9 When and How to Perform Free Flaps

Joon Pio Hong and Hyunsuk Peter Suh

9.1 Introduction

The treatment of diabetic foot ulceration is complex with multiple considerations involving the multidisciplinary team. Despite the efforts of the team, the aggravation of the wound often leads to limb amputation. Throughout this book, important concepts such as multidisciplinary approach, understanding the overall systemic condition, improving vasculopathy, treating infection, and wound bed preparation all leads to enhance the outcome for reconstructive surgery. Thus understanding what value the multidisciplinary team brings to the overall treatment is crucial for reconstructive surgeons. An example would be evaluating the patient's nutrition status and correcting accordingly prior to surgery. Prealbumin with a half-life of 2–3 days is a good indicator for acute nutritional status. Low prealbumin values have been reported to be a risk factor for poor healing and postoperative infection [1]. Another example would be to properly control blood sugar level prior and after surgery as poor glycemic control is related with significantly higher complications after surgery [2]. Most of all, understanding the vascularity of the limb is crucial when planning the reconstructive surgery as flap success is determined by the vascular status and supply. Building from the foundation of previous chapters, this chapter will focus on the reconstructive aspect of using free flaps to salvage the diabetic limb. The reconstructive surgeon brings on the capability to achieve healing by soft tissue manipulation. The surgeon may follow a reconstruction algorithm to manage and salvage diabetic foot ulcers. Having the reconstructive option in the treatment spectrum may enhance the healing process and increase the chances for salvage. Figure 9.1 shows the spectrum of care for diabetic foot. Understanding the spectrum of care and the role of each discipline will increase the chance for healing. While the systemic condition of the patient is being optimized wound specialists or surgeons can direct attention to the foot ulcer. Depending upon general condition, peripheral vascular status, bone pathology, wound depth, location, duration, involvement of chronic osteomyelitis, and patient motivation, wounds can be treated with debridement and other related surgical procedures [3].

Traditionally patients with diabetic foot have been regarded as relative contraindication for microsurgical free tissue transfer as it was felt that diabetic patients have arteriolar occlusive disease, which can cause vascular compromise to the flap and complication during the postoperative course [4]. But studies have failed to

J. P. Hong (✉) · H. P. Suh
Department of Plastic Surgery, Asan Medical Center
University of Ulsan, Seoul, Korea
e-mail: joonphong@amc.seoul.kr; hyunsuk.suh@amc.seoul.kr

J. P. Hong, H. Suh (eds.), *Diabetic Foot Reconstruction*,
https://doi.org/10.1007/978-981-16-9816-3_9

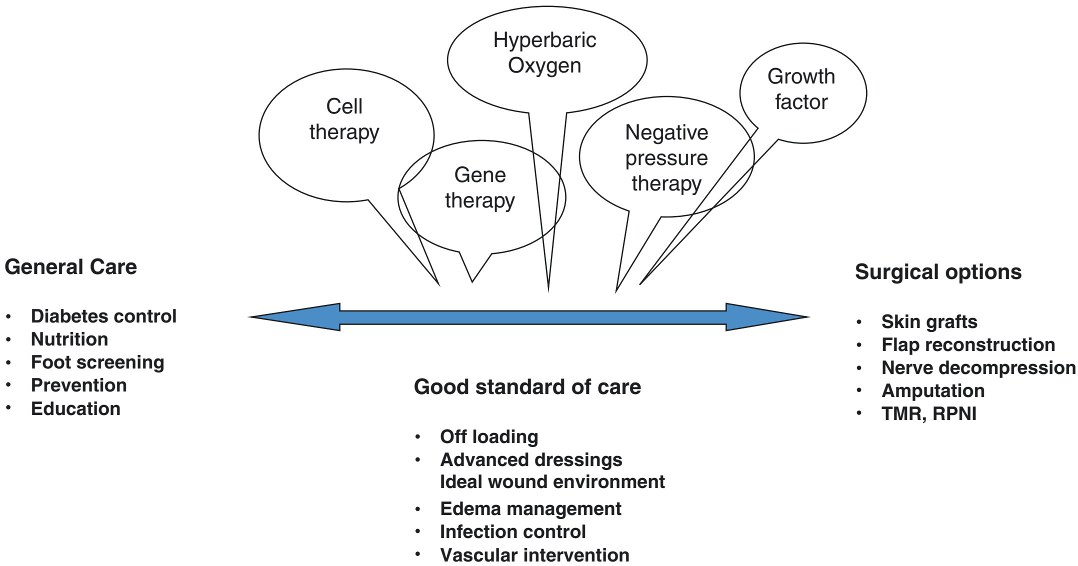

Fig. 9.1 The treatment spectrum of diabetic foot. Note the surgical options are listed on the right as the options for complex and complicated diabetic foot wounds

demonstrate significant increase of arteriolar occlusive disease or endothelial proliferation in diabetic foot [5–8]. A thickening of the capillary basement membrane has been documented, but capillary narrowing or occlusion has not [8]. The same study showed that diabetics often have atherosclerotic occlusion of the tibial arteries, but the occlusive disease occurs mainly in the leg so that the arterial system in the foot is less involved. Colen stated that diabetic neuropathy rather than microvascular disease is the primary cause of foot lesions in the presence of normal or near-normal arterial systems and advocated reconstruction [9]. However, the diabetic foot with complex conditions and often leading to amputations are the ischemic types. In clinical reality, the diabetic foot cases are often mixed with neuropathic as well as ischemic types complicating the reconstructive process. Thus reconstruction should be dependent upon the patient's overall condition rather than types of diabetic foot. Understanding the relative risk factors for failure and managing to reduce these risks can be the right strategy for successful reconstruction. The multidisciplinary approach as mentioned above is the critical step toward reducing these risks.

Today, the microvascular free flaps to reconstruct diabetic foot have been reported as comparable to nondiabetic patients [3, 9–23]. A meta-analysis of a systematic review of free tissue transfer in 528 diabetes patients in 18 studies showed that flap survival was 92% and limb salvage rate of 83.4% over a 28 months average follow-up period [24]. Furthermore, the impact of limb salvage by reconstructive microsurgery against 5-year survival rate has shown to reach 86.8% compared to the amputation group, which the 5-year mortality rate can range from 39% to as high as 80% [21, 25, 26].

This chapter will explore the aspect of microsurgical approach, indication, preoperative evaluation, intraoperative techniques, and postoperative care for diabetic foot reconstruction using free flaps.

9.2 Reconstruction Algorithm

While the medical care for the patient with diabetic foot ulceration begins with control of blood sugar, maintaining adequate nutrition and stabilization of the patient, the surgical care begins with debridement and control of infection. After the patient and the wound are stabilized, further evaluation of the wound is made. Unless immediately indicated for major amputation, the reconstructive algorithm may guide you through the necessary steps, as shown in Fig. 9.2. If simple with minimal or no vital structures exposed, conservative care with various treatments can be considered. If the wound is large that may take a long time to heal and healthy granulations are noted after wound preparation, skin graft or a small local flap can be performed [27]. Well-granulating wounds are an indication for good vascularity. The use of NPWT often enhances granulation formation and can be used to prepare the wound for reconstruction. However, if healing is stalling, then further evaluation using transcutaneous oxygen pressure measurement (TcPO2) or angiograms may be warranted to evaluate the arterial flow and prepare for vascular intervention. The same evaluation and approach to ensure vascularity is needed for complex wounds waiting for reconstructive procedure.

The philosophy to reconstruct diabetic foot follows the principle of reconstructive elevator and orthoplastic approach. Although reconstructive ladder still valued and widely taught, the reconstructive ladder comes from the concept of wound closure ladder dating back beyond the era of modern reconstructive surgery [28]. In the era of modern reconstructive surgery, one must consider not only adequate closures but form and function. A skin graft after plantar defects will provide coverage, but a skin or muscle flap with good padding and thicker skin will provide superior functional results in addition to coverage. A simpler reconstructive option may not necessarily produce optimal results. This is especially true for diabetic foot reconstruction, where consequences of inadequate coverage will lead to complications such as additional soft tissue loss, osteomyelitis, functional loss, increased medical cost and even amputation. Furthermore, one should understand the orthoplastic approach to assure adequate biomechanics of the foot is achieved to have optimal function after reconstruction [29]. Often requiring to have secondary or tertiary procedures of the bone, adequate coverage is essential. Correct skeletal correction is also essential to minimize post-reconstruction

