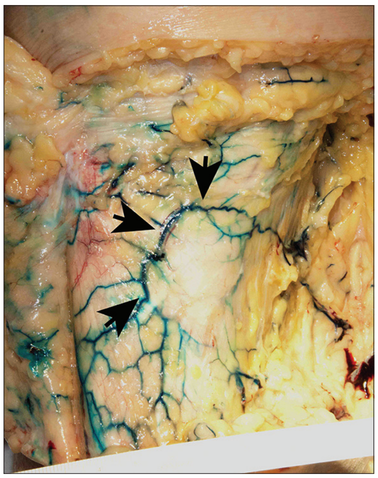

Figure 5: Arching artery (arrows) on the crural fascia surrounding approximately the footprint of the inserting tendons of the pes anserinus superficialis

semitendinosus muscles), as well as between the different donors. The average amount of perfusion originating from the IMGA for these tendons can be seen in Table 1.

After external evaluation of the tendons' perfusion, intratendinous perfusion of the three tendons was evaluated. In the first step, all tendons were transected at a distance of 1 cm and the cross section examined macroscopically with the help of a surgical microscope. Although the investigators were able to identify small intratendinous blood vessels, they were not filled by the methylene-blue-solution.

Thereafter, also the histologically prepared slices were evaluated. Moreover with this method, intratendinous blood vessels were clearly visible [Figure 6a-c].

Operative procedure

An arthroscopic ACL reconstruction with pedunculated semitendinosus-gracilis grafts was successfully performed in all 5 knees. The fixation of the grafts was accomplished in 4 knees by a TightRope (Arthrex Inc. Naples, FL, USA) in the femoral tunnel and a hybrid fixation of a PushLock (Arthrex Inc. Naples, FL, USA) in combination with a bone cylinder and the native tendon insertions at the pes anserinus in the tibial tunnel. In 1 knee, the graft was fixed by interference screws in both tunnels.

Table 1: Measured distance of macroscopic perfusion from the different muscle tendons of the PAS by the IMGA

Muscle tendon	*n*	Distance	Minimum (cm)	Maximum (cm)
Sartorius muscle	12	8.0±2.6	0	10.0
Gracilis muscle	12	10.4±4.6	0	14.3
Semitendinosus muscle	12	7.2±3.9	0	14.0

PAS=Pes anserinus superficialis, IMGA=Inferior medial genicular artery

First of all, a 5 mm arthroscope was inserted through a central portal for a diagnostic examination of the joint. For instrumentation, a classic anteromedial portal was used. The native ACL was removed by a shaver, and the notch was prepared.

The gracilis and semitendinosus tendons were harvested through a small incision at the anteromedial surface of the Tibia. The insertion of the tendons at the pes anserinus was left as undisturbed as possible. The tendon stripper was inserted at an average distance of 4 cm from the tibial crest. The harvesting was performed by an open tendon-stripper to maintain the vascularization of the distal tendon insertions at the pes anerinus. The peritendinous connective tissue was saved as much as possible. Distal fibrous connections between the tendons until in average 3.5 cm from the tibial crest were left unattended; all other interconnections were severed.

The femoral tunnel was drilled analog to the anteromedial technique, using a guide wire with a spade top to measure the length of the transcondylar duct.

The tibial tunnel was drilled from outside in by a cylinder trephine using a conventional aiming device. The gained bone cylinder was preserved for graft fixation [Figure 7].

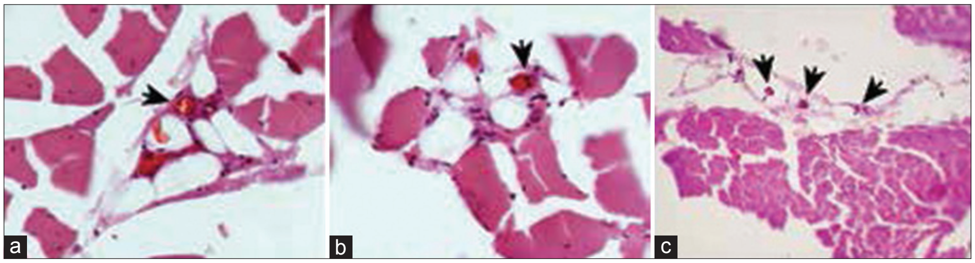

Figure 6: H and E stained histological transsection of the three tendons of the pes anserinus superficialis, arrows on intratendinous arteries: (a) Sartorius tendon, (b) Gracilis tendon, and (c) Semitendinosus tendon

To form the graft, the tendons were shortened to the accordant length of the bone tunnels. Only the free ends of the tendons were sutured, while the pedunculated ends were left in their native insertions and not additionally armed, as would be usually done in the conventional surgical procedure. In this step, the grafts had to be pulled in a cranial direction toward the tibial tunnel to prevent an unequal distribution of tension between the tendons [Figures 8 and 9]. In the result, a quadruple semitendinosus-gracilis graft was generated by a double loop of both the gracilis and the semitendinosus tendon.

