The safety and feasibility of a less invasive distal femur closing wedge osteotomy technique: a cadaveric dissection study of the medial aspect of the distal femur

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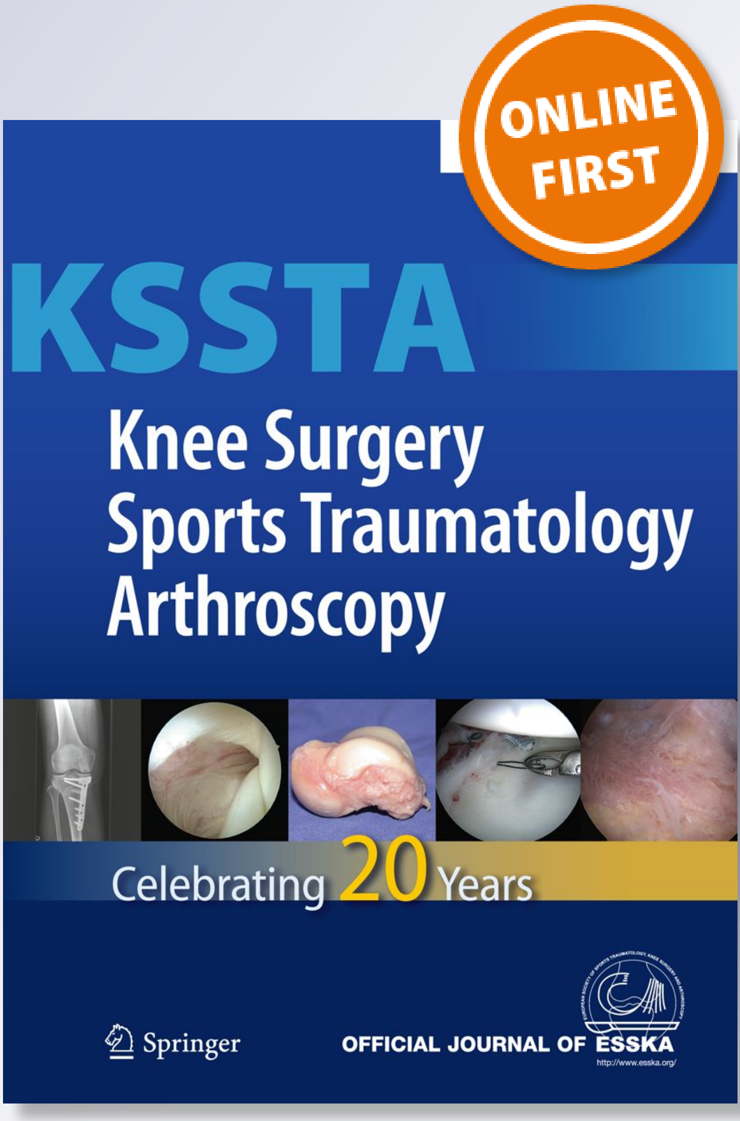

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The safety and feasibility of a less invasive distal femur closing wedge osteotomy technique: a cadaveric dissection study of the medial aspect of the distal femur

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Abstract
Purpose To investigate the feasibility and safety of a less invasive surgical approach to the distal medial aspect of the femur in supracondylar medial closing wedge osteotomy for the treatment of lateral compartment osteoarthritis of the knee. The aim of a less invasive approach is to minimize soft tissue disruption, reduce damage to neurovascular structures and thereby prevent muscle atrophy and optimize bone healing potential.
Methods A human cadaver dissection study on the vascular and neural structures of the medial side of the distal femur was conducted. Surgical dissection ($n = 4$), cryomicrotomy and subsequent 3D reconstruction of the anatomy ($n = 1$), and surgical dissection after performance of a supracondylar osteotomy through a less invasive approach ($n = 1$) were performed in 6 legs in total.
Results The surgical dissection and 3D reconstruction showed that a branch of the femoral artery, the distal genicular artery, supplies the distal area of the vastus medialis (VM) muscle. This artery has several branching patterns; crucial in the presented less invasive approach is its musculo-articular branch, which has an oblique course through the VM to the superomedial pole of the patella. The femoral nerve and saphenous nerve innervate the VM. These structures are at risk in the traditional subvastus approach, whereas no major damage was observed in the leg in which a less invasive approach was performed.
Conclusions In this cadaveric dissection study, a less invasive approach to the medial side of the distal femur proved to be feasible and safe. Damage to the VM and its neurovascular structures is minimized as compared to the traditional subvastus approach.