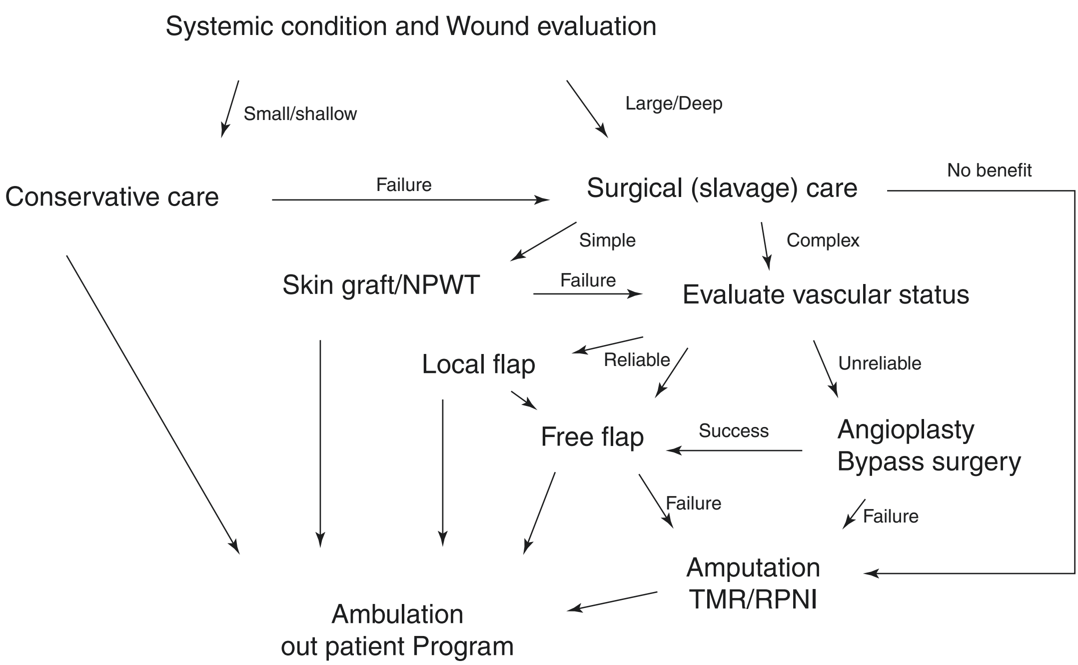

Fig. 9.2 The reconstruction algorithm

complications. Often missed is to correct tight Achilles tendon. If the Achilles is not lengthened, then the forefoot will have increased pressure during the gait and will likely cause additional ulceration due to the increased pressure. Thus to provide optimal form and function, we jump up and down the rungs of the ladder to correct the not only the soft tissue but the skeletal and tendon deformities as well. This paradigm of thought does not eliminate the concept of reconstructive ladder but replaces it as a ladder of wound closure and makes its mark in the field where variety of advanced reconstructive procedures and techniques are not readily available (Fig. 9.3). Based on the reconstructive elevator and orthoplastic approach, method of reconstruction of soft tissue and bone should be chosen based on procedures that results in optimal function as well as appearance [30].

9.3 Debridement and Infection Control

The first step of treatment for diabetic foot wound is to evaluate, debride, and treat infection [31]. Missing timely management will lead to amputations and longer hospital days [32]. As other chapters has covered these topics, this chapter will focus on the reconstruction perspectives. Optimal management of diabetic foot infection can potentially reduce incidence of major limb amputations and other related morbidities. All nonviable and infected soft tissue and bone should be excised during debridement. Milking along the proximal tendon can be helpful to identify and limit ascending infection. Tissue culture should be sent prior to debridement and after debridement. Post-debridement antibiotics selection should be based on the post-debridement culture. Sufficient irrigation should follow after debridement to reduce bacterial count [33]. Recent advance in technology introduced a hydrosurgery system that allows debride while preserving viable tissues and irrigating simultaneously allowing reduced surgical time [34, 35].

The understanding of vascular distribution of the foot, angiosome, helps to plan not only reconstruction but debridement [36]. When planning for reconstruction, one can avoid violating the angiosome territory while designing a local flap that may lead to flap breakdown [37]. Also by performing debridement according to the angiosome territory, one may enhance flap survival by increasing the chance for marginal vascularization from healthy surrounding angiosome terri-

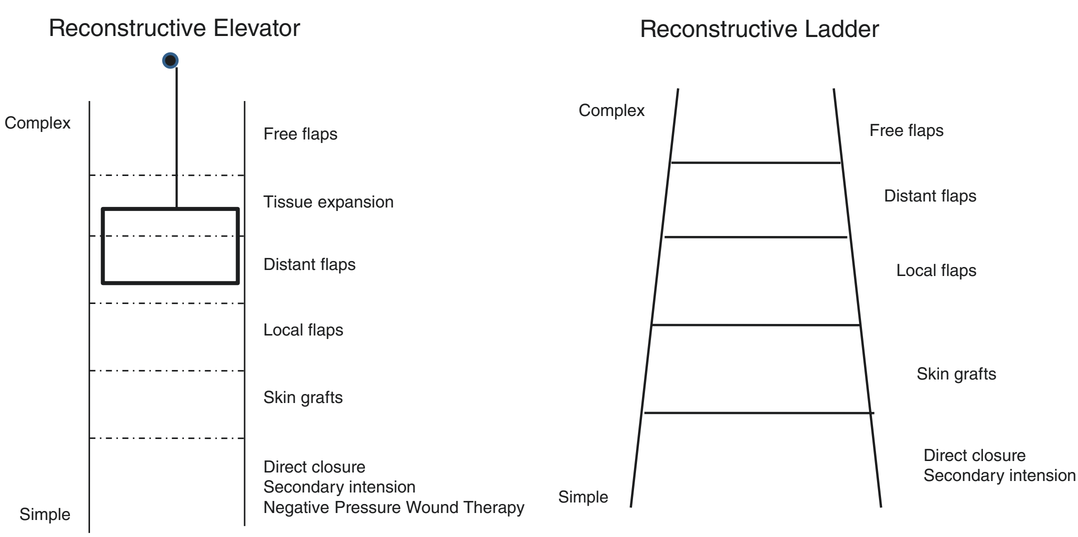

Fig. 9.3 The reconstructive elevator versus the ladder. Note that the reconstructive elevator finds the ideal option based on the reconstructive needs rather than climbing up each rung of options from simple to complex

tory [23]. This approach of using angiosome based debridement can be critical to allow inosculation from well-vascularized tissue, especially when reconstructing ischemic diabetic foot [23, 36]. The transcutaneous oxygen measurement (TcPO2) also plays a role in our protocol. Measurement over 30 mmHg in normobaric oxygen is a relative predictive factor for successful healing whereas pressure less than that of 30 mmHg is likely to follow an unfavorable course [38, 39]. If peri-wound $TcPO_2$ measurements were over 30 mmHg, then further treatment, including reconstructive procedures, were planned otherwise, amputations at according levels were performed.

Repetitive debridement should be performed as part of wound preparation for reconstruction while monitoring c-reactive protein for possible hidden infections and using it as an index for possible infection after reconstruction. In between the debridements, the use of NPWT can increase the rate of granulation and prevent the communication of external and internal bacteria from entering and escaping from the wound.

If the obvious wound and infection do not improve or subside even after the proper surgical debridement and antibiotics, surgeons should question the current treatment and seek the cause behind the uncontrolled infection. Monitoring the C-reactive protein (CRP) can be a good indicator to monitor inflammatory states in regard to infection [40]. When the infection focus is in question, the use of magnetic resonance imaging can help find hidden pockets of infection.

9.4 Evaluating and Enhancing the Vascular Status

As mentioned in the reconstruction algorithm, all patients considered for reconstruction using flaps should be evaluated for the vascular status. Although there are multiple evaluation tools, direct visualization of the vessels is preferred when considering reconstruction. The Ankle Brachial Index (ABI) is not used as it is not reliable in diabetic patients due to the high incidence of calcified vessels causing falsely elevate values [41]. Typically, the neuropathic type will have a patent vessels but often is accompanied by an ischemic component. Often the distinction between ischemic and neuropathic type is not clear and the foot and the extremity can be a mixed neuroischemic type showing early signs of calcification even in neuropathic types. Thus it will be prudent to perform angiograms for patients undergoing any reconstruction with flaps. The CT angiogram provides information regarding general vascular anatomy of the lower extremity, shows atherosclerotic change of vessels, which is useful information when choosing recipient's vessels and allows to select the flap donor site on the leg. This overview of the vascularity of the entire limb is important as collateral vessels may be the main supply to the distal limb, and the wrong selection of donor flaps can end in catastrophic complication (Fig. 9.4). After the examination, if vascular status is in doubt, then revascularization by angioplasty or bypass surgery is required. Although preoperative angiograms may indicate intact anatomy of the artery to the foot, actual findings upon surgery can be different. In order to confirm the distal vascular flow, we use ultrasound duplex scans to obtain physiologic information regarding the quality of the flow [3, 23, 42]. Our recent experience shows that peak blood flow velocity over 15–20 cm/s on the recipient vessels allows the flap to survive [23, 42]. Thus, one of the aims for intervention in regard to flap reconstruction is to reach this minimal flow velocity that allows free flap reconstruction.

In our center, the first approach for vascular intervention is endovascular approach using balloon angioplasty and stents. It is preferred due to the simplicity and minimal invasiveness of the approach. In diabetic patients, the atherosclerosis most significant occlusions occur in the crural arteries often sparing the arteries of the foot [8]. Bypass to dorsalis pedis or posterior tibial artery of the foot or angioplasty with or without stent placement procedures result in high success to restore perfusion pressure to the distal circulation of the foot reestablishing palpable pulse.