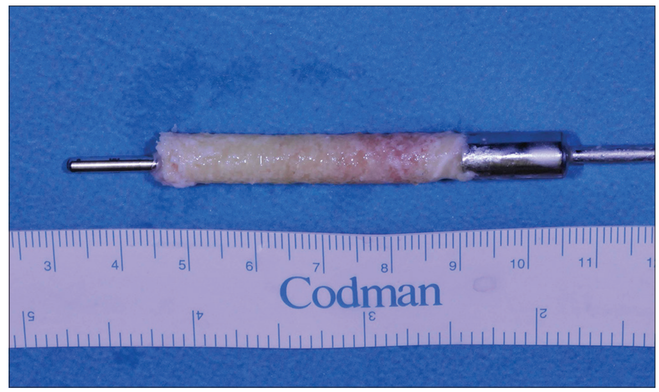

Figure 7: Gained bone cylinder by drilling with a cylinder trephine. This bone cylinder was preserved for graft fixation

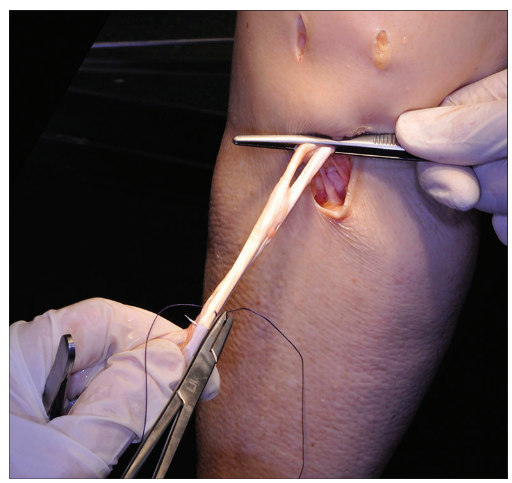

Figure 8: Position of the graft for proper graft suturing

To place the graft inside the joint, it was pulled in through the tibial tunnel by the loop of a TightRope until the anchor tilted at the tunnel exit of the lateral femoral condyle. The remaining distance from the graft to the end of the femoral tunnel at that point could be calculated by subtracting the length of the whole transcondylar duct minus the length of the femoral tunnel from the length of the TightRope loop. Before pulling the graft forward into the joint, the tensioning threads were marked at the skin level of the anteromedial portal to visualize the continuing graft-movements [Figure 10]. The graft was now pulled into the femoral tunnel until a residual distance of about 1 cm to the tunnel end was reached. The last centimeter was used for graft-tensioning after the tibial fixation.

The tibial fixation was performed in 4 knees by a hybrid technique consisting of 3 combined fixations. The pedunculated graft-end stayed inserted at the pes anserinus to maintain the native vascularization. The free ends were fixated in the extraarticular tibial bone using a PushLock®. In addition, the bone cylinder was stamped back into the tibial tunnel to tighten it up and add cohesiveness [Figures 11 and 12].

After tibial fixation, the graft was tensioned manually by pulling it up in the residual space of the femoral tunnel using the TightRope.

An alternative fixation using interference screws was performed in 1 knee. The shaping and placement of the graft were done analogically to the TightRope fixation technique. The graft was pulled into the joint by a thread loop instead of the TightRope, with 1 cm remaining at the end of the femoral tunnel. After the tibial interference screw was placed, the graft could be tensioned by the thread loop and fixated by a femoral interference screw [Figure 13].

In none of the 5 specimen a problem with the length of the graft occurred, although having to sacrifice some of its length due to the pedunculated design. In all knees, the femoral ends of the grafts extended to at least two thirds of the tunnel after tensioning, the tibial ends of the graft filling the complete tunnel.