Keywords Less invasive · Osteotomy technique · Distal femur · Vascularization · Cadaver · Anatomy

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Introduction

Lateral compartment osteoarthritis of the knee with a valgus leg alignment can be treated with a supracondylar varus osteotomy (SCO), using either medial closing or lateral opening wedge techniques [10, 15–18, 20, 21, 26, 29].

A lateral approach similar to the Minimally Invasive Percutaneous Plate Osteosynthesis (MIPPO) technique in fracture surgery can be used, minimizing soft tissue damage and vascular disruption, optimizing bone healing potential [5, 6, 12–14, 31]. An important disadvantage of the standard subvastus approach for medial SCO is that a large incision is needed. The vastus medialis (VM) needs to be stripped of its septum severing neurovascular structures causing VM hypotrophy (Fig. 1a–c) [16, 29]. This may be prevented with a less invasive approach analogous to the lateral MIPPO technique using a distal incision large enough for the osteotomy and distal plate fixation combined with a stab incision for proximal plate fixation.

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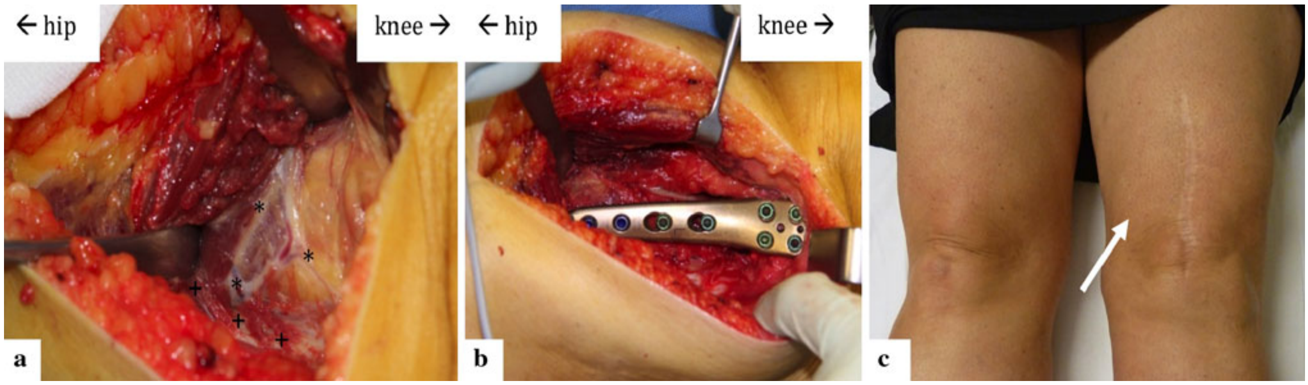

Fig. 1 Medial view of traditional medial subvastus approach in a left leg. **a** Distal part of the m. vastus medialis is retracted ventrolateral with Hohman retractors. Neurovascular bundles (*) originating from the dorsal intermuscular septum (+) prevent further exploration proximally and need to be cut to sufficiently expose area for biplane osteotomy and plate fixation. **b** Vastus medialis retracted ventrolaterally after stripping the muscle from the intermuscular septum severing neurovascular bundles; plate fixation after osteotomy. **c** Vastus medialis atrophy (*arrow*) after standard subvastus approach in the left leg of a patient after supracondylar osteotomy

The neurovascular anatomy of the medial side of the distal femur has been studied in the midvastus approach in total knee replacement surgery [1, 22] and for vascular tissue grafts of the medial femoral condyle [4, 9, 30], but not with respect to SCO [1, 4, 9, 22, 30]. The VM's main blood supply is from the descending genicular artery (DGA) which branches off from the distal femoral artery [30]. Innervation of the middle and distal part of the VM is provided by the medial branch of the femoral nerve along the posterior edge of the VM, with branches into the VM, and the VM obliquus [11, 27].

The standard single plane medial closing wedge SCO has been modified to a biplane osteotomy with an angle stable implant (LCP) for fixation (Fig. 1) [2, 3, 7, 28, 29]. It is the preferred technique because it provides increased axial stability and stiffness, less soft tissue disruption, and a shorter rehabilitation time [7, 28].

