Original Article

Repair of severe peri-knee soft tissue defect using an anterolateral thigh flap with the descending genicular vessels as the recipient pedicle: a case series of 14 patients

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Background: The application of free skin flaps to repair severe peri-knee soft tissue defects is a common clinical approach. This article aims to investigate clinical efficacy and precautions of using a free anterolateral thigh flap with the descending genicular vessels as a recipient pedicle for repairing Gustilo IIIB and IIIC soft tissue defects around the knee.

Methods: We retrospectively analyzed the data of the patients with severe peri-knee Gustilo IIIB or IIIC soft tissue defects operated on from January 2015 to December 2019. All patients underwent repair of the severe soft tissue defect using anterolateral thigh flap transplantation with the descending genicular vessels as the recipient pedicle.

Results: All patients completed effective follow-up for an average of 14.1 [6–30] months. For two patients with larger flaps, necrosis occurred in the distal tip of the flaps, 6 cm and 4 cm in size. The necrotic flaps were removed, and the wound healed after skin grafting. In the other 12 patients, the skin flaps fully survived.

Conclusions: Using a free anterolateral thigh flap with descending genicular vessels as the recipient pedicle to repair Gustilo IIIB and IIIC soft tissue defects around the knee is a convenient and preferred technique that can achieve satisfactory efficacy.

Keywords: Anterolateral thigh flap; descending genicular vessel; descending branch of lateral femoral circumflex vessel; case series

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Introduction

Gustilo IIIB and IIIC peri-knee injuries caused by high-energy trauma have become more common year by year and are common in patients with compound injuries and multiple injuries. Such patients present with local skin and soft tissue defects with exposure of important tissues after the injury or exposure of important tissues due to secondary skin necrosis caused by severe soft tissue defects. Most of them require skin flap repair. Gustilo IIIB and IIIC injuries are high-energy injuries. Some patients with these types of injury have large wounds that are difficult to repair using local flaps. Therefore, free flap transplantation has become a common option. Among this type of flap, the free anterolateral thigh flap is one of the preferred choices due to its easy use in transplantation and sufficient supply of skin.

The unavoidable issue with the use of free flaps is how to select the blood vessels at the recipient site, especially the recipient site's arteries. The conventional choice in the lower extremities is to use the anterior tibial or posterior

tibial vessels. However, the anterior tibial and posterior tibial vessels are deep at the level of the knee joint, so it is difficult to dissect them. Gustilo IIIB and IIIC fractures, which are high-energy injuries, most likely cause anterior tibial and/or posterior tibial vessel injury which may result in secondary vascular occlusion. In addition, the course of the injury treatment may exceed 3 weeks due to various reasons, and there is obvious local inflammation in the injury site. A new vascular pedicle is needed reduce the likelihood of postoperative vascular crisis and avoid skin flap necrosis and limb salvage failure, but it is extremely hard to use the anterior tibial or posterior tibial vessel as a vascular pedicle in the recipient site. Therefore, it has been difficult to repair this type of wound in clinical practice.

From January 2015 to December 2019, a total of 14 patients with large skin and soft tissue defects and important tissue exposure due to Gustilo type IIIB and IIIC Peri-knee injury were treated in our department. During the operation, a free anterolateral thigh flap with the descending genicular artery as the recipient pedicle was used for grafting and repair. The clinical efficacy was satisfactory. We present the following article in accordance with the AME Case Series reporting checklist (available at http://dx.doi.org/10.21037/apm-21-827).

Methods

General data

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of Wuxi No.9 People's Hospital affiliated to Soochow University (ID: 20191101) and informed consent was taken from all the patients. A total of 14 patients (8 men and 6 women) were included in this study. Their mean age was 38.3 months (range, 20–56 years). The causes of injury included traffic accidents (10 patients), a falling heavy item (2 patients), and accidental compression by a machine (2 patients). According to the Gustilo classification, nine and five patients had IIIB and IIIC injuries, respectively. Two patients had tibial plateau fractures, two tibial plateau and fibular head fractures, one tibial plateau and patella fractures, eight tibia and fibula fractures, and one femoral condyle, patella, tibial plateau, and fibular head fractures. According to the location of the wound, the injury was on the left side in 10 patients and on the right side in four patients. All were located around the knee. The exposed area of important tissues ranged from 18 cm × 5 cm to 32 cm × 4 cm.