Figure 9: Note the different tension of the two tendons in graft preparation. This is due to the different position of the tendons at their insertion at the pes anserinus superficialis. Graft shortening should be performed while pulling the tendons proximally. Pulling the tendons after suture toward distal, the semitendinosus tendon should be much slacker than the gracilis tendon due to its insertion more distally on the tibia

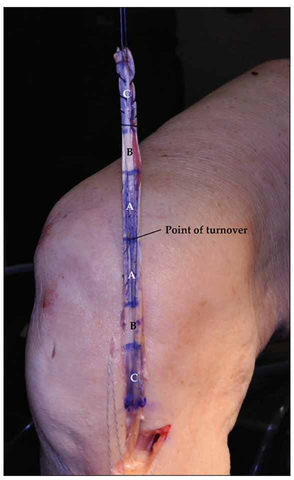

Figure 10: Visualization of intraosseous and intraarticular parts of the graft and the exact position of the TightRope-loop. A=intrafemoral part, B=intraarticular part, and C=intratibial part

A Lachman test and pivot shift test were performed on all specimen to confirm the stability of the reconstruction. Adequate stability was achieved in all specimen.

Afterward, the perfusion of the PAS through the IMGA was again checked by methylene blue injection. In all 5 knees, sufficient coloration of the blood vessels was observed. The presence of vascularity of the graft was assumed due to the presence of dye in the intraarticular fluid.

Discussion

In this study, we were able (1) to show the high vascularity of the PAS tendons supplied by the IMGA and (2) developed a new technique for single bundle

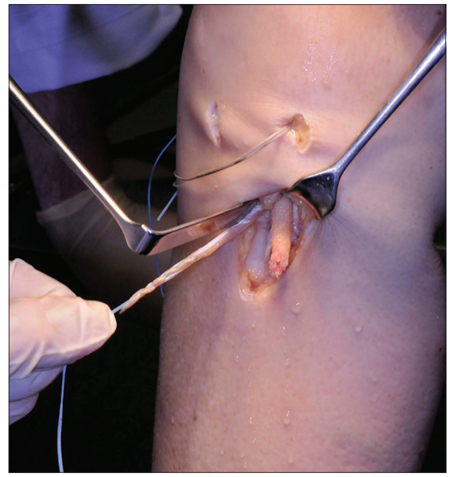

Figure 11: Press-fit fixation in the tibial tunnel through the preserved bone cylinder

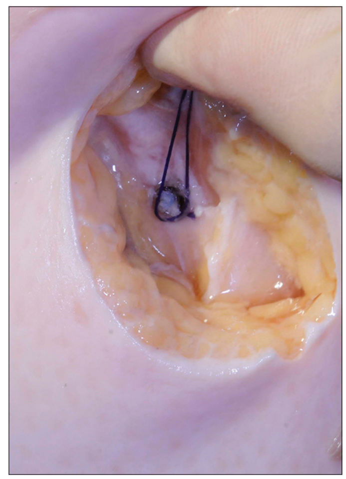

Figure 12: Fixation of the tibial TightRope by PushLock

ACL reconstruction leaving the distal insertion of the PAS tendons intact and therefore also preserving their vasculature as much as possible.

Zaffagnini *et al*.[23] already published in 2003 a very informative study regarding the vascularity and the neuroreceptors of the PAS, describing the vascular arch at the insertion of the tendons and showing the number and diameter of intratendinous vessels seen histologically. In contrast to the work of Zaffagnini *et al*., our additional question was, how far proximally the blood supply of the tendons originated from the IMGA and whether the intratendinous vessels originated from the same artery. The results shown in this study were two-sided. On the one hand, the peritendinous vasculature could be documented very clearly by dye injection. On the other hand, the intratendinous vasculature supplied from distally could not be documented.

This could have several reasons. In this study, the authors only perfused the IMGA, although Zaffangini *et al*.[23]

Figure 13: Fixation of the tibial graft by interference screw

described, that the vascular supply of the PAS originates from three main arteries of the knee – the IMGA, the inferior lateral genicular artery, and the anterior recurrent tibial artery. As those arteries, however, have many anastomoses and as the results of these studies showed the complete perfusion of even the saphenous branch of the DGA, this factor should be negligible. As the body donations to an anatomic institute are on average beyond the age of sixty, any severity of atherosclerosis is always present, making perfusion of larger and smaller vessels difficult.