Although fixation with a LCP does allow for a less invasive approach until now, only a traditional subvastus approach has been used. Only one other report on a less invasive approach to the femur for SCO exists but is lacking an anatomical foundation [25]. Therefore, to potentially minimize soft tissue damage and neurovascular disruption in the medial approach to the distal femur in SCO, the current study was designed to investigate the safety and feasibility of a less invasive approach. For this purpose, six human cadaver legs were investigated.

Specific research questions were as follows: (1) what variations are there in the vasculature of the distal medial aspect of the femur, (2) is there a clearly distinguishable plane between the VM obliquus (VMO) and VM longus (VML) and if so does this plane and the neurovascular structures allow dissection through it, and (3) is a less invasive approach for a biplane medial closing SCO technically feasible and safe regarding neurovascular structures at risk, and what risk of neurovascular damage exists if screws are placed percutaneously through the VM?

Materials and methods

Six legs of four different human cadavers were obtained from the Department of Functional Anatomy of the University Medical Center Utrecht (Table 1). First in cadavers 1–5, blood was removed with a soap solution, the leg was perfused with 1 L of 10 % formalin solution, and then, Araldite was introduced into the femoral artery, coloring all arterial structures red [23]. Each leg was then amputated from the trunk about 10 cm below the hip joint, the skin was removed, and the foot was amputated at the level of the conjoint fascia of the soleus and gastrocnemius muscle. Thereafter, the legs were dehydrated in six baths with increasing concentrations of alcohol (50–70–80–96–96 %), each step taking 1 week. In the final preparation step, after dehydration, the specimens were immersed for a few months in methylbenzoate, which makes the soft tissue slightly transparent.

A less invasive SCO was performed in the sixth leg. To mimic the physiologic elastic properties of the vessels, in this leg the vessels were not filled with Araldite, which makes them solid, but were filled with a mixture of gelatine and gouache. No dehydration was performed in this leg.

Dissection and sectioning

In legs 1–4, the medial structures covering the distal femur were dissected manually using regular sharp surgical dissecting techniques. The arteries were solid, red, and easily dissectible from the other structures. This resulted in a clear overview of all branches of the femoral artery and

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Table 1 Demographics of human cadaveric legs and dissection methods

Specimen	Gender, age	Procedure	DGA	VMO-VML
1	Male, 93, left	Dissection	+	−
2	Male, 88 left	Dissection	+	+
3	Male, 93, right	Dissection	+	+
4	Male, 88, right	Dissection	+	−
5	Female, 65, left	Cryomicrotome sectioning	+	−
6	Male, 50, right	Dissection after SCO	+	−

The descending genicular artery (DGA) was present in all specimens

A different fiber alignment between the vastus medialis obliquus (VMO) and the vastus medialis longus (VML) was identified in only two specimens

their location in the VM muscle. All sectioning layers were photographed. In the images, the angle of the musculo-articular branch of the DGA related to the longitudinal axis of the femur and its external diameter were measured using ImageJ software (ImageJ 1.45 s, National Institutes of Health, USA). The longitudinal axis of the femur was determined in the sagittal plane (Fig. 4) by the line from the midpoint of the medial condyle to the middle of the femoral shaft at the proximal end of the specimen. External diameter of the musculo-articular branch was measured directly after branching off the femoral artery.

Cryomicrotomy was used in the fifth leg. The leg was frozen in carboxymethylcellulose gel at −25 °C. Using a heavyduty sledge cryomicrotome (PMV 450; LKB Instruments, Stockholm Sweden), consecutive sagittal sections using 25-micrometer intervals were obtained. The surface of each section was photographed (Nikon D1X; Nikon Corporation, Chiyoda-ku, Tokyo, Japan) at a resolution of 300 pixels/inch. The exact dimension of the part of the leg that appeared on the photographs was documented and was the same for each picture taken; in total 1,043 sequential images were collected. Thereafter, the coronal and transversal planes were reconstructed using Enhanced Multiplanar-reformatting Along Curves software (E-MAC Group, Department of Information and Computing Sciences, Utrecht University, Utrecht, The Netherlands). Using this technique, it is possible to show all three dimensions of a specimen in which surfaces can then be measured while the topographic relations remain unaltered [19]. Via synchronous display of all planes using a custom made Interactive Image Sequence Viewer program (N. Moayeri and G. J. Groen, Utrecht, The Netherlands) and E-MAC, all soft tissue structures of the medial aspect of the distal femur were visualized and analyzed in a 3D model [19] (Fig. 2). Using this software, surface areas were measured of arteries, veins, and nerves in the coronal section 12 cm above the knee joint line (Fig. 2c).