The role of vascular intervention may also extend to the postoperative period. Re-stenosis after

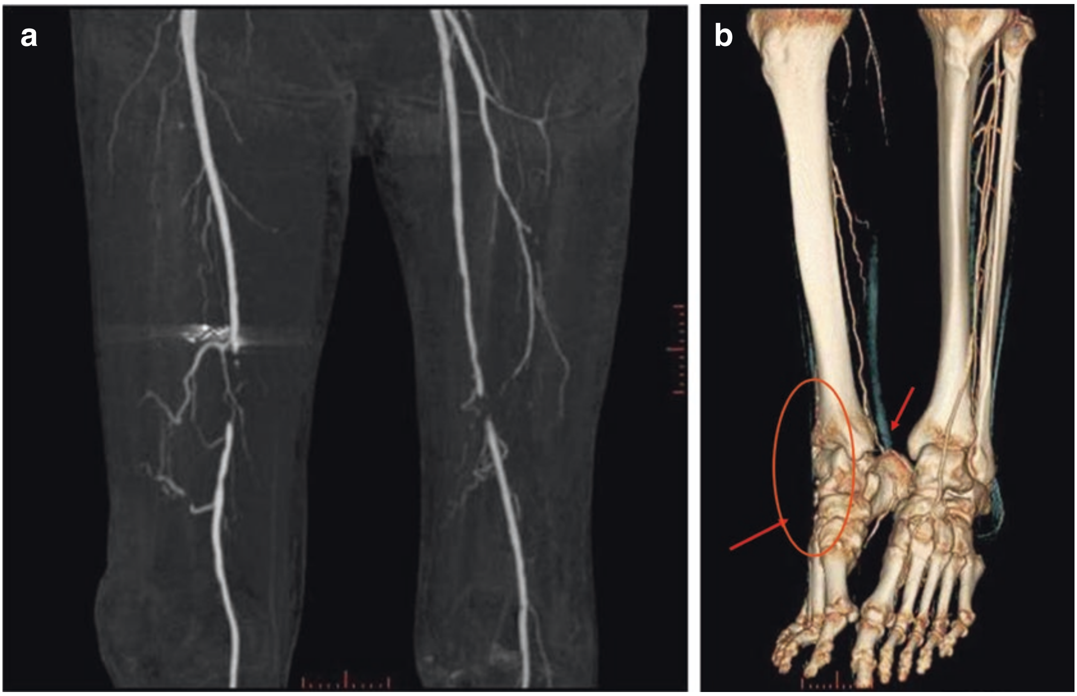

Fig. 9.4 CT angiogram of the flap donor site. Note that the femoral artery is totally obstructed and the flow distal to the leg is mainly supplied by the descending branch of the lateral femoral circumflex artery bypassing the obstruction (**a**). The 3D reconstruction of the CT angiogram shows the calcified and the calcification spared segment of the major arteries (**b**)

endovascular intervention can be as high as 50–60% within the first 6–12 months, and this can happen as early as the first or second week after surgery [43, 44]. In these cases, the flap can be salvaged by emergency angiogram to identify the obstruction leading to angioplasty reestablishing the flow to the flap. It is prudent to keep a keen observation for any early ischemic changes of the flap.

Reperfusion is most essential prior to any reconstruction using graft, local flaps and microsurgical reconstruction. If vascular intervention fails and wound progresses, amputation is warranted.

Skin grafts and local flaps have been discussed in other chapters.

9.5 Indications for Free Flap

1. Stagnant healing despite good wound care.
2. Wounds that are complex and/or exposed vital structures needing timely coverage.
3. No significant systemic illness likely to be exacerbated by multiple operations and prolong rehabilitation.
4. Previously ambulatory with the aim to restore a functional limb.
5. Reasonably patent crural vascular status with minimal recipient artery flow velocity of 15–20 cm/s.

An inclusion criteria from a meta-analysis of free tissue transfer in 528 diabetes patients in 18 studies suggests: (1) Lower limb defect which has not displayed any signs of granulation or healing despite adequate debridement or necrotic tissue and conservative treatment; (2) No significant renal function impairment; (3) No significant systemic illness likely to be exacerbated by multiple operations and prolong rehabilitation; (4) Previously ambulatory with the aim to restore a functional limb; (5) Likely to engage with the significant physiotherapy required for return to normal living; and (6) Peak flow velocity of >40 cm/s in recipient artery [24]. We generally agree with the suggested inclusion criteria except for the significant renal disease. In our experience, we have not found an increased risk for failure despite the fact that uremia may causes a decrease in cell-mediated immunity and impair wound healing [45, 46]. However, patients after kidney transplantation who received immunosuppression had an odds ratio of 4.857 of having flap failure ($p = 0.041$). I would rather prefer to present the contraindication rather than the indications for flap reconstruction as microsurgery technique evolves using small recipient vessels rather than a major vessels for reconstruction [47]. The most important factor may be the perfusion of the recipient vessel. If any small vessel is seen with good pulsatile flow, it would be indicated for microsurgery. As mentioned above, our experience shows that recipient vessels with minimal flow velocity of 15–20 cm/s will be adequate. Thus an absolute contraindication would be no flow to the foot without any sign of perfusion from any distal small vessels.

9.6 Timing for Reconstruction

As shown in the indication, when the systemic condition of the patient can tolerate the surgery, vascular supply is reasonable, wound bed prepared, and infection controlled, reconstruction can take place. However, the timing for reconstruction can be challenging when vascular status is compromised.

The timing of when to perform reconstruction after vascular intervention is not clear. Reports have shown successful free flap transfer with simultaneous vascular reconstruction to salvage the limb [48]. But early bypass failures within 30 days are reported to be high [18, 49]. In our experience, partial flap loss or total loss was suddenly noted after 2–3 weeks in the cases combined with simultaneous or reconstruction following few days after vascular interventions. This may suggest that there should be a sufficient stabilization period after vascular bypass surgery. However, for endovascular angioplasties, we usually perform microsurgery as soon as possible. Knowing that re-stenosis after endovascular intervention can be as high as 50–60% within the first 6–12 months, early reconstruction will increase the chance of flap survival during the window period of the patent flow [43, 44].

9.7 Choosing the Recipient Vessel and Microanastomosis

1. Preoperative diagnostic tools should be used to map out the ideal recipient artery in terms of anatomy, physiology, and pathology.
2. When selecting a major artery, end-to-side approach will maintain adequate distal flow.
3. If the target artery is calcified, search for a calcification free segment (end-to-side) or a branch from the major artery (end-to-end).
4. Perforator or small arteries can be used as a recipient vessel when the flow velocity is at least 15–20 cm/s.
5. Understand the angioplasty technique and if possible avoid the segment of the artery that underwent angioplasty.

The biggest challenge in reconstructive microsurgery for diabetic foot is finding an adequate recipient vessel, especially in ischemic diabetic foot. Biphasic pulsatile signal or acoustic wave from handheld Doppler does not guarantee a good recipient vessel for anastomosis. The sensitivity of handheld Doppler is very high and can trace a vessel less than 0.2–0.3 mm diameter and even severely calcified vessels often misleading the surgeon to think that it can be a reliable recipient source. The surgeon should select the recipient vessel based on anatomical knowledge, preoperative angiograms, ultrasound findings, and intraoperative visual inspection. When the major vessels are calcified, it may be very difficult to select the recipient vessel. Careful examination of CT angiograms may provide clues on how to find a reliable recipient vessel [50]. Even with a visual pulsation to the artery of the foot, atherosclerosis of the artery can make anastomosis very difficult. The separation of intima and adventitia layers of the artery caused by calcification makes intima to intima contact difficult and may increase the risk for thrombosis. Thus calcification spared segments of the major artery can be used to anastomose the flap in an end-to-side manner, or you can find a branch from the major artery and use it to anastomose end-to-end (Fig. 9.5) [3, 20, 22]. In our experience, using the branch from the major artery as a recipient may be a better choice. It is not common to see branches from posterior tibial and dorsalis pedis arteries to be calcified and by using these branches, one can easily anastomose to a supple and soft artery without diminishing distal flow. An alternative anastomosis may be the T-style anastomosis, where bypassing artery segment with a branch to the flap is inter-anastomosed between the proximal and distal recipient artery. If a T-style anastomosis is not possible, using a vein graft in between the calcified artery, then anastomosing the flap pedicle as an end-to-side fashion on the vein graft can be an alternative. We try to avoid using major artery as an end-to-end fashion as using the major vessel in this manner will decrease the distal flow to the foot and will have a negative impact on the overall circulation of the foot [3, 23].