The important information gathered from this first part of the study is the vascular contribution from distally for the tendons of the PAS. Looking at the other graft frequently used in ACL reconstruction, this is the major difference between the two. The patellar tendon is mostly supplied through the peripatellar plexus, with almost no contribution coming from tibial.[30-32] Using the patellar tendon in ACL reconstruction, the surgeon implants therefore a completely avascular structure, even when leaving the tibial insertion intact. The semitendinosus-gracilis graft, left at its insertion on the tibia, could, therefore, be a veritable alternative, providing the possibility of a rapid revascularization after the surgical procedure.

The ACL repair with pedunculated single-bundle semitendinosus-gracilis grafts from the PAS is a new reconstruction method, which is modified from the classic semitendinosus-gracilis technique. There are no major differences in the technical equipment, the arthroscopic ports, and the tunnel drilling in the anatomic position. The essential variation is the way of harvesting and forming of the graft, as well as the positioning and tensioning of the graft. Already the ambitious work of Marcacci *et al.*,[25-28] who introduced the first idea of reconstructing the ACL leaving the gracilis and semitendinosus tendons intact, was able to show highly satisfactory results of this sort of surgical technique even after 11 years. Zaffagnini *et al.*[29] (2013) did introduce the possibility of double-bundle reconstruction of the ACL leaving the tibial insertions of the semitendinosus and gracilis tendons intact. Their technical description, however, is geared to surgeons with experience in double-bundle ACL reconstruction, allowing the independent tensioning and positioning of the two tendons. As the ACL is currently mostly reconstructed with a single-bundle method, the technique described in this study takes the current surgical trend of single-bundle ACL reconstruction into account.

As described, the grafts were not detached at their distal insertion, but proximally harvested with an open tendon stripper, leaving their insertion at the PAS. The information of using the open stripper is important to mention as the surgeon cannot sever the tendons distally to thread them into the closed tendon stripper. This is a fact which is not clearly described in the technical note of Zaffagnini *et al.*,[29] who used a blunt stripper.

The usual preparation of the graft on the preparation table was omitted, as well as the pretension of the graft. As a consequence, the pedunculated grafts could have a higher laxity compared with pretensioned free semitendinosus-gracilis or patella tendon grafts.[24] Only the free tendon ends were armed with a suture, while the graft had to be pulled in the direction of the tibial tunnel entrance, to avoid a disparity of tension between the gracilis and the semitendinosus graft limb.

The pedunculated graft was placed in the joint through tibial bone tunnel. While pulling it into the femoral tunnel, it was important to leave a residual distance of 1 cm. Unlike the conventional method, tensioning of the graft could only be arranged on the femoral side and also only after tibial fixation. Only in this way an equal tension on the two limbs of the quadruple semitendinosus-gracilis graft was achieved. The correct calculation and measurement of the residual tunnel distance with the possible result of the insufficient tension of the graft could be a potential pitfall of this operation.

The fixation was successfully performed by TightRopes and interference screws. The use of TightRopes and PushLocks facilitated the tensioning of the graft, while interference screws are suspected to have negative effects on the vascularization of the grafts due to high external pressures inside the bone tunnel. For this reason, the fixation outside of the tunnel would be favorable, especially as this would minimize active pressure on the inserted tendons and facilitate vascularization originating from the tibial insertion.

Another potential complication is the native tendon insertion at the PAS. It was observed that the insertions yielded a few millimeters by a pull to proximal or tensioning. This can lead to incorrect values in former measurements and should be taken into account. A too long transplant was nonetheless unproblematic, as it could be diverted through the tibial tunnel exit.

The pedunculated semitendinosus-gracilis graft is a new method in ACL repair, with a connection to the vasculaturization of the pes anserinus, which was evaluated as a highly perfused structure in former studies.[23] This technique enables the use of the anatomic findings for the further development of ACL reconstructions and the postoperative rehabilitation. The remaining vasculature of the graft can imply that the ligamentization-process runs faster and the graft reaches its final stability earlier than in free avascular grafts. The result would be an earlier return to sportive activities. This implication needs to be proved *in vivo* in future studies, as it cannot be shown in this cadaveric study.

Limitations

In this study, the authors only perfused the IMGA. As all the arteries of the arterial network of the knee joint anastomose with each other, and as the results of these studies showed the complete perfusion of even the saphenous branch of the DGA, this factor should be negligible in assessing the vascular architecture of the tendons of the PAS. A more important role plays in this investigation the vascular state of the anatomical specimen. As the to body donated an anatomic institute, beyond the age of of sixty atherosclerosis is always present, making perfusion of larger and smaller vessels difficult.