Osteotomy

In the sixth leg, a medial closing wedge biplane SCO was performed using a LCP for fixation (Tomofix MDF, Synthes, Bettlach, Switzerland). A 4.5-cm longitudinal incision positioned over the distal part of the VM halfway between the ventral and dorsal aspect of the leg was used (Fig. 3). This incision and a limited subvastus approach using the natural opening under the distal part of the VM leaving as much of the VM's attachment, including the neurovascular structures, to the septum intact, enabled sufficient exposure of the osteotomy area. Thereafter, a blunt retractor was positioned subperiostially to protect the dorsal neurovascular structures, and with a small muscle elevator, the vastus muscle belly was elevated enough to expose the bone for the osteotomy cuts (Fig. 3a). K-wires were inserted in the bone to guide the 0.8-mm 90/65 sawblade used to make the transverse osteotomy cuts starting 6.5 cm proximal to the medial knee joint line as well as the biplane anterior osteotomy cut [7]. After wedge removal, the osteotomy was closed. Through the same incision insertion of the plate under the vastus muscle belly, distal plate fixation and insertion of the compression screw proximal of the osteotomy were possible (Fig. 3b). A stab incision positioned over the most proximal plate hole was then made, and after blunt dissection with a clamp, a drill guiding sleeve was positioned on the plate (Fig. 3b), while its position was controlled by the surgeon's index finger slid under the muscle belly. The three proximal plate holes could be reached by repositioning the drill sleeve through the same proximal incision. After pre-drilling through the drill sleeve, unicortical screws were inserted, and as a final step, the compression screw was exchanged for a bicortical screw through the distal incision. After standard surgical closure of the wounds, the area of surgery was dissected to assess the disruption of vascular structures. Institutional review board approval (University Medical Center Utrecht, Utrecht, The Netherlands) was obtained for this study.

Results

In the four manually dissected cadavers, the descending genicular artery (DGA) and its branches that supply the distal part of the VM, the distal femur and the knee joint, could be clearly identified. In all cadavers, a musculo-articular branch was present running to the superomedial pole of the patella. The external diameter of this branch was 1.9 ± 0.3 mm; the average angle with the longitudinal axis of the femur was 35 ± 9 degrees. More proximal

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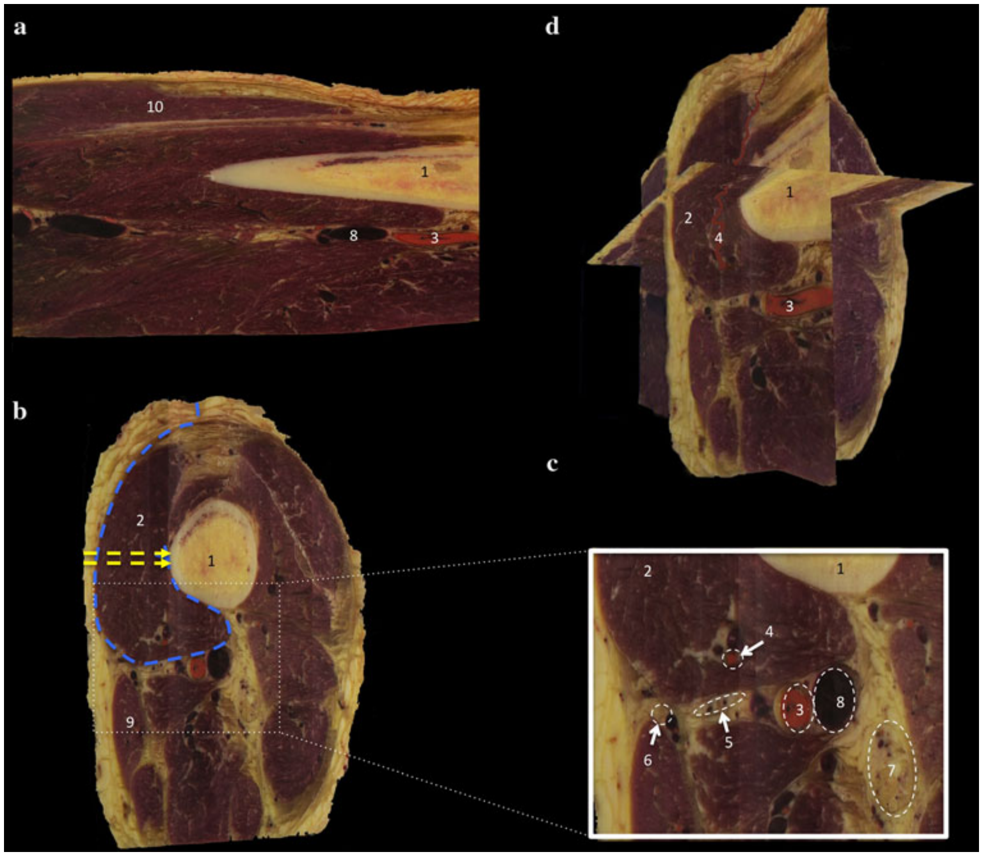