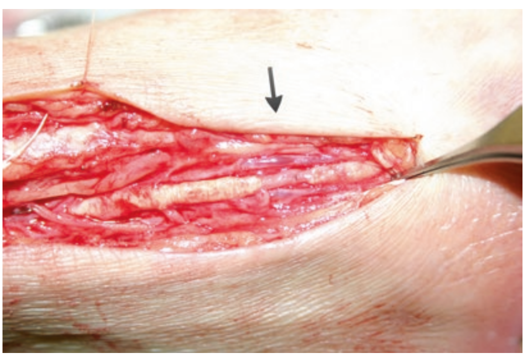

Fig. 9.5 Calcification of the dorsalis pedis artery is shown. Note that there is a calcification spared segment that allows for side of the dorsalis pedis artery to be used as a recipient to the end of the flap donor artery. Also note that the branches from the dorsalis pedis are spared from calcification being a potential source for recipient artery in an end-to-end fashion

When approaching arteries that underwent angioplasties, one must be aware how the angioplasty was performed. After angioplasties, frequently damage to the intimal layers can occur, and this will increase the burden to an already challenging anastomosis. Avoiding the segment that underwent angioplasty will make the anastomosis but easier. Sometimes, angioplasty can be performed between the intima and adventitia as the lumen of the artery is collapsed, making angioplasty impossible. In these cases, the microsurgery will become very difficult not to mention the increased risk for thrombosis. Thus knowing how the angioplasty was performed may guide the microsurgeon in selecting the right recipient for microsurgery.

However, what if there are no major vessels available? Is microsurgery possible? One can often see even when limbs have no sufficient major vessels, most of the skin of the ischemic limb is still intact with good bleeding. This is most likely due to the slow occlusion of the major artery leading to persistent formation of collateral vessels supplying the distal limb and subdermal plexus of the skin [50]. Often, the territory of ischemia and necrosis coincides with the angiosome territory, and the surrounding angiosome is spared from necrotic change [23, 31, 36, 37]. Thus, a terminal perforator artery or a small vessel within the healthy angiosome adjacent to the necrotic lesion can be used as a recipient vessel. These small perforators can be traced using a handheld Doppler or Duplex ultrasound to confirm an adequate velocity of the arterial flow. In our experience, a small artery can be used when the flow velocity was over 15–20 cm/s [23, 42]. As most of the perforator flaps have a flow velocity over 20 cm/s for the perforating artery, these small recipient perforators can be an ideal recipient source. However, one must visually confirm the adequacy of the recipient vessel prior to anastomosis. The use of these small perforators or vessels require a supermicrosurgery technique and usually perform end-to-end as perforator-to-perforator (Fig. 9.6) [23]. The overall success rate for supermicrosurgery approach can be high as 90.5% [22, 23]. This it is comparable but slightly lower to any nondiabetic foot

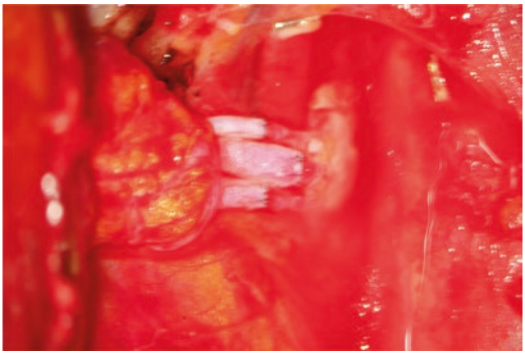

Fig. 9.6 Perforator-to-perforator anastomosis is shown. The recipient and the donor vessels needs to be sufficiently enlarged by using a vessel dilator prior to microanastomosis

reconstruction as well as diabetic foot reconstruction using the classical approach.

The selection for veins is relatively easier compared to the artery. Usually, the veins are spared from developing any pathology. Superficial veins can be used reliably. However, when the diabetic foot undergoes ischemic change, the soft tissue may be fibrosed, and perivascular scarring can make the dissection difficult.

As the recipient's vessel, despite the preoperative evaluation, can be different when actually dissected. The recipient's vessels need to be isolated and visually confirmed first prior to flap elevation. This will allow for better planning to select the right flap. The surgeons should always have a flexible mind and adjust accordingly when challenges are met.

9.8 Free Flaps

The flap for reconstruction of diabetic foot should provide a well-vascularized tissue to control infection, adequate contour for footwear, durability, and solid anchorage to resist shearing forces. Controversy still remains which flap, whether muscle flaps with skin grafts, fasciocutaneous flaps and recently added perforator flaps, offers the optimal solution to reconstruct the foot, especially the weight-bearing surface. But as long as the large defect is covered with any well-vascularized tissue, it will provide an independent and well-nourished vascular supply to eradicate infection, increase local oxygen tension, enhancing antibiotics activity, and neovascularization to the adjacent ischemic tissue [51, 52]. In our clinical experience, we are shifting toward using perforator flaps such as anterolateral thigh (ALT) perforator flap, gluteal artery perforator (GAP) flap, superficial circumflex iliac perforator (SCIP) flap and medial plantar perforator flap as it provides, a thin flap to minimize shearing, can take only the superficial fat to imitate the fibrous septa of the sole to adhere tightly, enhance neovascularization of the subdermal plexus with adjacent tissue, and provide adequate blood supply to fight infection. In this section, we will focus on the perforator flaps.

Our experience shows that microsurgical approach to reconstruct diabetic foot may have flap survival rate of 91.7% and limb salvage rate of 84.9%, which are similar with other reports [21, 24]. Although significant increase of failure was noted in patient with poor arteries requiring multiple angioplasties, with peripheral arterial disease and taking immunosuppressive agents after kidney transplantation, the overall success rate and the limb salvage rate justifies the use of reconstructive microsurgery [21]. What was more interesting was that the impact on free flap reconstruction and limb salvage may have not only on the improving quality but on patient survival. The death rate after 5 years for a major amputation can be as high as 78% [53–55]. In our previous reported series, according to the Kaplan-Meier survival estimate curve, the 5-year survival rate for reconstructed patients against patients amputated above the ankle showed 86.8% and 41.4%, respectively [21]. Although the average age and ASA (American Society of Anesthesiologists) physical status classification of the major amputated patients was relatively higher (63 against 54.6 years, 2.7 against 2.3) than the reconstructed patients in that series, it was not statistically significant. This strongly suggests that reconstruction rather than amputating above the ankle will increase 5-year-survival rate.

As mentioned briefly above, the introduction of supermicrosurgery concept allows exploring more options for the recipient vessels. Based on the idea that surrounding angiosomes around the ischemic defects are healthier, one can find a very small artery or a perforator which is an end vessel going into the skin and use it as a recipient vessel [22, 23]. The overall success rate for supermicrosurgery approach in diabetic foot is 90.5%. This it is comparable but slightly lower to any nondiabetic foot reconstruction as well as diabetic foot reconstruction using the classical approach [23]. The reconstruction by perforator flap using supermicrosurgery approach provides well-vascularized tissue that covers diabetic foot defect without being dependent on major vessels. This concept may provide solution to even to the more progressed ischemic diabetic foot. Figure 9.7 illustrates an approach with using the supermicrosurgery approach to reconstruct a diabetic foot ulcer.

One must also remember to correct any bone or tendon deformity that may alter the biomechanics of the foot. The orthoplastic approach is critical to minimize long-term flap complications such as re-ulcerations of the flap.

Fig. 9.7 Demonstrating the supermicrosurgery approach. After angioplasty and increasing the flow, small collaterals are seen more vividly. One of the collateral near the defect after debridement was used as the recipient artery for the SCIP free flap

9.8.1 Flap Selection Algorithm for Perforator Flaps

When we consider to select a flap for reconstruction, these are the factors to consider; (1) patient position, (2) flap size, (3) Thickness of the flap, (4) flap composition and (5) pedicle length required [56]. We believe this approach helps to optimize form and function, decrease operative time, while minimizing donor site morbidity and secondary procedures. Although this algorithm was evaluated based on our experience with perforator flaps, this can be applied to muscle flaps as well.

We prefer to select a flap based on the patient's position following defect preparation. Avoidance of an intraoperative position change helps to minimize operative time and avoids potential anesthetic complications such as inadvertent extubation, peripheral nerve compression or intravascular line malposition [57, 58]. Flaps can be selected without changing the patient position to harvest the flap. Defect sizes dictate which flap to select and although not all flaps can be designed large, most flaps can be designed small. Understanding the limit of the flap is important when selecting the flap. The thickness of the flap is an important issue as the thicker the flap, the more shearing can occur, leading to future complications of ulceration [20]. For optimal footwear and to minimize shearing achieving the right thickness is essential. However, if the thickness cannot be controlled, secondary debulking will allow to achieve the right thickness. The SCIP flap can be one of the thinnest flap possible to elevate, and when other perforator flaps are used, elevation on a superficial plane may help to harvest the perforator flap with the right thickness [59–61]. The flap composition required is determined by the defect dimensions and missing components. Many flaps, such as the ALT or the SCIP flap, can be used as combined/chimeric flap. Understanding what component each flap can add will allow to have a better reconstruction addressing the missing components of the defect. Regarding the pedicle length, any flap can be harvested with a short pedicle. However, there are flaps with a short maximum pedicle length, limiting their universal use. Thus one should consider the pedicle length required in flap selection, despite other ideal characteristics it may have for coverage. This is especially important in ischemic diabetic foot, where the source of recipient vessels can be limited. In our experience, we often reside in using the anterior tibial artery and vein for heel defects as defects in this region frequently occur from having a poor peroneal and posterior tibial arterial supply requiring a flap with a long pedicle [62]. Fig. 9.8 shows the algorithm for perforator flap selection.