In the surgical procedure, the usual preparation of the graft on the preparation table was omitted, as well as the pretension of the graft due to the intact tibial insertion of the tendons. As a consequence, the pedunculated grafts could have a higher laxity compared with pretensioned free semitendinosus-gracilis or patella tendon grafts.[24] In addition, unlike the conventional method, tensioning of the graft after its insertion through the tunnels could only be arranged on the femoral side and this also only after tibial fixation. The correct calculation and measurement of the residual tunnel distance with the possible result of the insufficient tension of the graft could be a potential pitfall of this surgery.

Another potential complication is the native tendon insertion at the PAS. It was observed that the insertions yielded a few millimeters by a pull to proximal or tensioning. This can lead to incorrect values in former measurements and should be taken into account.

A limitation of the investigated technique concerning the preservation of the native vascularization could possibly be the kink of the pedunculated graft at the entrance of the tibial tunnel. The graft vessels could also be compressed through high tension or pressure caused by the fixation tools.

Conclusion

The operative method of distally pedunculated single-bundle semitendinosus-gracilis grafts was technically described in this study and represents an alternative to the classic semitendinosus-gracilis method due to the related operative procedures and technical requirements. The persisting connection to the vascularization of the pes anserinus could possibly accelerate the postoperative remodeling *in vivo*, which has to be proved in future studies. This technical note delivers the base for future investigations in the field of ACL surgery with the purpose of shortening the postoperative rehabilitation period.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. Clin J Sport Med 2012;22:116-21.
2. Herbort M, Raschke MJ, [Ligament ruptures of the lower extremity in the elderly]. Unfallchirurg 2011;114:671-80.
3. Hadjicostas PT, Soucacos PN, Paessler HH, Koleganova N, Berger I. Morphologic and histologic comparison between the patella and hamstring tendons grafts: A descriptive and anatomic study. Arthroscopy 2007;23:751-6.
4. Sadoghi P, Kröpfl A, Jansson V, Müller PE, Pietschmann MF, Fischmeister MF. Impact of tibial and femoral tunnel position on clinical results after anterior cruciate ligament reconstruction. Arthroscopy 2011;27:355-64.
5. Gobbi A, Mahajan V, Karnatzikos G, Nakamura N. Single- versus double-bundle ACL reconstruction: Is there any difference in stability and function at 3-year followup? Clin Orthop Relat Res 2012;470:824-34.
6. Kondo E, Merican AM, Yasuda K, Amis AA. Biomechanical comparison of anatomic double-bundle, anatomic single-bundle, and nonanatomic single-bundle anterior cruciate ligament reconstructions. Am J Sports Med 2011;39:279-88.
7. Chen CH, Gadikota HR, Gill TJ, Li G. The effect of graft fixation sequence on force distribution in double-bundle anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2011;19:712-8.
8. Strauss EJ, Barker JU, McGill K, Cole BJ, Bach BR Jr, Verma NN. Can anatomic femoral tunnel placement be achieved using a

