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Cutaneous angiosome of the chimeric SLGA perforator flap: Anatomical study and clinical considerations☆

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Summary *Background:* The superior lateral genicular artery (SLGA) is the basis for a chimeric perforator flap in the lateral knee region, which may include bone, cartilage, fascia, and/or skin. To the best of our knowledge, a detailed description of the corresponding perforator-based skin area is missing in the literature. The aim of this study was to describe the extent and possible variations of the cutaneous angiosome of the SLGA.
Methods: In an anatomical study on 21 fresh frozen lower limbs, the SLGA was injected with toluidine blue. The anatomy of the vessel and its perforators was explored, and the skin containing the cutaneous angiosome was harvested and photo-documented. Evaluation of the images was performed using ImageJ software. In addition, the versatility of the SLGA perforator flap is illustrated as both a pedicled local and a free tissue transfer.

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Lateral femoral
condyle flap

Results: For each vessel, there were 1.75 ± 0.9 (range 1-3) perforators at an average position of 47.3 ± 21.3 mm lateral to the superolateral patella and 42.5 ± 18.7 mm proximal to the knee joint. The angiosome area was 222.8 ± 57.6 cm^2 with a length of 20.9 ± 3.0 cm and a width of 15.4 ± 3.0 cm. At the longitudinal axis of the highest perforator density, the proximal end and the distal end of perfusion averaged 13.4 ± 4.1 cm proximal and 2.5 ± 2.0 cm distal to the knee joint, respectively.
Conclusion: Our results show that the SLGA supplies a constant angiosome over the anterolateral proximal knee joint. Its description and visualization will guide surgeons in preoperative planning and further extend the use of this versatile chimeric perforator flap.

Introduction

The superior lateral genicular artery (SLGA) supplies the lateral femoral condyle, as well as the surrounding muscle, fascia, and skin.[1] A fasciocutaneous flap based on the perforators of this vessel has first been described in anatomical studies conducted by Laitung in 1989 and Hayashi et al. in 1990.[2,3] In one of the earliest clinical reports by Spokevicius et al., the use of a local sliding flap at the lateral knee and two vascularized free flaps for skin reconstruction around the thumb was described.[4] Since then, different authors have used a pedicled fasciocutaneous SLGA flap for soft tissue reconstruction around the knee. Indications included exposed endoprostheses, defects after tumor resection, chronic skin lesions, and reconstruction after trauma, with reports of excellent esthetic and functional results.[5-7] More recently, Higgins and Bürger introduced the lateral femoral condyle flap as a source of vascularized bone.[8] This free osteochondrous flap was applied in talar and mandibular defects as an alternative to the medial femoral condyle flap.[8,9] In addition to bone and cartilage, the presence of septocutaneous perforators allows inclusion of fascia and skin into this chimeric flap based on the SLGA.[1] This versatility, in combination with low donor site morbidity and reliable anatomy,[10,11] would facilitate the use of this flap for the reconstruction of complex defects requiring multiple tissues. However, as the range of possible clinical applications is not well explored and some of its indications are just emerging, the SLGA perforator flap has not yet entered the standard repertoire of most reconstructive surgeons. Furthermore, while harvesting technique has been reported, to date, there are no detailed descriptions of the cutaneous angiosome of the SLGA. Thus, the purpose of this study was to delineate the extent of cutaneous perfusion and its variability to elucidate the skin area that can be safely harvested and thereby guides future clinical applications. Additionally, we review the anatomy of the vessel and its perforators and present two clinical cases.

Methods

The study was conducted at the Division of Anatomy of the Medical University of Vienna and was approved by the local institutional review board. A total of 21 individual fresh frozen extremities of 14 human body donors (5 females, 9 males) were included. Mean age of the donors was 82.1 ± −9.2 years (range 68–103 years). Inclusion criteria were defined as no prior surgery with visible scars at the knee or distal thigh level, as well as the absence of severe atherosclerosis. Given the average donor age, some degree of atherosclerosis was seen in the majority of cadavers. The decision to exclude a specimen was made when palpation of the SLGA suggested a high degree of calcification or when injection of the vessel was possible only with increased resistance or impossible at all.