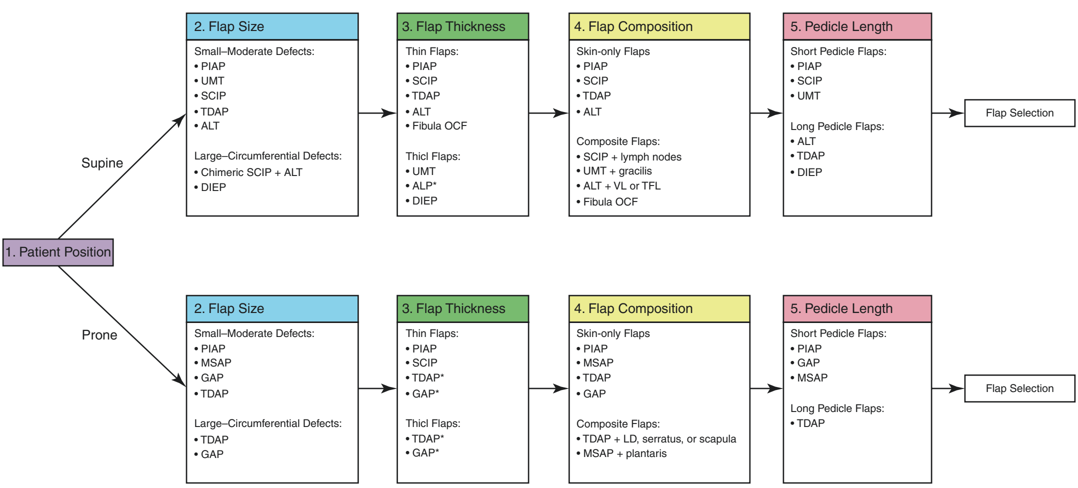

Fig. 9.8 The algorithm for perforator flap selection is shown

9.8.2 Perforator Flaps: Technical Aspects

9.8.2.1 SCIP (Superficial Circumflex Iliac Artery Perforator) Flap

The SCIP flap is an evolution from groin flap. The groin flap, supplied by the superficial circumflex iliac artery (SCIA), is one of the first free flaps successful in reconstruction. This flap was first described as a pedicle flap by McGregor and Jackson and then introduced as a free flap by Daniel and Taylor [63, 64]. Koshima et al. modified it as a skin flap elevated above the deep fascia based on the SCIA perforator overcoming some disadvantages such as bulkiness and variable arterial anatomy [65–67]. But even with these evolved technique and concept, the SCIP flap was still challenging to use due to the short pedicle, small vessel caliber, relative bulkiness, especially in obese patients, and donor site morbidity such as lymphorrhea. Further modifications were made where Hong et al. harvested the flap on the superficial fascia making the flap thinner (superthin flaps) while avoiding injuries to the lymphatic system which is located on the deep fat below the superficial fascia, thus minimizing lymphorrhea [47, 60, 68–71].

The advantages of using the SCIP flap is; (1) to obtain a thin flap, (2) to have reliable perforator anatomy (medial and lateral branches) and superficial vein, (3) to have the capability to either elevate a small or a large flap (from 4 × 3 cm to 12 × 35 cm), (4) to have a primarily closed hidden donor scar, and (5) to elevate as a composite flap (including lymph nodes, iliac bone, and part of Sartorius muscle). The disadvantages of using SCIP flap is; (1) to have a relatively short pedicle, and (2) small perforator artery diameter (Table 9.1). The use of skin flaps for chronic osteomyelitis has been shown to have no difference in outcome, and the same can be said for the SCIP flap. When a small dead space is noted, part of the flap can be de-epithelialized to obliterate the dead space [72]. The main contraindications for the SCIP flap would defects that needs a long pedicle to reach the recipient vessels. A relative contraindication would be defects that exceed the coverage potential of the

Table 9.1 Advantages and disadvantages of the SCIP flap

Pros	Cons
Well concealed donor site	Smaller vessel lumen
Thin and pliable skin flap – allows single stage resurfacing	Short pedicle
Septocutaneous pedicle (medial branch)	Learning curve to elevate as thin flap
Expedient harvest	Supermicrosurgery technique required for certain defects
Composite with lymph node and bone	
Medium to large skin dimension	

SCIP flap and unable to close primarily. Although one can perform skin grafts for the donor defect, it would less ideal to utilize the advantages of the flap. The authors also recommend to avoid harvesting the SCIP flap on the side that underwent percutaneous angiograms or angioplasty prior to surgery. When hematoma is collected, it makes identifying the perforators very difficult.

Preoperative ultrasound Doppler or a handheld Doppler is used to mark the potential perforators of the SCIP flap. There are two major perforators to base the SCIP flap on. In 95% of the SCIP flaps, of the medial (superficial) perforator of the SCIA penetrates the deep fascia within an oval of 4.2 × 2 (vertical × horizontal) cm, with the center of the oval point located 4.5 cm lateral and 1.5 cm superior from the superolateral corner of the pelvic tubercle (Fig. 9.9) [73]. The medial perforating branch then can be divided into two distinctive patterns; The axial pattern (44%) shows the perforator runs in an axial pattern on the superficial fat passing the anterior superior iliac spine (ASIS) reaching the flank region, while the anchoring pattern (56%) displays the perforator reaching the subdermal plexus without further branching [73]. This anatomy becomes relevant, especially when longer SCIP flaps need to be harvested, which the axial pattern would be safer to use. The lateral (deep) branch can be detected on the lateral region of the axis drawn from the pubic tubercle to the ASIS. It usually traveling laterally beneath the deep fascia and often with an intramuscular pathway perforating the deep fascia on the lateral aspect (deep branch) near the ASIS. The CT angiogram allows to visualize the medial (deep) and lateral (superficial) branches with accuracy, allowing safer design, especially in respect to size of the flap [73]. Recently, the use of ultrasound has helped to define the not only the exact location but the pathway of the perforator and the superficial vein as well with high accuracy. One should remember that the SCIP flap can be designed based on the either the medial and lateral perforators or take both when needed (Fig. 9.10). Table 9.2 shows the points to consider when selecting either the medial or lateral branch of the SCIA of the SCIP flap. The venous drainage of the flap often can be based on the superficial vein. When the superficial vein is not available or is not included in the flap, accompanying vein can be used as well but will have a very small vessel diameter to work with. The most common presentation of the venous drainage is the accompanying vein draining into the superficial venous system [60].

Elevation of the flap should first keep in mind which perforator will be the main pedicle. The medial branch is always a direct cutaneous perforator having an easy dissection, while the lateral branch travels underneath the deep fascia, often

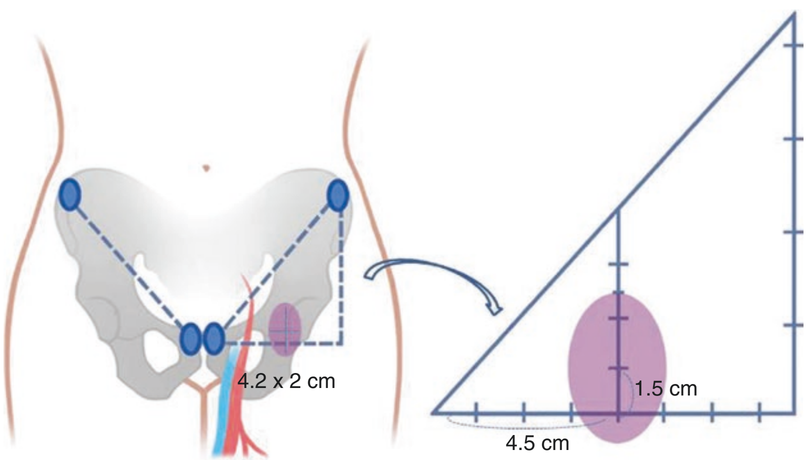

Fig. 9.9 The medial perforators of the SCIA penetrate the deep fascia within an oval of 4.2 × 2 (vertical × horizontal) cm with the center of the oval point located 4.5 cm lateral and 1.5 cm superior from the superolateral corner of the pelvic tubercle

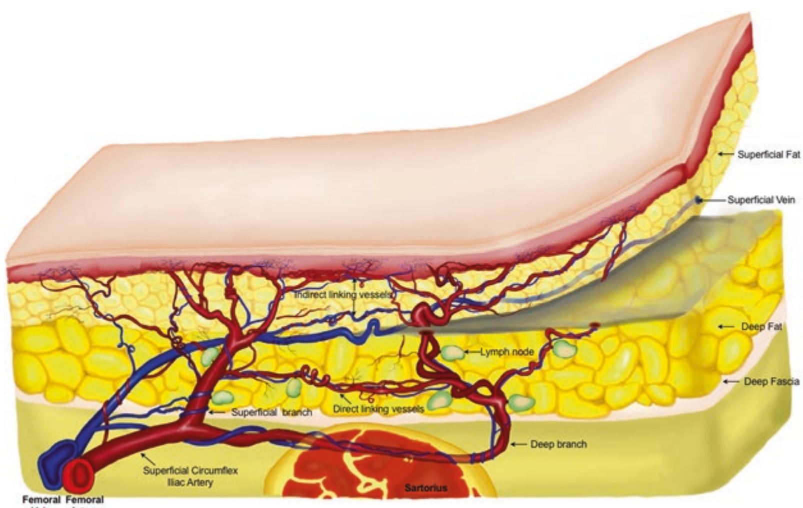

Fig. 9.10 There are two major perforators of the SCIP flap. The medial (superficial) branch is a direct cutaneous branch with and easy and quick dissection while the lateral (deep) branch travels laterally beneath the deep fascia and often with an intramuscular pathway perforating the deep fascia on the lateral aspect near the ASIS