Fig. 2 Three-dimensional reconstruction of a left femur after cryo-microtome sectioning (specimen 5). *1* femur; *2* vastus medialis muscle; *3* femoral artery; *4* DGA; *5* adductor magnus tendon; *6* saphenous nerve; *7* femoral nerve; *8* femoral vein; *9* sartorius muscle; *10* rectus femoris muscle (**a**) Sagittal sections were made initially. Transversal and coronal sections were reconstructed using E-MAC software. (**b**) In a coronal section 12 cm above the knee joint line, the traditional subvastus approach (*blue line*) and the percutaneous approach (*yellow line*) are projected. In the percutaneous approach, the VM is not stripped of the intermuscular septum at this level in order to spare branching nerves and vessels. **c** Magnification of the coronal section. Structures in the intermuscular septum are encircled. Surface areas of arteries, veins, and nerves were measured: *3* femoral artery: 22.8 mm^2; *4* DGA: 2.6 mm^2, *6* saphenous nerve: 2.3 mm^2; *7* femoral nerve: 56.7 mm^2, *8* femoral vein: 46.8 mm^2. **d** Perspective caudal view of left upper leg, femoral condyles removed for better view. The course and caliber of the Descending Genicular Artery (DGA) in the m. vastus medialis is shown

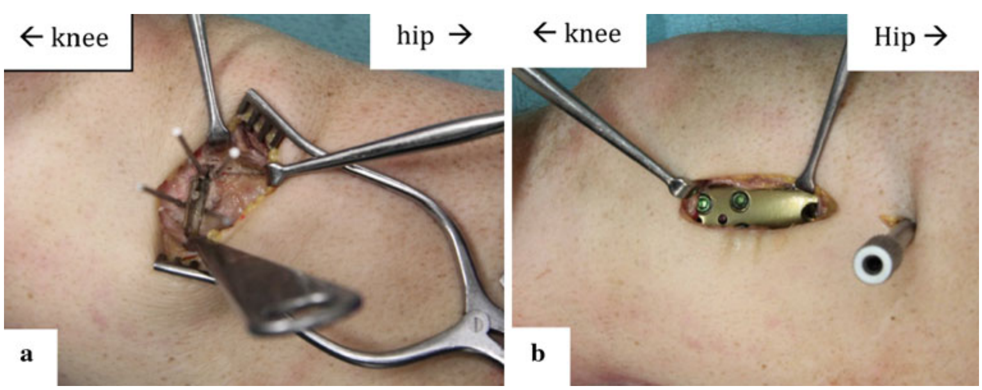

Fig. 3 Medial view of less invasive approach in a cadaveric right leg. **a** Distal part of the m. vastus medialis is retracted ventrolateral with small soft tissue retractors. K-wires inserted to guide sawcuts of biplanar osteotomy cuts, and small Hohman retractor protects posterior soft tissues. **b** Plate fixation: distal screws and first screw proximal of osteotomy inserted, drill sleeve positioned in most proximal plate hole through stab incision

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muscular branches were also identified in the VM muscle. The course of these vessels in the muscle is projected on the femur in Fig. 4 in which the position relative to the femoral artery, the femur and the adductor magnus tendon, the osteotomy, and the LCP is also shown (Fig. 4). A border between the VMO and the VML could be objectified as a different alignment of the muscle fibers in only two specimens. No intramuscular septum was found between the VMO and VML in the specimens in this study.