Figure 1. Cutaneous angiosome of the SLGA on the left leg after injection of toluidine blue.

Dissection was made as a longitudinal incision along the posterior thigh up to just below the knee joint. Using standard surgical instruments, the tissues were meticulously dissected until the popliteal vessels were fully visualized. The femorotibial joint was then cannulated to determine its exact plane. The branches of the popliteal artery were separately explored, and the SLGA was identified according to prior anatomical descriptions. The distance of its origin to the knee joint line was measured. The artery was then cut at the origin, and its external diameter was measured using a digital caliper. Its lumen was cannulated with a 22-gauge catheter and secured by ligation. If the middle genicular artery was a branch of the SLGA, care was taken to push the cannula past the branching point and place the ligation more distally. Using a 5-ml syringe, a solution of 1:4 diluted toluidine blue was carefully injected into the artery, under constant observation of the corresponding skin area. After demarcation (Figure 1), the cutaneous angiosome was

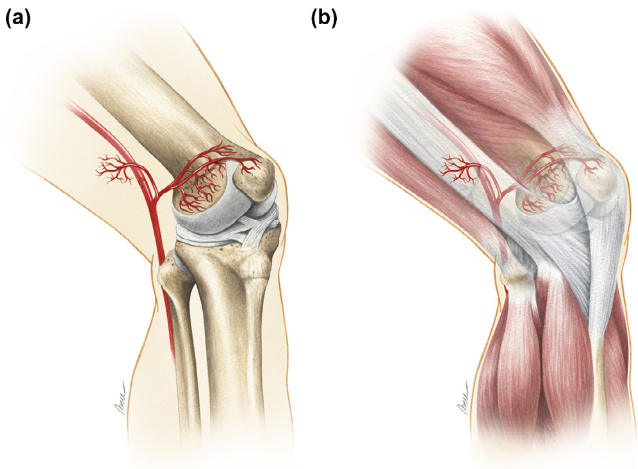

Figure 2. Anatomical illustrations depicting the course of the SLGA, including a perforator.

encircled with a marker and the anatomical reference points were labeled on the skin.

The SLGA was then further dissected along its course. Branching patterns were explored and noted, until all septocutaneous perforators were dissected free. The piercing points of the perforators through the deep fascia were labeled on the skin, and pedicle length from origin at the popliteal artery to the passage through the fascia was measured. The skin area containing the angiosome as well as all points of reference was harvested and photographed in a standardized fashion. Image analysis with measurement of cutaneous angiosome dimensions and perforator positions was carried out using ImageJ software (ImageJ, Version 1.51, National Institutes of Health, USA).

Statistical analyses were performed in Excel (Microsoft Excel, Version 15.36) using mean value and standard deviation.

Results

The SLGA was identified as a branch of the popliteal artery in 20 out of 21 lower extremities (95%). In the remaining specimen, no appropriate vessel was found exiting the popliteal artery after all branches were sufficiently explored. The average point of origin was 38.5 ± 9.4 mm (range 20.7–69.4 mm) proximal to the knee joint line, and diameter at origin was 2.0 ± 0.2 mm (range 1.6–2.4 mm). The SLGA showed a consistent course, running anteriorly along the distal posterolateral femur, just proximal to the lateral femoral condyle (Figure 2). From its beginning, it emits multiple muscular and osseous branches until it reaches the lateral intermuscular septum. There it divides into the superficial and deep branches, consistently producing a septocutaneous perforator dorsal to the septum. After passing beneath the septum, either one of the main branches may provide one to two perforators. In each of the 20 vessels, one to three septocutaneous perforators were found, on average 1.75 ± 0.9 per specimen. The perforators pierced the fascia at an average distance of 42.5 ± 18.7 mm (range -3.0 to 88.1 mm) proximal to the knee joint and 47.3 ± 21.3 mm (range 8.9–89.9 mm) lateral to the superolateral patella. Total pedicle length until perforator passage through the fascia was 93.6 ± 14.0 mm (range 74.9–121.5 mm). The deep branch runs close to the femur, supplying the distal diaphysis and lateral condyle. The superficial branch also produces osseous branches to the femoral condyle and terminates at the superolateral patella.