All patients underwent emergency surgery after their injury. The limbs were fixated with a conventional external fixation device. Exploration was performed to repair important tendons, nerves, and blood vessels. The main fractures were managed with limited internal fixation, and the wound was treated with vacuum sealing drainage (VSD). The average time from injury to skin flap repair was 20.6 days (range, 9–48 days). The patients underwent an average of 2.1 debridements before the skin flap was used to cover the wound. Color Doppler sonography (CDS) and/or computed tomography angiography (CTA) were performed to locate the perforating vessels of the bilateral anterolateral thigh flaps, the descending branch of the lateral femoral circumflex artery, and the descending genicular artery and to locate the great saphenous vein on the affected side 1 to 5 days before operation.

The inclusion criteria were (I) age between 18 and 60 years; (II) unilateral Gustilo IIIB or IIIC peri-knee injury, but without medial knee injury; (III) no injury to the bilateral thighs or the contralateral limbs; (IV) preoperative blood vessel examination showing that the difference in the arterial diameter did not exceed 2-fold; and (V) no history of varicose veins or related operations in the lower extremities. The exclusion criteria were (I) age less than 18 years or over 60 years old; (II) medial knee injury or previous surgery history; (III) thigh trauma or history of thigh surgery; (IV) preoperative blood vessel examination showing a difference in the arterial diameters of more than 3-fold or that this difference did not exceed 2-fold but the intraoperative exploration confirmed that the preoperative measurement was inaccurate, and the descending genicular artery was significantly smaller and could not be anastomosed; (V) varicose veins of the lower extremities and related surgical history; (VI) surgical contraindications, such as severe cardiopulmonary disease.

Surgical approaches

Exploration of the blood vessels and nerves in the recipient site

The surgery was performed under general anesthesia with the patient in the supine position. As the wounds had been thoroughly (repeatedly) debrided in the early stage, the wounds appeared relatively clean. The operative field was disinfected and draped, with the wound temporarily covered by sterile dressing during surgery. A straight incision was made in the proximal posterior-medial knee to incise the

skin and subcutaneous tissue, then dissect and separate the saphenous vein and accompanying saphenous nerve, which were marked with temporary ligation. Blunt separation was performed between the medial femoris muscle and the tendon of the adductor magnus to carefully dissect the descending genicular vessel trunk. Further separation continued distally to free the articular branches and saphenous branches along the main trunk, while ligating any small branches. The diameter of the articular branches and saphenous branches were observed. The articular branch or saphenous branch was dissected to the farthest end, divided, and marked with ligation for use in the next step as a pedicle to the donor site flap. Ultimately, the articular branch of the descending genicular vessel was selected as the recipient's blood vessel pedicle in six patients, the saphenous branch of the descending genicular vessel in eight.

Management of donor site and recipient site

The thigh of the healthy side was routinely selected as the flap's donor site. The patient was placed in the supine position with elevation of the heathy-side hip. Based on the perforator position determined by the preoperative CDS and/or CTA and condition of the exposed important tissue, a skin flap was designed. The axis of the flap was the line between the anterior superior iliac spine and the lateral edge of the patella. During surgery, the flap was harvested routinely with preservation of the lateral femoral cutaneous nerve and the main descending branch of the lateral femoral circumflex artery, which were divided and marked for use in the next step. The donor site was closed primarily. The width of the flap in these patients was designed to be less than 8.0 cm.