Table 9.2 Comparison between the flaps based on medial versus lateral branches of the superficial circumflex iliac artery. Note that flaps can be based on both medial and lateral branch as well

Medial (superficial) branch	Lateral (deep) branch
Septocutaneous perforator	Muscular path included
Short pedicle	Relatively longer pedicle
Topographically constant perforator	Non-constant perforator
Two distinct type of perforator – Axial pattern – Anchoring pattern	Mostly axial pattern perforator
Medium size skin paddle (anchoring type) Large size skin paddle (axial pattern)	Large size skin paddle
Expedient harvest	Slower harvest
Composite with lymph node	Composite with bone and muscle

needing dissection near or in the Sartorius muscle making the dissection more complicated than the medial branch. The lateral branch is usually an axial pattern perforator traveling toward the flank, allowing to take a larger skin paddle.

Required dimensions of the SCIP flap are outlined as per the defect. The flap is first elevated along the inferior and lateral borders under loupe magnification as this approach allows to best identify the superficial fascia lying between the superficial and deep fat. This is a distinct white film-like layer, and elevation of the flap on or above this plane avoids injury to the lymphatic system which are found in the deeper adipose tissue [60, 69–71]. This plane is also avascular, allowing a bloodless field needed to identify the perforators piercing this plane. Once any reliable perforator is identified near the Doppler marked region, the rest of the flap can be elevated. Multiple other perforators can be further identified during the elevation. When multiple perforators are dissected, one can decide which branch (perforator) best serves the reconstructive purpose and then skeletonize toward the source vessel passing the deep fascia [60]. The deep fascia can be incised to obtain a longer pedicle length and a larger vessel diameter. If one needs to take part of the iliac bone, a branch toward the crest from the lateral (deep) branch can be identified and elevated together [74–76]. A superficial vein running from the ASIS toward the pubis is normally identified and is preserved. The accompanying vein of the medial branch often drains into the superficial vein thus need to harvest only one vein. In cases where there is a small or absent superficial vein, the accompanying vein of the perforator is usually of a larger caliber. Whenever the donor vessels are small, dissection is should be performed under the microscope. Figure 9.11 shows the overall sequence of elevation.

9.8.2.2 Anterolateral Thigh (ALT) Free Flap

One of the most used workhorse flaps among the perforator flaps is the anterolateral thigh perforator flaps. First described by Baek and Song and with refinements from Wei et al., it has become one of the ideal flaps for reconstruction providing reliable anatomy, long pedicles, thin flaps, sensation and a reasonable donor site scar with minimal morbidity [77–79]. The method of elevation is determined on whether the deep fascia is harvested together. If the flap is elevated with the deep fascia, it is called a subfascial elevation, whereas if the deep fascia is left intact and the flap is elevated above the deep fascia, it is called suprafascial elevation [79]. In either case, the flap may still be bulky in some cases and additional debulking may be required to achieve the right thickness after elevation. Thus the superficial fascia located between the deep and the superficial fat can be used as a plane of elevation (superthin flap), minimizing the need for immediate or late debulking [59, 80].

The advantages of using the ALT flap are that it has a reliably located perforator, provides a long pedicle, can be elevated as a thin flap on the superficial fascia plane, can be innervated, and can be harvested as a large flap. The major disadvantages can be the tedious process of dissecting the perforator especially if it has an intramuscular path, and donor site morbidity, especially when harvested in a large dimension. Preoperative evaluation using CT angiograms or Duplex ultrasound may provide clues in selecting the ideal pathway

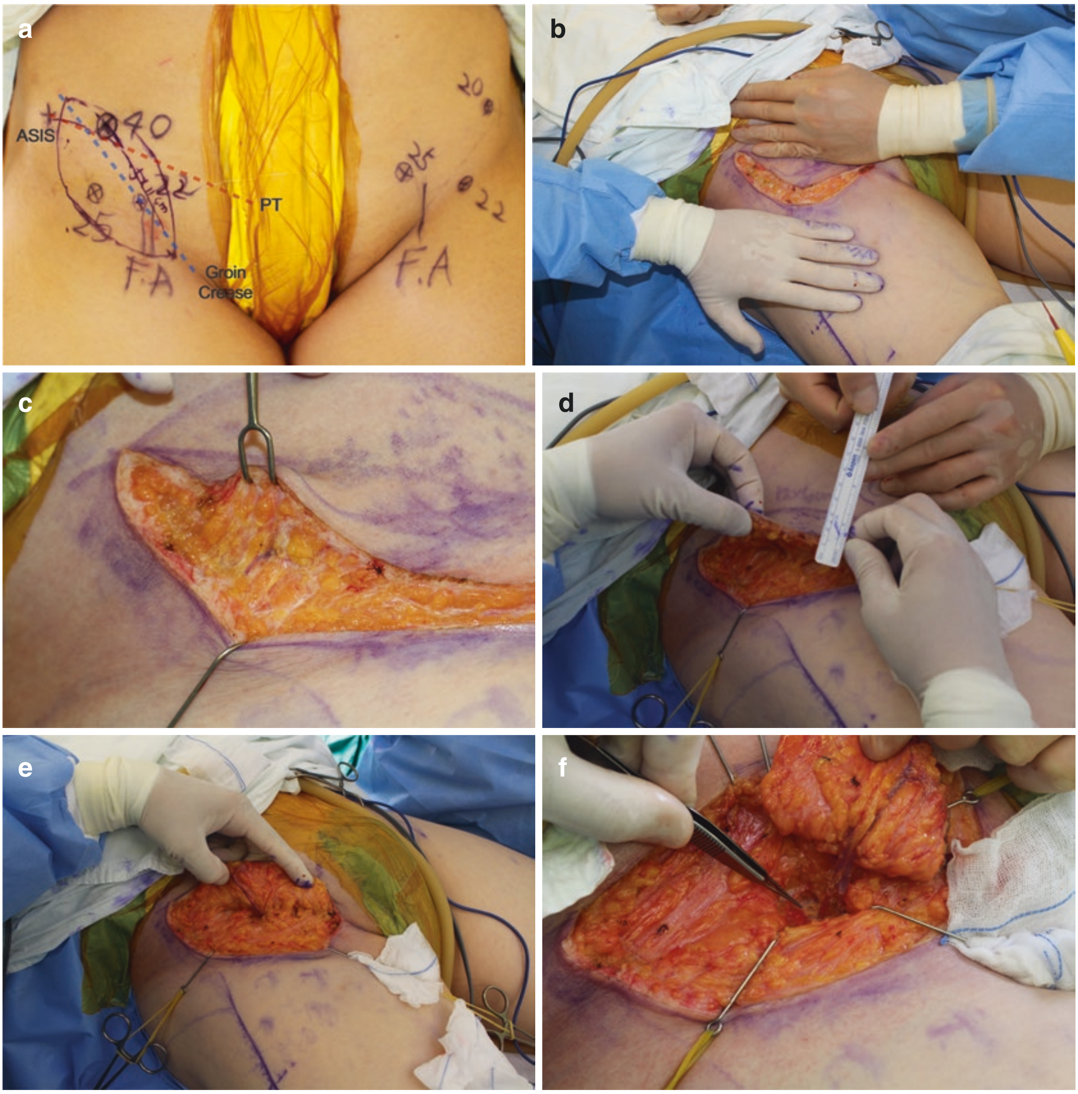

Fig. 9.11 The sequence of the elevation of the SCIP flap is shown. The SCIP flap design should be made along the axis between the groin crease and the ASIS (anterior superior iliac spine) where the SCIA usually travels. Using the handheld Doppler, the medial and lateral perforators can be identified and marked (**a**). The elevation begins from the lateral inferior margin with traction as the superficial fascia will be most evident (**b**). Once the superficial fascia plane is found, the elevation proceeds from lateral to medial and caudal to cephalic until the perforators are seen (**c**). Note that the superficial vein is included in the flap (**d**). The lateral branches are identified first followed by the medial branch (**e**). After dissecting both medial and lateral branches, one can determine which perforator to use or can use both (**f**)

of the pedicle as well as the most dominant perforator [42, 81, 82]. Another advantage of using preoperative CT angiogram is that it can provide information about the status of the flap pedicle. The descending branch can often be affected with calcification, and one should consider to use the side with less calcification to minimize complication. One should also remember that the descending branch can be the major collateral when the femoral artery is totally obstructed.