A perspective view of the cryomicrotome dissected specimen was created to show the course of the musculo-articular branch (Fig. 2d). Its maximal surface was 2.7 mm^2. The saphenous nerve, its course running along the medial side of the femur, was found located in the septum posterior from the VM muscle. The surface areas of relevant arteries, veins, and nerves were measured 12 cm above the medial knee joint line: DGA: 2.6 mm^2; saphenous nerve: 2.3 mm^2; femoral artery: 22.8 mm^2; femoral vein: 46.8 mm^2; femoral nerve: 56.7 mm^2 (Fig. 2c). At this level, the DGA has already branched off the femoral artery. This is the level of percutaneous entry through the VM for proximal plate fixation (Fig. 2b). In the traditional subvastus approach, the muscle needs to be stripped of the intermuscular septum up to this level in order to perform the proximal plate fixation.

The minimally invasive bi-plane SCO in the sixth leg was technically feasible: a 4.5-cm incision was sufficient to perform the osteotomy and placement of the distal screws and the most distal of proximal screws. Via one stab incision, the three proximal screws could be inserted. On dissection of the surgically exposed area, the DGA was found unharmed in its course through the VM as was expected from the other specimens. One small vessel branch from the DGA appeared to be damaged by the stab incision and preparations for proximal percutaneous screw insertions (Fig. 5).

Discussion

The most important finding in this study is that a less invasive approach for medial SCO is a feasible surgical technique without causing damage to the main neurovascular supply of the VM. This approach preserves neurovascular structures branching from the intermuscular septum into the VM that are damaged in the traditional subvastus approach. Several patterns of vascularization of the medial distal part of the femur were identified, all dependent on the course of the DGA and its branches. These arteries are all potentially at risk for damage in less invasive plate fixation in medial SCO (Figs. 1, 4). However, no major vascular damage was found in the SCO that was performed using the presented less invasive approach.

Variations in vascularization

At risk in medial SCO is the branch from the femoral artery that runs an oblique course to the superomedial pole of the patella (Fig. 4) and is referred to in the literature as the articular, the osteoarticular, the musculo-articular branch, or DGA [1, 4, 9, 22, 30]. The data in this study are in accordance with the variable course of the DGA and its branches that have been previously described [1, 4, 9, 22, 30]

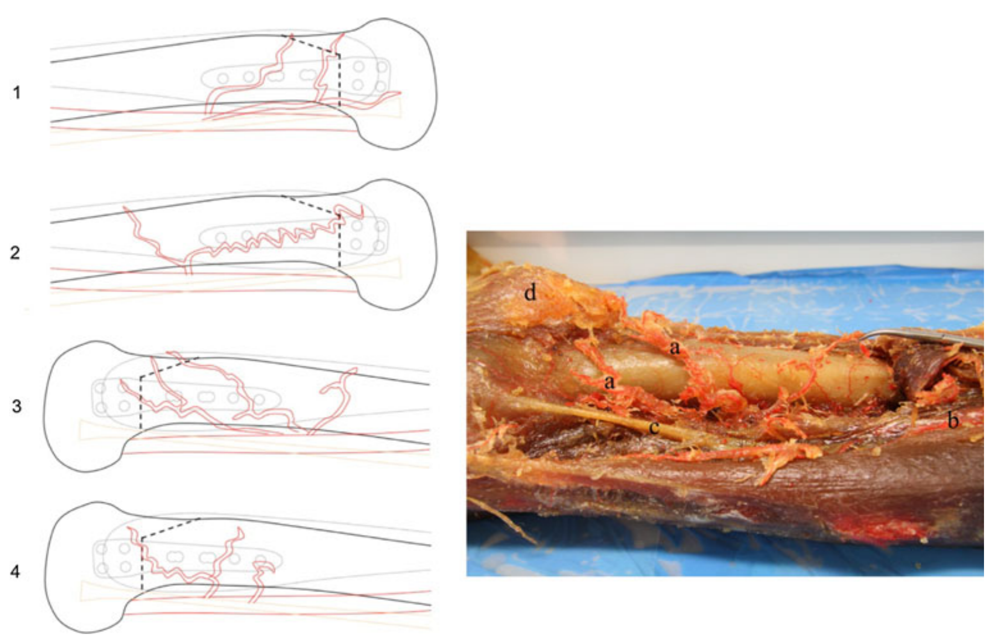

Fig. 4 Schematic representation of the descending genicular artery (DGA) and its branches as found within the VM muscle in the manually dissected cadaver legs (specimen *1–4*) projected on the femur. Femoral artery, adductor magnus tendon, biplane osteotomy and LCP are also projected on the femur. Right: original image after dissection of specimen *3* (**a** DGA, **b** femoral artery, **c** adductor magnus tendon, **d** patella)