Dimensions of the cutaneous angiosome are shown in Table 1. Perfusion was confined to the lateral and anterior parts of the distal thigh and knee region. Figure 3 shows an overview of the individual angiosome sizes and positions as well as perforator positions in relation to the main points of reference.

Case 1

A 92-year-old male was admitted to our hospital because of a large prepatellar soft-tissue tumor of his right leg. MRI scans showed a 5 cm enlargement located epifascially ventral to the patella, and ultrasound-guided biopsy revealed a myxofibrosarcoma. After wide resection of the tumor, the remaining defect was covered with a pedicled fasciocutaneous SLGA flap (Figure 4). A perforator was located following preoperative Doppler evaluation. Dimensions of the skin paddle were 10×5 cm. A strip of fascia lata was included in the flap and used to repair the knee joint capsule, which had been removed partly during tumor resection. The flap showed excellent perfusion at all times and the wounds were healed at suture removal. At the 6-week follow-up, the patient had regained full range of motion in the knee joint and was pleased with the esthetic result.

Case 2

A 60-year-old male suffered a loss of his left Achilles tendon due to a fistulating infection after tendon reconstruction. Multiple debridement resulted in total loss of the tendon as well as significant soft tissue deficit. Six months later, a free composite SLGA perforator flap containing fascia and skin island was used for secondary reconstruction of the tendon as well as overlying soft tissue (Figure 5). Preoperative Doppler ultrasound was used for locating the perforator. Dimensions of the skin paddle were 12×4 cm, with a fascia length of 16 cm. After harvest of the flap, the SLGA and accompanying vein were attached to the posterior tibial vessels through end-to-side anastomosis. The fascia was then doubled and sutured between the stumps of the Achilles tendon. Postoperation, the patient received cast fixation of the ankle joint for 6 weeks. The skin flap showed delayed healing at distal tip; hence, a small area (6×3 mm) was subsequently excised and closed by direct suture. At 9-month follow-up, the scars at the reconstruction and donor sites had adequately healed and the flap showed a good esthetic match to the surrounding skin, without excessive bulk. Functionally, the patient had regained normal ambulation and good active range of motion with sufficient power for unilateral toe stance.

Table 1. Dimensions of the cutaneous angiosome of the SLGA. *These measurements refer to the proximal and distal ends of perfusion as well as the resulting length along a longitudinal axis through the point of the highest perforator density (4.7 cm lateral to the superolateral patella), where flap length is commonly determined during harvest.

	Mean	Maximum	Minimum	Std. Deviation
Size (cm^2)	**222.8**	308.1	91.2	57.6
Maximal Length (cm)	**20.9**	27.4	15.5	3.0
Maximal Width (cm)	**15.4**	20.6	8.3	3.0
Perfusion proximal to knee joint (cm) *	**13.4**	22.8	4.8	4.1
Perfusion distal to knee joint (cm) *	**2.5**	5.8	−1.4	2.0
Length (cm)*	**15.8**	23	5.8	4.4