The harvested flap was transposed to the recipient site and secured with intermittent suture to temporarily cover the wound. The match between the vessels in the flap and those in the recipient site was assessed. The end-to-end anastomoses of the nerves and vessels were performed in the order of nerves, arteries, and veins. During the operation, end-to-end anastomosis between the lateral femoral cutaneous nerve and the medial saphenous nerve was carried out. At the step of the anastomosis of the blood vessels, the arteries were anastomosed first. According to the needed length of the descending genicular artery and the descending branch of the lateral femoral circumflex artery, the descending genicular artery was incised obliquely at the site where the largest diameter of the incised artery could be obtained. The adventitia was trimmed, and the artery was dilated mechanically and anastomosed to the descending branch of the lateral femoral circumflex artery (end-to-end anastomosis). Two methods of venous anastomosis were used. In patients recruited in the early part of this study period, we noticed that most of the descending genicular arteries were accompanied by narrow veins that had less than one-third the diameter of the veins associated with the lateral femoral circumflex artery. Thus, only one accompanying vein of the descending branch of the lateral femoral circumflex artery was selected for end-to-end anastomosis with the great saphenous vein. However, in patients recruited later, we noticed that the two accompanying veins of the descending genicular artery in four patients were wider, and their diameters did not differ more than 2-fold from that of the vein accompanying the lateral femoral circumflex artery. Thus, we selected one artery and two veins for anastomosis, i.e., one accompanying vein was anastomosed to the great saphenous vein, and the other accompanying vein was anastomosed to the accompanying vein of the descending genicular artery.

Postoperative management and follow-up

After the operation, a drainage strip was placed under the skin flap. The affected limb was immobilized with a cast at a position of 15° flexion. One week of strict bed rest was required. The blood supply of the flap was observed every 2 hours after operation, and abnormal signs were managed immediately. The room temperature was kept at approximately 25.0 ℃. The patient was told to abstain from smoking. The symptomatic treatments included multimodal analgesia, anti-inflammatory, anticoagulation, and antispasmodic treatment.

After discharge from the hospital, the patients were followed up regularly (once a month for 6 months and once every 3 months afterward). The follow-up parameters were (I) observation of the blood supply, elasticity, swelling degree, and sensory recovery of the skin flap in the recipient site; (II) observation of the healing of the skin flap and the donor area of the skin graft and scar hyperplasia; (III) observation of whether the pin track of the external fixation device was infected; (IV) radiography to determine fracture healing and choose the regimen for phase II.

Results

All patients completed effective follow-up for an average of 14.1 months (range, 6–30 months). In two patients with larger flaps, necrosis occurred in the distal tip of the flap, 6 and 4 cm in size. The necrotic flaps were removed, and

the wound healed after skin grafting. The skin flaps of the other 12 patients fully survived. Of those, repair with a flap alone was performed in five patients and repair with a flap and skin grafting in seven patients. Since the designed flap was too small in a patient, bone transport and flap extension were performed for wound healing. Limb salvage failed in a patient, so knee-salvage treatment was performed with skin flaps and grafting treatment. One patient underwent supracondylar amputation of the femur due to severe infection of the limbs, and the survival skin flap was used to cover the limb stump. Arterial crisis occurred in one of 14 patients after flap grafting, which was resolved after timely exploration (*Table 1*). All incisions at the donor site of the flaps healed primarily. The follow-up showed that the flaps were soft in texture and satisfactory in appearance and thickness, and some of them recovered with superficial sensation and sweating activity.

Typical case

A 30-year-old woman was admitted to the hospital due to an open fracture of the upper left tibia and fibula (Gustilo IIIC) caused by a traffic accident. Emergency debridement along with posterior tibial vessel repair, tibial short Kirschner wire fixation, extended ankle-knee external fixation, and VSD negative-pressure drainage were performed. A free right anterolateral thigh flap (20 cm × 6 cm) was transplanted to repair the anterior knee wound on the 18th postoperative day. During the operation, the descending genicular artery was anastomosed with the descending branch of the lateral femoral circumflex artery, the accompanying vein was anastomosed with the great saphenous vein, and concurrent skin grafting was performed for the popliteal fossa and calf wounds. After the operation, the flap and skin graft fully survived. Because the limb was shortened by 4 cm, Ilizarov limb lengthening was performed 6 weeks after the flap grafting, and minimally invasive osteotomy was performed in the distal tibial metaphysis. The limb lengthening was performed intermittently starting on the 7th day after the operation, at a speed of 0.6–1 mm/d for 4 months. Then, weight-bearing exercise was started. The tibia had healed 10 months after the operation. The external fixation was removed, and then weight-bearing walking exercise was started. Functional exercise continued for 2 months, and the limb function was good (*Figure 1*).