The elevation begins after identifying the perforators with handheld Doppler or Duplex ultrasound tracing along the axis between the anterior superior iliac spine (ASIS) and the lateral patella, the skin flap is designed to include the perforator. Once perforators are marked, the elevation begins from either margins of the flap, but the authors prefer approaching the lateral border of the flap first. The incision is made deep to the superficial fascia dividing superficial and deep fat. It is easy to identify based on the characteristics of the fat lobule. The small lobules suddenly become bigger as it passes a very thin fascia-like structure. It is easier to identify this fascia while retracting the skin from both sides of the incision (Fig. 9.12). After locating the fascia, then elevation is made on this plane until reaching the axis between ASIS and the lateral patella. Dissection under loupe magnification allows to see the small perforators and minimizes the risk of trauma. The same approach is performed from the medial side. When elevating far outside where the perforators are suspected (hot zone), one can quickly elevate without worrying about perforator injury (cold zone). One must keep this plane of dissection clean as possible, performing meticulous coagulation as bleeding can cause identifying the perforator difficult. After locating multiple perforators, the favorable one or multiple perforators are traced through the deep fat and deep fascia in a freestyle approach. The fat around the perforator can be skeletonized or maintained with some surrounding fat. We prefer to skeletonize the deep fat around the pedicle. Once traced to the deep fascia, a vertical linear incision on the fascia allows to dissect the pedicle proximally to harvest adequate length for anastomosis [59, 80].

9.8.2.3 Case

A 55-year-old female patient is seen with bilateral ulcerations and ischemic changes of the foot (Fig. 9.13). The right foot shows ischemic first and second toes and exposed tendons on the dorsum of the foot, while the left foot shows chronic wound that led to rupture and contracture of the Achilles tendon with an open wound (Fig. 9.13a, b). After angioplasty and minor surgery of both foot, the foot showed improved circulation with marginal epithelization and granulation. Repetitive angioplasty was performed as the wound no longer improved. On the day of the reconstruction the right foot shows the first two toes amputated with the medial defect with tendon exposure, and the right foot shows reconstructed Achilles tendon with skin defect (Fig. 9.13c, d). The SCIP flap was harvested from the left groin to reconstruct the right dorsum of the foot and the ALT was harvested to reconstruct

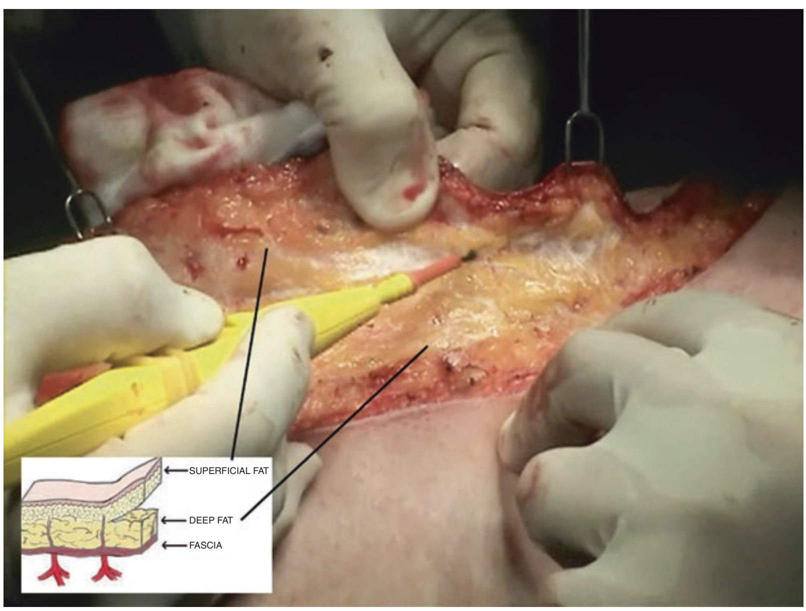

Fig. 9.12 Elevation of the ALT flap is shown. The plane of elevation is on the superficial fascia plane (superthin) between the superficial and the deep fat

Fig. 9.13 Case presentation using both SCIP and the superthin ALT to reconstruction bilateral diabetic foot wounds. (**a**) Ischemic ulcer of the right foot. (**b**) Chronic ulceration leading to Achilles tendon ruture and surrounding granulation. (**c**) After debridment and toe anputations of the right foot. (**d**) After debridement and Achilles tendon repair. (**e**) Desing for elevation using ALT free flap on the left thigh and scip flap from the left groin. (**f**, **g**) Postoperative view after 2 years

Fig. 9.13 (continued)

the left heel (Fig. 9.13e). In both reconstructions, anterior tibial artery was used as it was the only patent artery available. At 3 years after reconstruction the patient shows good function and contour of both sides (Fig. 9.13f, g).

9.9 Postoperative Care

Monitoring during the postoperative period should not only be focused on the flap but on the overall systemic condition of the patient as diabetic patients may have increased morbidity. It is especially important to monitor hemodynamic and blood sugar level. Input and output of fluid should be monitored closely as distal perfusion is primarily affected by hypotensive episodes. Patients who have chronic renal failures and require the assistance of dialysis often remove large volumes which can make fluid maintenance difficult. Limiting the range of motion may be needed for flaps covering the joints as extension or flexion may increase the tension of the pedicle. Monitoring flaps, especially free flaps in the first 24 h is essential due to the majority of thrombosis occurring at this time. According to Chen et al., up to 85% of the compromised flaps can be salvaged when the first sign of vascular compromise is clinically noted during the first 3 days after microsurgery [83]. There is no ideal method of flap monitoring but recent techniques such as tissue oxygen measurement, implantable Doppler device, laser Doppler flowmetry, Duplex ultrasound and fluorescent dye injections may assist the judgment made from clinical evaluation which remains as the golden standard of monitoring. One thing that the surgeons should keep in mind is the possibility of re-occlusion of the artery proximal to the anastomosis, as re-occlusion after angioplasty can be as high as 60% in 6 months. Emergency angiogram can help to actually pin point the location of the obstruction and determine whether angioplasty may be needed. Emergent reexploration should be performed once pedicle compromise is noted.

Although there are no clinical reviews that conclusively show any agents that increase flap survival rate, about 96% among surveyed 106 microsurgeons use some form of prophylactic antithrombotic treatment such as heparin, dextran, and aspirin or in combinations with other agents [84–86]. The routine use of dextran should be carefully approached due to allergic reaction and pulmonary edema, but aspirin, heparin, or low molecular weight heparin can be considered on theoretical basis and related studies from different disciplines. Thrombolytics such as urokinase can be used when flow is not immediately re-established after pedicle rearrangement or revision anastomosis [86]. But no agent can replace the meticulous surgical technique and early diagnosis of flap compromise.

Leeches have a role in the postoperative care for jeopardized flap. In cases of venous congestion, by injecting a salivary component called hirudin which inhibits platelet aggregation and coagulation cascade, leeches can decongest by extracting blood directly and further by oozing after it detaches. The use of leeches for 5–7 days can sometimes help salvage the flap that does not resolve despite reexploration of the venous flow.

Compression of the flap after the flap is taken and stabilized may help to reduce edema and allow the patient to engage in early ambulation [87]. If the patient underwent angioplasty, then compression needs to wait until the flap is fully incorporated with the surrounding skin. If the patient has stable vascular flow, then early compression can be performed on day 4 or 5 with about 30–40 mmHg using compression bandages. The bandages are maintained for 6 months until swelling is no longer seen during weight bearing. If the reconstruction was performed on the plantar aspect, the patient is asked to maintain the compression for longer duration and especially during the gait.

After discharge, constant education on how the patient monitors the flap is essential. Measuring the temperature of the flap as well as visual inspection can be critical in detecting early complications as the patient frequently will have peripheral neuropathy.

9.10 Conclusion

Plastic surgeons are an important component in any multidisciplinary approach for the treatment of diabetic foot wounds. When technically feasible, the trend of management has shifted from major amputation to limb salvage [88]. Using free flaps with an elevator approach can be a critical component in salvaging the limb with diabetic foot.