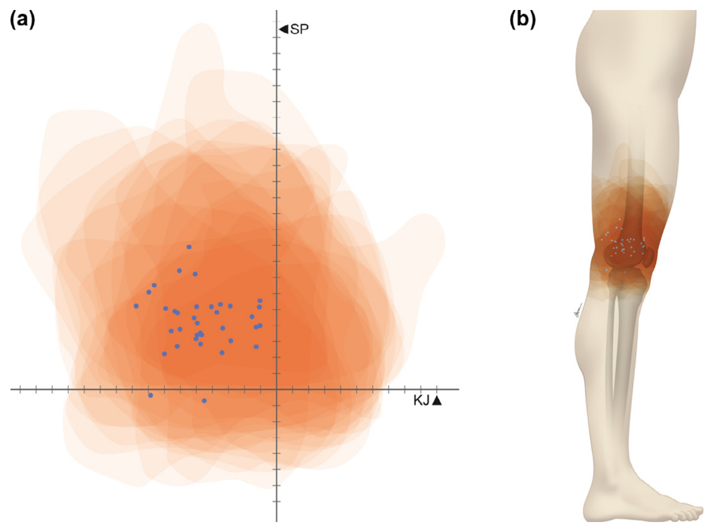

Figure 3. Overlay graphic of all angiosomes for the right leg (images from the left side were mirrored and included) as well as perforator locations (blue points). (A) The axes depict reference structures (KJ = knee joint, SP = superolateral patella), each segment is 1 cm. (B) Position of the angiosomes and perforators projected onto a leg.

Discussion

Different authors have described the anatomical specifications of the SLGA, including its detailed branching pattern. Most of them have found the vessel to consistently originate from the popliteal artery.[1,6,10,11] However, in the first description of the lateral genicular artery flap in 1990, Hayashi et al. described 20% of the vessels to originate from a sural artery.[3] In our study, the SLGA was found exiting the popliteal artery in 20 out of 21 limbs. In one specimen, the vessel could not be identified. This suggests some anatomical variability of the SLGA and might be explained by an alternative source vessel. Our observed point of origin from the knee joint, as well as external diameter at origin, is largely consistent with those reported in prior investigations.[1,10,11] Wong et al. described a pedicle length range between 3.5 and 6.3 cm for the corticoperiostal lateral femoral condyle flap.[1] Zumiotti et al. measured the pedicle length of cutaneous perforators from the "identifiable portion in the subcutaneous tissue" up to the popliteal artery as 6.1 ± 1.9 cm.[12] The current study has found pedicle lengths between 7.5 and 12.2 cm when measuring from the origin of the vessel at the popliteal artery up to the piercing point of the perforator at the deep fascia. Considering the additional length of perforators, it is expected to find longer pedicles for the fasciocutaneous flap than for the condyle flap. However, the discrepancy in the findings described by Zumiotti et al. has no apparent explanation and therefore might be the result of differences in methodology. The perforator lengths observed in this study are comparable to workhorse flaps such as the anterolateral thigh flap.[13] These findings suggest that the indications for a fasciocutaneous flap based on the SLGA may be expanded to reconstructive situations where a longer pedicle is needed.

Our dissections have revealed one to three septocutaneous perforators originating from each SLGA. Nguyen et al. and Morsy et al. described similar numbers and consistency of perforators.[6,10] The latter study further stated that the perforators had their origin close to the branching point into superficial and deep branches and could originate from either the main trunk or one of the branches. These possible origins were also observed for the perforators in our study, which then traveled either posterior or anterior to the intramuscular septum. The superficial branch may provide an additional skin perforator close to the patella that pierces the fibrous knee joint capsule. These distal perforators were not included into our measurements, as harvest of that vessel would necessitate dissection through the joint capsule. The points of perforator passage through the deep fascia are demonstrated in Figure 3. Out of