Discussion

High-energy trauma around the knee often results in Gustilo type IIIB and IIIC open fractures with large soft tissue defects (1). The knee is a very important weight-bearing and movable joint of the lower limbs, so the peri-knee soft tissue often must have good flexibility after repair, and the formation of patch scar tissue should be avoided as much as possible. Therefore, how to repair this type of wound is always a major difficulty in microsurgery.

To save the knee joint function after this kind of injury to the greatest extent, in addition to good fracture management, timely and appropriate flap repair is the best choice (2). Three main types of flaps are currently available: free flaps, partial flaps, and cross-leg flaps, each having its advantages and disadvantages (3-6). Among them, the anterolateral thigh flap is recognized as a "universal flap" and is widely used to repair various soft tissue defects and wounds, and good clinical results have been achieved (4). The anterolateral thigh flap is commonly used as a free flap. The free flap should be supplied by appropriate blood vessels in the recipient site. For this purpose, the anterior tibial or posterior tibial vessels are most often selected (5). However, from an anatomical point of view, it is more difficult to use these two blood vessels as recipient blood vessels at the knee joint level. Due to various unfavorable factors, it is very common that these two blood vessels cannot be used clinically (5). To reduce the risk from surgery, it is often recommended to use cross-leg flaps or free flaps combined with a bridging blood supply from the vessels in the contralateral lower leg, and this approach has yielded relatively satisfactory results (6,7). Although the above methods are associated with a high success rate, they require a forced posture that can lead to a painful experience for the patient. If there were a surgical plan that is more conducive to the patient's recovery, it would become the first choice.

With the advent of ultramicrosurgery, perforator vascular anastomosis to form a pedicle for a free skin flap became possible in the recipient site, and there are no obvious technical obstacles (8). The diameter of the descending genicular blood vessels is rarely less than 1 mm, and it can be anastomosed by ultramicrosurgery (9-12). Based on the above considerations, we used free anterolateral thigh flaps