transtibial technique for hamstring anterior cruciate ligament reconstruction? Am J Sports Med 2011;39:1263-9.
9. Amiel D, Kleiner JB, Roux RD, Harwood FL, Akeson WH. The phenomenon of "ligamentization": Anterior cruciate ligament reconstruction with autogenous patellar tendon. J Orthop Res 1986;4:162-72.
10. Falconiero RP, DiStefano VJ, Cook TM. Revascularization and ligamentization of autogenous anterior cruciate ligament grafts in humans. Arthroscopy 1998;14:197-205.
11. Li H, Chen C, Ge Y, Chen S. Spray-painted human fibronectin coating as an effective strategy to enhance graft ligamentization of a polyethylene terephthalate artificial ligament. Biotechnol Lett 2014;36:1079-88.
12. Janssen RP, Scheffler SU. Intraarticular remodelling of hamstring tendon grafts after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2014;22:2102-8.
13. Keklikci K, Yapici C, Kim D, Linde-Rosen M, Smolinski P, Fu FH. The effect of notchplasty in anterior cruciate ligament reconstruction: A biomechanical study in the porcine knee. Knee Surg Sports Traumatol Arthrosc 2013;21:1915-21.
14. Rougraff B, Shelbourne KD, Gerth PK, Warner J. Arthroscopic and histologic analysis of human patellar tendon autografts used for anterior cruciate ligament reconstruction. Am J Sports Med 1993;21:277-84.
15. Vogrin M, Rupreht M, Dinevski D, Hašpl M, Kuhta M, Jevsek M, *et al*. Effects of a platelet gel on early graft revascularization after anterior cruciate ligament reconstruction: A prospective, randomized, double-blind, clinical trial. Eur Surg Res 2010;45:77-85.
16. Bedi A, Kovacevic D, Fox AJ, Imhauser CW, Stasiak M, Packer J, *et al*. Effect of early and delayed mechanical loading on tendon-to-bone healing after anterior cruciate ligament reconstruction. J Bone Joint Surg Am 2010;92:2387-401.
17. Matsumoto T, Kubo S, Sasaki K, Kawakami Y, Oka S, Sasaki H, *et al*. Acceleration of tendon-bone healing of anterior cruciate ligament graft using autologous ruptured tissue. Am J Sports Med 2012;40:1296-302.
18. Wang CJ, Weng LH, Hsu SL, Sun YC, Yang YJ, Chan YS, *et al*. pCMV-BMP-2-transfected cell-mediated gene therapy in anterior cruciate ligament reconstruction in rabbits. Arthroscopy 2010;26:968-76.
19. Butler DL, Grood ES, Noyes FR, Olmstead ML, Hohn RB, Arnoczky SP, *et al*. Mechanical properties of primate vascularized vs. nonvascularized patellar tendon grafts; changes over time. J Orthop Res 1989;7:68-79.
20. Yao LW, Wang Q, Zhang L, Zhang C, Zhang B, Zhang YJ, *et al*. Patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction: A systematic review and meta-analysis. Eur J Orthop Surg Traumatol 2015;25:355-65.
21. Yasuda K, Kondo E, Ichiyama H, Kitamura N, Tanabe Y, Tohyama H, *et al*. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. Arthroscopy 2004;20:1015-25.
22. Yasuda K, Kondo E, Ichiyama H, Tanabe Y, Tohyama H. Clinical evaluation of anatomic double-bundle anterior cruciate ligament reconstruction procedure using hamstring tendon grafts: Comparisons among 3 different procedures. Arthroscopy 2006;22:240-51.
23. Zaffagnini S, Golanò P, Farinas O, Depasquale V, Strocchi R, Cortecchia S, *et al*. Vascularity and neuroreceptors of the pes anserinus: Anatomic study. Clin Anat 2003;16:19-24.
24. Kawano CT, de Moraes Barros Fucs PM, Severino NR. Pretensioning of quadruple flexor tendon grafts in two types of femoral fixation: Quasi-randomised controlled pilot study. Int Orthop 2011;35:521-7.
25. Marcacci M, Molgora AP, Zaffagnini S, Vascellari A, Iacono F, Presti ML. Anatomic double-bundle anterior cruciate ligament reconstruction with hamstrings. Arthroscopy 2003;19:540-6.
26. Marcacci M, Zaffagnini S, Giordano G, Iacono F, Presti ML. Anterior cruciate ligament reconstruction associated with extra-articular tenodesis: A prospective clinical and radiographic evaluation with 10- to 13-year followup. Am J Sports Med 2009;37:707-14.
27. Marcacci M, Zaffagnini S, Iacono F, Neri MP, Loreti I, Petitto A. Arthroscopic intra-and extra-articular anterior cruciate ligament reconstruction with gracilis and semitendinosus tendons. Knee Surg Sports Traumatol Arthrosc 1998;6:68-75.
28. Marcacci M, Zaffagnini S, Iacono F, Vascellari A, Loreti I, Kon E, *et al*. Intra- and extra-articular anterior cruciate ligament reconstruction utilizing autogeneous semitendinosus and gracilis tendons: 5-year clinical results. Knee Surg Sports Traumatol Arthrosc 2003;11:2-8.
29. Zaffagnini S, Marcheggiani Muccioli GM, Bonanzinga T, Nitri M, Grassi A, Marcacci M. Anatomic double-bundle anterior cruciate ligament reconstruction leaving hamstrings tibial insertion intact: Technical note. Musculoskelet Surg 2013;97:39-43.
30. Scapinelli R. Studies on the vasculature of the human knee joint. Acta Anat (Basel) 1968;70:305-31.
31. Alm A, Strömberg B. Vascular anatomy of the patellar and cruciate ligaments. A microangiographic and histologic investigation in the dog. Acta Chir Scand Suppl 1974;445:25-35.
32. Ginsburg JH, Whiteside LA, Piper TL. Nutrient pathways in transferred patellar tendon used for anterior cruciate ligament reconstruction. Am J Sports Med 1980;8:15-8.