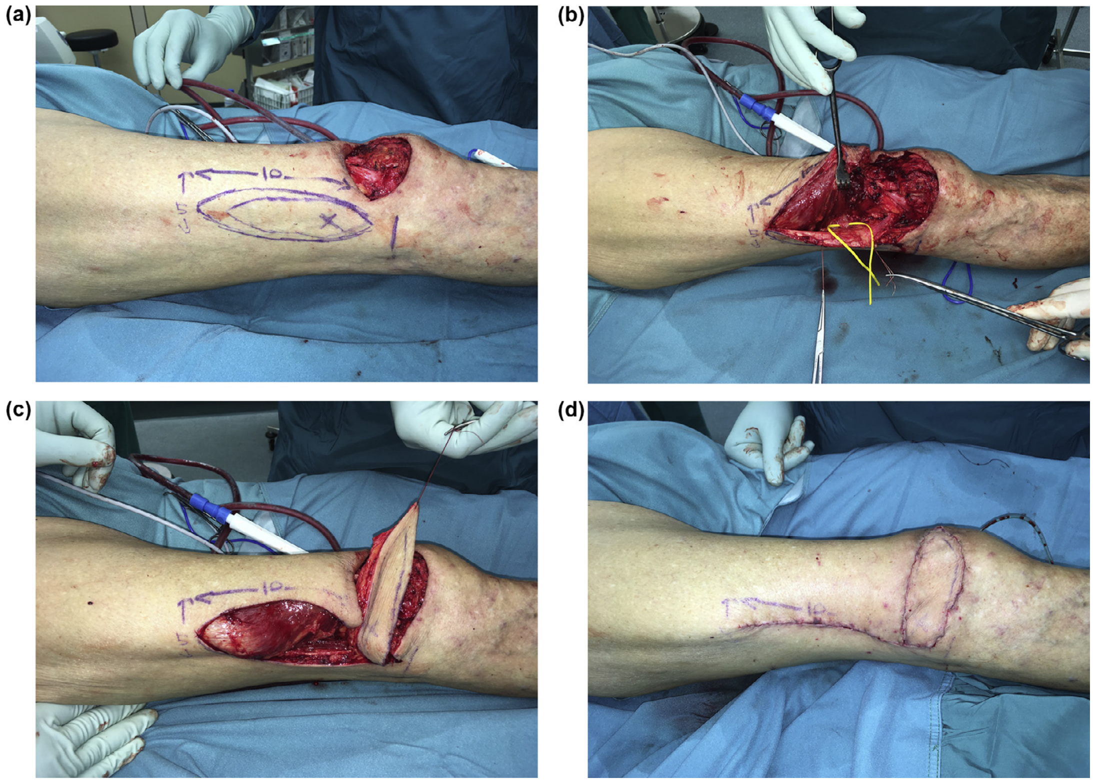

Figure 4. Reconstruction of a defect after resection of a prepatellar soft tissue sarcoma, using a pedicled fasciocutaneous SLGA flap: after tumor resection, the flap dimensions were planned with a surgical marker, including perforator position and plane of the knee joint (A). The perforator vessels were exposed (B) and the flap rotated for defect coverage (C). The joint capsule was reconstructed using fascia, and skin at the donor and coverage sites was subsequently closed (D). The six-month follow-up revealed total survival of the flap and an esthetically pleasing result.

35 perforators, 29 were found within 2 and 7 cm proximally to the knee joint and 25 out of 35 between 2 and 7 cm laterally to the superolateral patella. In 16 out of 20 specimens, at least one perforator was present within both of these boundaries. This 5 × 5 cm square area is where perforators can be expected in the clinical setting (Figure 6), which was consistent with the two clinical cases described. As there are some outliers, even going slightly distal to the knee joint or very close to the patella, preoperative sonography is strongly recommended. The authors still often use handheld Doppler because of availability and convenience. However, Duplex sonography has proved more reliable in locating perforators and is able to provide more information about the detailed anatomy.[14,15] Therefore, in light of the anatomical variability of the SLGA and its rather superficial course, which may lead to false-positive signals from the main vessel, Duplex is recommended as the method of choice for this flap. The use of Duplex is particularly helpful in elderly patients with atherosclerosis, where evaluation of blood flow may be necessary.