Table 1 Patient general information

Patients	Age (years)	Sex	Affected side	Mechanism of injury	Gustilo classification	Size of skin flap (cm^2)	Blood vessel and its size in the recipient site (mm)	Tissue flap vessel and its size (mm)	Complications	Follow-up
1	42	Male	Left	Traffic accident	IIIB	38×8	Descending genicular vessel: artery 1.6, accompanying vein 1.4	Descending branch of lateral femoral circumflex artery: artery 3.0, 2 accompanying veins 3.5 and 1.2	Skin flap necrosis 6 cm	6
2	26	Female	Left	Traffic accident	IIIB	18×8	Descending genicular vessel: artery 1.1, accompanying vein 0.9	Descending branch of lateral femoral circumflex artery: artery 2.0, accompanying veins 1.8	No	30
3	45	Female	Left	Strangulation by a machine	IIIB	30×6	Descending genicular vessel: artery 1.2, accompanying vein 1.0	Descending branch of lateral femoral circumflex artery: artery 2.3, accompanying veins 2.4	No	28
4	38	Male	Left	Traffic accident	IIIB	28×7	Descending genicular vessel: artery 1.4, accompanying vein 1.1	Descending branch of lateral femoral circumflex artery: artery 2.6, accompanying veins 2.4	No	12
5	20	Male	Left	Strangulation by a machine	IIIB	26×8	Descending genicular vessel: artery 1.3, accompanying vein 1.0	Descending branch of lateral femoral circumflex artery: artery 2.4, accompanying veins 2.4	No	12
6	35	Female	Right	Traffic accident	IIIB	34×6	Descending genicular vessel: artery 1.2, accompanying vein 0.8	Descending branch of lateral femoral circumflex artery: artery 2.3, accompanying veins 2.2	Skin flap necrosis 4cm	14
7	56	Male	Left	Injury by falling heavy item	IIIB	28×7	Descending genicular vessel: artery 1.3, accompanying vein 1.1	Descending branch of lateral femoral circumflex artery: artery 2.1, accompanying veins 2.3	No	9
8	50	Female	Right	Traffic accident	IIIB	25×7	Descending genicular vessel: artery 1.3, accompanying vein 1.1	Descending branch of lateral femoral circumflex artery: artery 2.3, accompanying veins 2.0	No	12
9	30	Female	Left	Traffic accident	IIIC	20×6	Descending genicular vessel: artery 1.2, accompanying vein 1.0	Descending branch of lateral femoral circumflex artery: artery 2.1, accompanying veins 1.9	No	13
10	39	Male	Right	Traffic accident	IIIC	20×7.5	Descending genicular vessel: artery 1.2, accompanying vein 1.0	Descending branch of lateral femoral circumflex artery: artery 2.4, accompanying veins 2.2	No	6
11	36	Male	Left	Traffic accident	IIIC	25×7	Descending genicular vessel: artery 1.3, accompanying vein 1.1	Descending branch of lateral femoral circumflex artery: artery 2.1, accompanying veins 2.0	Amputation after severe infection, transposed flap to cover the stump	12

Table 1 (*continued*)

Table 1 *(continued)*

Patients	Age (years)	Sex	Affected side	Mechanism of injury	Gustilo classification	Size of skin flap (cm^2)	Blood vessel and its size in the recipient site (mm)	Tissue flap vessel and its size (mm)	Complications	Follow-up
12	49	Male	Left	Traffic accident	IIIC	20×8	Descending genicular vessel: artery 1.2, accompanying vein 1.0	Descending branch of lateral femoral circumflex artery: artery 2.2, accompanying veins 2.5	No	16
13	21	Male	Left	Injury by falling heavy item	IIIC	28×8	Descending genicular vessel: artery 1.5, accompanying vein 1.4	Descending branch of lateral femoral circumflex artery: artery 2.3, 2 accompanying veins 2.6	Limb salvage failure, skin flap for repair and protection of the knee	14
14	49	Female	Right	Traffic accident	IIIB	26×7	Descending genicular vessel: artery 1.0, accompanying vein 0.8	Descending branch of lateral femoral circumflex artery: artery 2.1, accompanying veins 2.2	No	13

with descending genicular blood vessels as the recipient pedicle to repair Gustilo IIIB and IIIC peri-knee wounds and achieved satisfactory results.

Relevant anatomy of the descending genicular vessels and the descending branches of the lateral femoral circumflex artery

The descending genicular artery originates at a site 10.5±1.7 cm away from the adductor tubercle and travels anteroinferiorly along with the adductor magnus tendon. The outer diameter of the origin is 1.8±0.6 mm, the major trunk of the vessel is 1.2±0.5 cm in length, and it has two accompanying veins. The descending genicular artery usually gives off thick saphenous branches and articular branches (13). The outer diameter of the origin of the descending branch of the lateral femoral circumflex artery is 3.26±0.74 mm, the trunk length is 13.43±3.92 cm, and it has two accompanying veins (14). From the above anatomical data, the difference in the diameters between the two arteries in most cases rarely exceeds 3 times. With the improved accuracy of CDS and CTA, we only need to evaluate the suitability of the two arteries for anastomosis before the operation and then confirm this in the receiving site during vessel exploration. In the 14 patients of this study, the retrospective analysis showed that all the blood vessels in the recipient site, especially the arteries, were basically consistent with the above description. However, due to the small sample size of this study, more patients are still needed to draw firmer conclusions about anastomosis in this surgery.