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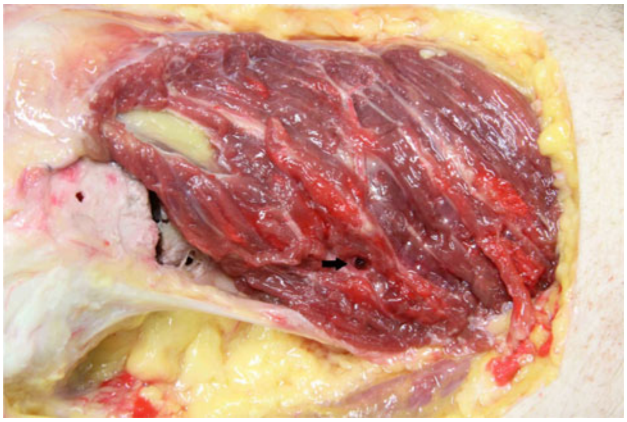

Fig. 5 Dissection of the medial aspect of the femur after biplane SCO and plate removal in specimen 6. Disruption of arteries in the vastus medialis muscle caused by the distal stab incision (*arrow*) was analyzed. A smaller branch of the DGA was damaged by the stab incision

(Table 2). It branches off into multiple perforating smaller vessels and runs distally and superiorly to the medial femoral condyle and superomedial pole of the patella.

Dubois et al. [4] presented five patterns of the DGA in a study on the options for a corticoperiosteal medial femoral supracondylar flap (Table 2). In a similar study on flap applications, Huang et al. [9] recently presented a comparable DGA branching classification. Yamamoto et al. [30] in a study on vascularized medial femoral condyle bone grafts found that the DGA was present in 89 % of human cadavers; it originated on average 13.7 cm proximal to the medial femoral condyle and had an average internal diameter of 1.1 mm. In the current study, the DGA was present in all with a comparable location of origin and course and had an external diameter of 1.9 mm (±0.3). In defining a safety zone for the midvastus approach for total knee arthroplasty, Basirar et al. [1] measured a 20°–40° entry angle of the DGA to the superomedial pole of the patella, measured in the frontal plane. In the current study in the sagittal plane, similar angles of the DGA in relation to the longitudinal axis of the femur were found (35° ± 9°), which is easily recognizable during surgery. In all specimens, branches of the DGA project over the LCP from a medial point of view (Fig. 4). But the most proximal plate hole was found to be located outside the DGA branching pattern. The stab incision for proximal screw insertion should be made in this area.

Cryomicrotome sectioning was used in the current study to produce 3D images of the medial aspect of the distal femur. Although very elaborate, it is an accurate and therefore invaluable technique. A high resolution camera was used to photograph sequential 25-micrometer coupes. Since each layer of sectioning is photographed in true full color, different contrast agents can be used to highlight structures, as was done with Araldite for the arteries in the current study. Because the leg was frozen, subsequent sectioning did not alter the position of anatomical structures. After software reconstruction of the two other anatomical planes, synchronous display of all three planes allowed 3D visualization of the specimen. Surfaces and distances can be measured exactly, and by defining a region of interest in consecutive slides, the course of independent structures can be reconstructed as was done with the DGA (Fig. 2d).

VMO-VML interval and surgical access

Recently, Smith et al. [24] presented a systematic review of 26 mostly cadaveric studies on the existence of the VMO and the VML. They concluded that there is insufficient evidence to suggest that the VM is composed of two separate components. In the majority of the included studies, the muscles could not be distinguished by a different alignment in fibers. In addition, in only 19–24 % of the cadavers studied, an actual fibrofascial plane between the muscles could be found. The findings in the six legs that were dissected in the present study are in accordance with their analysis; no fibrofascial plane was seen in any of the specimens, and a different alignment of fibers was objectified in only two cases. In addition to that, Jojima et al. [11] found small nerve fibers of the medial branch of the

Table 2 Overview of cadaveric studies concerning the anatomy of the descending genicular artery and its branches

	N	Purpose	Result	Artery to patella	Presence
Scheibel et al. [22]	32	Subvastus approach TKA	9 patterns	Musculo-articular branch	Always
Basirar et al. [1]	15	Midvastus approach TKA	Average angle and distance to patella	Descending genicular artery (DGA)	Always
Dubois et al. [4]	25	Composite tissue flap	5 patterns	Osteo-articular branch	Always
Yamamoto et al. [30]	19	Composite tissue flap	Presence of branches, location and diameter	Osteo-articular branch	89 %
Huang et al. [9]	34	Composite tissue flap	4 patterns	Articular branch	Always

Many patterns were identified: the branch running to the superomedial pole of the patella, which is potentially at risk in the less invasive approach, was given several names and was nearly always present

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femoral nerve crossing between the main body of the VM and distal oblique portion furthermore indicating that there is no clear watershed or cleavage plane in innervation between the two; creating such a plane might even cause damage to neural structures.