There have been some studies investigating perfusion area of the SLGA as well as clinical reports of skin flap dimensions. Nguyen et al. performed a CT angiography after injection of barium sulfate into a perforator of the SLGA.[6] In their paper, they briefly described the perforasome to be limited to the lower half of the thigh. In addition, they presented two clinical cases of pedicled flaps, sized 27 × 10 cm and 28 × 7 cm, which both showed minor tip healing delays. Wong et al. used latex infusion to delineate the supply of the SLGA and described skin perfusion at the anterolateral knee of up to 15 × 10 cm, without giving distinct margins or points of reference.[1] Hayashi et al. claimed safe harvest of the lateral genicular artery flap until midpoint between great trochanter and lateral condyle.[3] They also included clinical reports of two pedicled flaps: one measured 15 × 9 cm and subsequently revealed a 3 cm tip necrosis and the other measured 20 × 5 cm and healed completely. In a case series with 6 patients using a pedicled SLGA flap for soft tissue reconstruction around the knee, Wiedner et al. reported flap sizes ranging from 7 × 5 to 18 × 6 cm, with incomplete flap survival in three of the cases.[7] Taniguchi et al. published a case where a 17 × 5 cm pedicled fasciocutaneous flap was used for coverage of an exposed left knee prosthesis, with full survival of the flap.[5]

As there are no detailed descriptions of skin perfusion of the SLGA and clinical reports include a variety of flap sizes, we set out to delineate the exact extent of the cutaneous angiosome and its variability to propose recommendations for planning the skin paddle. The angiosome of the SLGA includes areas of anastomosis, in particular at the rete patellare and proximally to the descending branch of the lateral femoral circumflex artery.[7,10,16] Our findings revealed average dimensions of skin perfusion of 20.9 × 15.4 cm, with an average area of 222.8 cm^2. The extensions of the individual angiosomes are shown in Figure 3. The center of perfusion was just lateral to the superolateral patella and proximal to

Figure 5. Use of a free fasciocutaneous SLGA flap for combined Achilles tendon and soft tissue reconstruction: the skin flap was planned with dimensions of 12×3.5 cm including a perforator, which was preoperatively located using Doppler ultrasound (A). Fascia measuring 16 cm in length was included during flap harvest and the perforator identified subfascially (B). Scar resection at the heel revealed a tendon defect of approximately 12 cm (C). The flap containing skin and fascia was then elevated and pedicle sutured to the posterior tibial vessels through end-to-side anastomosis using 11–0 Ethilon sutures. The fascia was doubled and sutured into the defect using 2–0 Ethibond, and the wounds were subsequently closed. At a 9-month follow-up, the flap showed an esthetically pleasing result (D) with good functional regeneration, enabling normal ambulation and toe stance (E).

the joint plane, where the perforators are to be expected as well. As shown in Figure 3, there were some outliers, going slightly more proximal and/or ventral than average. This is suggestive of increased collateral perfusion to the adjacent vessels, which may be present because of moderate atherosclerosis in specimens that were not excluded.

The critical aspect when planning a skin flap based on the SLGA perforators is generally its longitudinal diameter. In our study, the maximal length of the cutaneous angiosomes ranged between 15.5 and 27.4 cm, averaging 20.9 cm. However, the maximal length of perfusion was not always oriented along the longitudinal axis of the leg, where flap

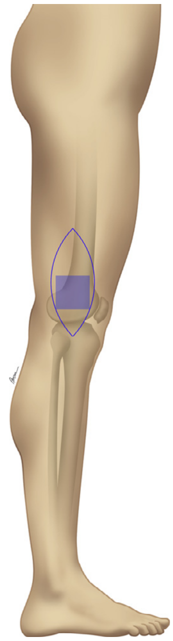

Figure 6. Schematic drawing of the possible flap size and position according to the results of the injection study, depicting a flap length of 16 cm. The square shows the 5 × 5 cm area where perforators can be expected.