The advantages and disadvantages of the descending genicular vessel as a recipient pedicle for the anterolateral thigh flap

Since its main blood vessels are not compromised, the free anterolateral thigh flap with descending genicular vessels as the recipient pedicle for repairing Gustilo IIIB and IIIC peri-knee wound results in almost no damage to the blood supply of the lower limbs. None of the 14 flaps in this study was harvested with the fascia lata. The incision at the donor site was directly sutured and eventually healed primarily. The complications at the donor site were significantly reduced (15). Compared to cross-leg flaps and free skin flaps, which are cross-supplied with the contralateral calf vessels, the biggest advantage of this approach is avoiding long-term bed rest with forced

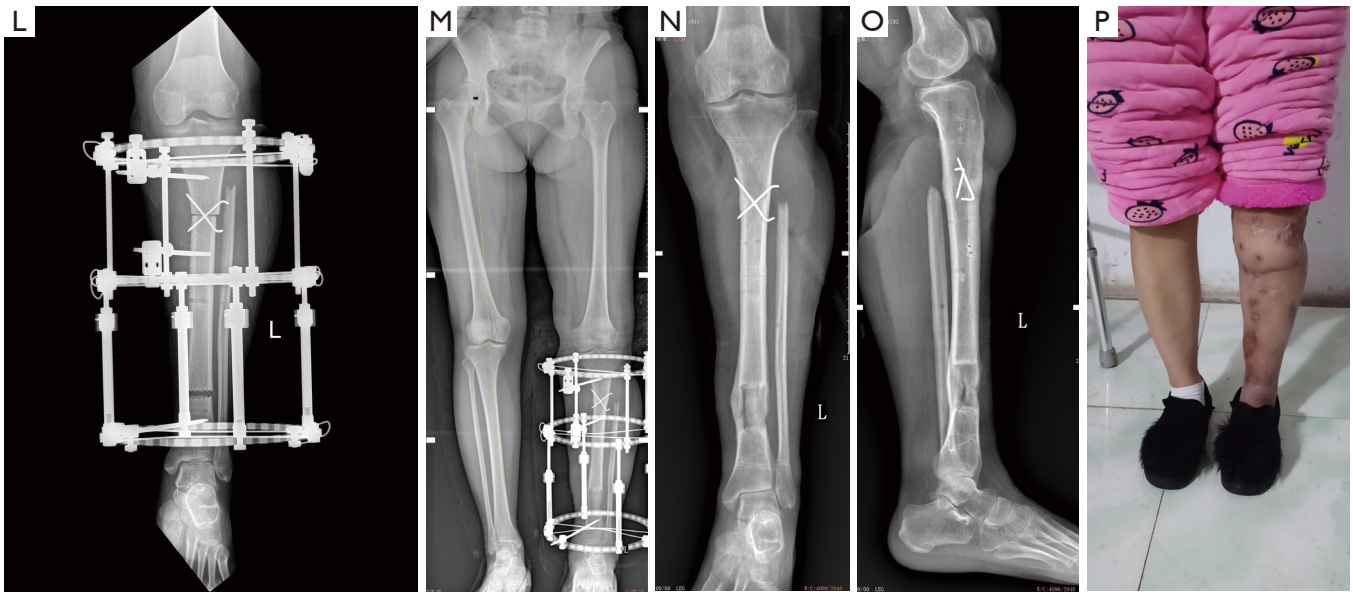

Figure 1 A typical case. (A,B) Appearance and radiograph of the knee injury before emergency operation; (C) repair of posterior tibial artery and vein during operation; (D,E) the appfearance and radiograph of the injured knee after emergency operation; (F,G) appearance of the wound in the recipient site and flap design in the donor site; (H) anastomosis of descending genicular vessel in the recipient area; (I,J) appearance of the injured knee after repair with the skin flap and skin graft; (K,L) photograph showing left limb lengthening during surgery and radiograph of the left limb a week after surgery; (M,N) full-length standing anteroposterior radiograph of the lower extremity; (O,P) appearance and radiograph of the lower limb 2 months after removing the external fixation device.