Safety and feasibility of the less invasive approach

The SCO in the sixth leg using a less invasive approach proved to be safe and feasible. The vascular damage was in accordance with what can be expected from the course of the DGA and its small muscular branches. One smaller vessel was disrupted, whereas the main DGA branch was intact. Using this new technique, the more proximal part of the VM that is otherwise also stripped of the septum and femur remained intact, which is likely to preserve the blood supply in that part of the VM.

Stahelin and Hardegger [25] also were able to use a less invasive approach by using a small malleable implant through a single medial incision but they did not provide a detailed anatomical description of the approach used, and there is no biomechanical data that support the use of a soft short malleable implant for medial SCO.

There is no literature on bleeding complications in percutaneous pins and wires placed at the medial side of the distal in placing external fixators near and/or over the knee joint; safe corridors can be created using drill sleeves.

To minimize the risk of damaging an artery in the presented less invasive approach, the VM should not be retracted ventrally at the distal incision site while making the stab incision proximally because in most vascularization patterns the DGA is then pulled into the area of penetration of the stab incision, whereas the stab incision is likely to pass the DGA ventrally with the muscle belly left in place.

Distally large nerve branches from the femoral nerve that run from dorsal to ventral relative to the septum innervating the VM either need to be cut in the traditional subvastus approach or are at risk for damage by stretching (Fig. 1). What's more, besides the most distal nerves that branch from the septum to the VM, a motor nerve sometimes branches off from the saphenous nerve, innervating the oblique part of the VM [8]. It is not known how much stretching of these nerve branches is allowed before permanent nerve damage occurs and muscle atrophy will sustain. In the less invasive approach, only the most distal part of the VM is lifted. This reduces the stretch on these nerves. In the area of the proximal stab incision, the size of the nerves was too small to visualize, because of that only little damage can be expected.

In addition, after the stab incision is made, blunt dissection to the plate and drilling through drill sleeves will further reduce the risk of damage. It is the current author's impression that using these techniques, the risk of vascular damage can be minimized. It should be noted, however, that just proximal to the most proximal part of where the current plate will sit on the femur, there is considerable risk of neurovascular damage at the location of the adductor canal (Hunter's canal). In this anatomic location, the femoral artery and vein as well as the muscular branch of the femoral nerve and saphenous nerve are at risk when performing stab incisions. MIPPO techniques for plate fixation on the medial side of the femur with plates longer than the plate in the current study used for medial SCO are therefore ill advised.

Important limitations of this study are the limited amount of legs that were investigated. This is mainly due to the fact that the preparation process applied is lengthy and expensive and the collection of data using the cryomicrotome is very time-consuming. It is the first time, however, that an anatomical study on the medial aspect of the femur has been performed specifically with respect to SCO. Furthermore, three modalities were combined: anatomic dissection, 3D analysis using a cryomicrotome, and the actual application of the less invasive surgical technique.

Clinical relevance of the less invasive approach described here is the potential for decreased neurovascular and muscular damage in SCO, while optimizing bone healing potential, subsequently shortening rehabilitation time without increasing complication risk. Plate removal can be performed through the same incision and approach to the femur with palpation over the plate from distal to proximally helping to locate the screws through the stab incision scar. Future placement of a total knee arthroplasty can be performed through a separate standard median incision and parapatellar approach to the femur. The clinical application of the less invasive technique described in the present study in patients that undergo a SCO will have to prove its safety though.

Conclusion

The vascularization of the medial aspect of the femur as documented in this study allows for a medial closing wedge SCO to be performed using a less invasive subvastus approach to the femur. Inserting the plate through the septum between the VMO and the VML is not feasible as a fibrofascial septum exists in only a limited number of cases. The less invasive approach is technically feasible and safe and damage to the VM and its neurovascular structures is minimized as compared to the traditional subvastus approach.

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Conflict of interest None declared by all authors.

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