length is usually determined during surgical harvest. The proximal end of perfusion measured 4.7 cm lateral to the superolateral patella along the longitudinal axis, which is the level of highest perforator density (Figure 3), averaged 13.4 cm proximal to the joint, and the distal end averaged 2.5 cm distal to the knee joint (Table 1). These measures represent a reference for planning flap size, theoretically allowing for a length of approximately 16 cm (Figure 6). However, reflecting the variability of perfusion shown in Figure 3, clinical results have also been variable, with reports of insufficient healing in a 7 × 5 cm flap[7] and good survival in pedicled flaps of up to 28 cm in length[6]. The latter may be possible in certain cases only, where a wide pedicle is preserved and sufficient anastomosis to the descending branch of the lateral femoral circumflex artery is left intact. In light of the current investigation as well as the clinical experience of the authors, such extensive lengths cannot be recommended. Proximal extension of the skin island can safely be planned according to the findings of our perfusion study. Distal harvest, however, should not extend below the knee joint, as perfusion at the distal tip can be problematic in free flaps (see Case 2) and wound healing impairment should not be risked at the knee level, where secondary coverage can be challenging. Regarding flap width, the limits are generally determined by the goal of primary wound closure. None of the flaps described in the literature were wider than 10 cm, which does not exceed the width of the angiosome according to our results. Nevertheless, as a general recommendation, the flap should not be wider than 5 cm. As the skin at the distal thigh is relatively tight, a larger horizontal diameter will inhibit primary closure in the majority of patients. Thus, while the anatomical results suggest possible flap dimensions of 16 × 10 cm, a more conservative approach seems warranted after consideration of clinical aspects. Further refinements of these suggestions will be guided by future high-volume clinical reports.

With regard to the donor site at the distal lateral thigh, there are generally no major functional or esthetic impairments following flap harvest. Nevertheless, the experience of the authors shows that harvest sites, which include fascia lata, have a tendency to develop postoperative seromas. Surgeons should therefore be aware of that risk and take according preventive measures such as tight postoperative dressing and prolonged drainage.

Currently, the standard approach for soft tissue coverage around the knee is local muscle flaps, most commonly the medial gastrocnemius flap. However, they exhibit various disadvantages: muscle harvest can lead to functional restrictions at the donor site, flaps are generally excessively bulky for the prepatellar region, and split-thickness skin grafts poorly match the appearance of the surrounding skin.[7,17] Furthermore, these flaps are not able to reach suprapatellar and prepatellar lesions. The SLGA flap offers a good alternative with minimal donor site morbidity and produces a much thinner and more esthetically pleasing reconstruction, with little to no donor site morbidity. If needed, fascia can be included during flap harvest and used for reconstruction of the joint capsule (see Case 1). The flap may, however, not be applicable for extensive lesions of the medial and distal areas around the knee, where the flap size and arc of rotation can be insufficient for proper coverage.[7,12]

The size of the artery and accompanying veins has proven to be sufficient for microanastomosis in free flaps. In our anatomical study, the average diameter of the SLGA was found to be 2 mm, slightly larger than that of the artery of the medial femoral condyle flap.[1,18] Another advantage of the chimeric SLGA perforator flap is that in addition to bone and skin, fascia can be harvested. Reported applications of free flaps based on the SLGA include soft tissue coverage around the hand[4], mandibular and talar reconstruction using corticoperiostal flaps,[8,9] and Achilles tendon reconstruction using a strip of vascularized iliotibial band[11]. Regardless of the indication, inclusion of a skin paddle provides the advantage of offering sufficient gliding tissue and tension-free closure as well as giving the possibility of monitoring the flap.[19] For Achilles tendon reconstruction, the fasciocutaneous free SLGA flap presents a promising alternative to the anterolateral thigh flap, which is commonly used in combined tendon and soft tissue defects.[20,21] The thin skin of the distal lateral thigh is a superior match around the heel in comparison to the thick subcutaneous tissue of the proximal thigh, which sometimes necessitates secondary debulking procedures.[20] The authors have had positive experience with the SLGA flap in this indication, warranting further larger scale investigations.

Conclusions

In conclusion, the SLGA provides a good basis for harvesting a composite flap, which can be employed for reconstruction of bone, cartilage, fascia, and skin defects. This study set out to delineate the position and size of the skin paddle, which can safely be included, thereby guiding clinicians in preoperative planning. We are therefore convinced that the SLGA perforator flap should be included in the reconstructive surgeon's repertoire as a local as well as distant tissue transfer, encouraging the exploration of further possible applications in the future.

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Conflict of interest statement

None of the authors have any financial and personal relationships with other people or organizations that could inappropriately influence (bias) this work.

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