postures, which greatly improves the comfort of the patient. Because we anastomosed the blood vessels on the same side, the difficulty of the operation was reduced. Phase II surgery is not needed for division of the pedicle, which is required in cross-leg flap operation, and there was no injury to the unaffected limb. The postoperative patient care was simpler, and the recovery period was shorter. These traits are conducive to the return of patients to normal activity. Compared with local flaps, the biggest advantage of free flaps is that they can be used to fully cover the main wound, avoiding such shortcomings of local flaps as a relatively small area and somewhat wasted coverage after pedicle rotation.

In contrast to the outstanding advantages in selecting the descending genicular blood vessel as the recipient's pedicle, the shortcoming of the free flap method is that although the rapidly advancing CDS and CTA have significantly improved precision of preoperative localization, the differences in experience between surgeon makes intraoperative verification of the blood vessels diameter and course not consistent. Therefore, some surgeons choose not to use this approach in some patients. At present, doctors who can perform this type of surgery are mainly those who master microsurgery techniques, but they generally lack knowledge about CDS and CTA, and they do not effectively communicate with related auxiliary departments, which restricts the promotion of the above-mentioned techniques (16,17).

There is still no effective approach to determine the blood supply capacity of the descending genicular vessels before surgery. In some cases, although the arteries in the recipient site are suitable for anastomosis, partial necrosis still occurred in the distal tip of the larger flap. This may somewhat lower the surgical efficacy. In the early stage of this study, necrosis in the distal tip occurred in two patients due to the excessively larger and longer flap design. Lee *et al.* (18) pointed out that excessive free flap size is an independent predictor of flap complications. When the flap size reaches 250 cm^2, flap crises and complications increase significantly. In the two patients with flap necrosis in this study, the size of the flap exceeded the above limit in one patient but not the other. The rest of the flap, designed to be less than 30 cm × 8 cm, were successfully survived. This result was basically consistent with the above assessment.

Precautions related to the descending genicular vessel as the recipient site pedicle

A few things need to be pointed out in particular: (I) clinicians should cooperate with relevant medical technology departments to further improve the preoperative accuracy of related blood vessel localization. (II) In most cases, the artery diameter of descending genicular artery is smaller than that of the artery in the flap. In order to avoid failure during the operation, the recipient site vessel must be explored first, and a back-up plan should be prepared. If it is not suitable for anastomosis, other surgical methods should be applied. (III) The intraoperative exploration has shown that the articular branches and saphenous branches of the descending genicular vessels have the same probability to be used in final anastomosis, but the sample size in this study is small, so comparative study is impossible for now. (IV) In most cases, the vascular pedicle should include one artery and one vein, that is, an accompanying vein of the descending branch of the lateral femoral artery is anastomosed with the great saphenous vein. This will not affect the survival rate of the flap (19). However, one artery and two veins should be included in the recipient pedicle if possible. After all, the pedicle include two veins can reduce complications compared to including one vein. However, the premise must be that the veins have matching diameters (20). (V) The incidence of crisis within 72 hours after free flap grafting is high. The blood supply should be observed every 2 hours. Once there is a crisis, exploratory surgery should be performed without delay. Otherwise, graft failure may occur.

In summary, an anterolateral thigh flap with descending genicular blood vessels as the recipient pedicle can be used to repair serious soft tissue defects around the knee. This has the following advantages of the descending genicular vessels: superficial location, constant anatomy, appropriate diameter, abundant blood flow, precise localization by CDS, and simple intraoperative dissection. However, due to limited size of this study, it is necessary to recruit more patients to further clarify the applied anatomy and variation of blood vessels to finally determine the relevant indications.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of Wuxi No.9 People's Hospital affiliated to Soochow University (ID:20191101) and informed consent was taken from all the patients.

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