References

1. Steed DL, Attinger C, Colaizzi T, Crossland M, Franz M, Harkless L, et al. Guidelines for the treatment of diabetic ulcers. Wound Repair Regen. 2006;14(6):680–92.
2. Endara M, Masden D, Goldstein J, Gondek S, Steinberg J, Attinger C. The role of chronic and perioperative glucose management in high-risk surgical closures: a case for tighter glycemic control. Plast Reconstr Surg. 2013;132(4):996–1004.
3. Hong JP, Oh TS. An algorithm for limb salvage for diabetic foot ulcers. Clin Plast Surg. 2012;39(3):341–52.
4. Goldenberg S, Alex M, Joshi RA, Blumenthal HT. Nonatheromatous peripheral vascular disease of the lower extremity in diabetes mellitus. Diabetes. 1959;8(4):261–73.
5. Barner HB, Kaiser GC, Willman VL. Blood flow in the diabetic leg. Circulation. 1971;43(3):391–4.
6. Conrad MC. Large and small artery occlusion in diabetics and nondiabetics with severe vascular disease. Circulation. 1967;36(1):83–91.
7. LoGerfo FW, Coffman JD. Current concepts. Vascular and microvascular disease of the foot in diabetes. Implications for foot care. N Engl J Med. 1984;311(25):1615–9.
8. Strandness DE Jr, Priest RE, Gibbons GE. Combined clinical and pathologic study of diabetic and nondiabetic peripheral arterial disease. Diabetes. 1964;13:366–72.
9. Colen LB, Reus WF, Kalus R. Posterior hindfoot reconstruction. J Reconstr Microsurg. 1990;6(2):143–9.
10. Colen LB. Limb salvage in the patient with severe peripheral vascular disease: the role of microsurgical free-tissue transfer. Plast Reconstr Surg. 1987;79(3):389–95.
11. Dabb RW, Davis RM. Latissimus dorsi free flaps in the elderly: an alternative to below-knee amputation. Plast Reconstr Surg. 1984;73(4):633–40.
12. Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg. 1986;78(3):285–92.
13. Irons GB, Wood MB, Schmitt EH. Experience with one hundred consecutive free flaps. Ann Plast Surg. 1987;18(1):17–23.
14. Khouri RK, Shaw WW. Reconstruction of the lower extremity with microvascular free flaps: a 10-year experience with 304 consecutive cases. J Trauma. 1989;29(8):1086–94.
15. May JW, Halls MJ, Simon SR. Free microvascular muscle flaps with skin graft reconstruction of extensive defects of the foot: a clinical and gait analysis study. Plast Reconstr Surg. 1985;75(5):627–41.
16. Oishi SN, Levin LS, Pederson WC. Microsurgical management of extremity wounds in diabetics with peripheral vascular disease. Plast Reconstr Surg. 1993;92(3):485–92.
17. Searles JM, Colen LB. Foot reconstruction in diabetes mellitus and peripheral vascular insufficiency. Clin Plast Surg. 1991;18(3):467–83.
18. Shenaq SM, Dinh TA. Foot salvage in arteriolosclerotic and diabetic patients by free flaps after vascular bypass: report of two cases. Microsurgery. 1989;10(4):310–4.
19. Ducic I, Attinger CE. Foot and ankle reconstruction: pedicled muscle flaps versus free flaps and the role of diabetes. Plast Reconstr Surg. 2011;128(1):173–80.
20. Hong JP. Reconstruction of the diabetic foot using the anterolateral thigh perforator flap. Plast Reconstr Surg. 2006;117(5):1599–608.
21. Oh TS, Lee HS, Hong JP. Diabetic foot reconstruction using free flaps increases 5-year-survival rate. J Plast Reconstr Aesthet Surg. 2013;66(2):243–50.
22. Suh HS, Oh TS, Hong JP. Innovations in diabetic foot reconstruction using supermicrosurgery. Diabetes Metab Res Rev. 2016;32(Suppl 1):275–80.
23. Suh HS, Oh TS, Lee HS, Lee SH, Cho YP, Park JR, et al. A new approach for reconstruction of diabetic foot wounds using the Angiosome and Supermicrosurgery concept. Plast Reconstr Surg. 2016;138(4):702e–9e.
24. Fitzgerald O'Connor EJ, Vesely M, Holt PJ, Jones KG, Thompson MM, Hinchliffe RJ. A systematic review of free tissue transfer in the manage-

ment of non-traumatic lower extremity wounds in patients with diabetes. Eur J Vasc endovasc Surg. 2011;41(3):391–9.
25. Moulik PK, Mtonga R, Gill GV. Amputation and mortality in new-onset diabetic foot ulcers stratified by etiology. Diabetes Care. 2003;26(2):491–4.
26. Reiber GE. The epidemiology of diabetic foot problems. Diabet Med. 1996;13(Suppl 1):S6–11.
27. Knox KR, Datiashvili RO, Granick MS. Surgical wound bed preparation of chronic and acute wounds. Clin Plast Surg. 2007;34(4):633–41.
28. Gottlieb LJ, Krieger LM. From the reconstructive ladder to the reconstructive elevator. Plast Reconstr Surg. 1994;93(7):1503–4.
29. Azoury SC, Stranix JT, Kovach SJ, Levin LS. Principles of orthoplastic surgery for lower extremity reconstruction: why is this important? J Reconstr Microsurg. 2019;37(1):42–50.
30. Hong JP. Reconstructive surgery: lower extremity coverage. In: Neligan P, editor. Plastic surgery. 4th ed. London: Elsevier; 2018. p. 127–50.
31. Attinger CE, Bulan EJ. Debridement. The key initial first step in wound healing. Foot Ankle Clin. 2001;6(4):627–60.
32. Reiber GE, Vileikyte L, Boyko EJ, del Aguila M, Smith DG, Lavery LA, et al. Causal pathways for incident lower-extremity ulcers in patients with diabetes from two settings. Diabetes Care. 1999;22(1):157–62.
33. Badia JM, Torres JM, Tur C, Sitges-Serra A. Saline wound irrigation reduces the postoperative infection rate in guinea pigs. J Surg Res. 1996;63(2):457–9.
34. Granick M, Boykin J, Gamelli R, Schultz G, Tenenhaus M. Toward a common language: surgical wound bed preparation and debridement. Wound Repair Regen. 2006;14(Suppl 1):S1–10.
35. Granick MS, Posnett J, Jacoby M, Noruthun S, Ganchi PA, Datiashvili RO. Efficacy and cost-effectiveness of a high-powered parallel waterjet for wound debridement. Wound Repair Regen. 2006;14(4):394–7.
36. Clemens MW, Attinger CE. Angiosomes and wound care in the diabetic foot. Foot Ankle Clin. 2010;15(3):439–64.
37. Attinger C, Cooper P, Blume P, Bulan E. The safest surgical incisions and amputations applying the angiosome principles and using the Doppler to assess the arterial-arterial connections of the foot and ankle. Foot Ankle Clin. 2001;6(4):745–99.
38. Christensen KS, Klarke M. Transcutaneous oxygen measurement in peripheral occlusive disease. An indicator of wound healing in leg amputation. J Bone Joint Surg Br. 1986;68(3):423–6.
39. Got I. [Transcutaneous oxygen pressure (TcPO2): advantages and limitations]. Diabetes Metab 1998;24(4):379–84.
40. Du Clos TW. Function of C-reactive protein. Ann Med. 2000;32(4):274–8.
41. Goss DE, de Trafford J, Roberts VC, Flynn MD, Edmonds ME, Watkins PJ. Raised ankle/brachial pressure index in insulin-treated diabetic patients. Diabet Med. 1989;6(7):576–8.
42. Cho MJ, Kwon JG, Pak CJ, Suh HP, Hong JP. The role of duplex ultrasound in microsurgical reconstruction: review and technical considerations. J Reconstr Microsurg. 2020;36(7):514–21.
43. Romiti M, Albers M, Brochado-Neto FC, Durazzo AE, Pereira CA, De Luccia N. Meta-analysis of infrapopliteal angioplasty for chronic critical limb ischemia. J Vasc Surg. 2008;47(5):975–81.
44. Saqib NU, Domenick N, Cho JS, Marone L, Leers S, Makaroun MS, et al. Predictors and outcomes of restenosis following tibial artery endovascular interventions for critical limb ischemia. J Vasc Surg. 2013;57(3):692–9.
45. Yue DK, McLennan S, Marsh M, Mai YW, Spaliviero J, Delbridge L, et al. Effects of experimental diabetes, uremia, and malnutrition on wound healing. Diabetes. 1987;36(3):295–9.
46. Berman SJ. Infections in patients with end-stage renal disease. An overview. Infect Dis Clin N Am. 2001;15(3):709–20, vii.
47. Hong JP. The use of supermicrosurgery in lower extremity reconstruction: the next step in evolution. Plast Reconstr Surg. 2009;123(1):230–5.
48. Randon C, Jacobs B, De Ryck F, Van Landuyt K, Vermassen F. A 15-year experience with combined vascular reconstruction and free flap transfer for limb-salvage. Eur J Vasc Endovasc Surg. 2009;38(3):338–45.
49. Bush HL Jr, Nabseth DC, Curl GR, O'Hara ET, Johnson WC, Vollman RW. In situ saphenous vein bypass grafts for limb salvage. A current fad or a viable alternative to reversed vein bypass grafts? Am J Surg. 1985;149(4):477–80.
50. Suh HP, Kim Y, Suh Y, Hong J. Multidetector computed tomography (CT) analysis of 168 cases in diabetic patients with Total superficial femoral artery occlusion: is it safe to use an anterolateral thigh flap without CT angiography in diabetic patients? J Reconstr Microsurg. 2018;34(1):65–70.
51. Shestak KC, Hendricks DL, Webster MW. Indirect revascularization of the lower extremity by means of microvascular free-muscle flap—a preliminary report. J Vasc Surg. 1990;12(5):581–5.
52. Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and random-pattern flaps. Plast Reconstr Surg. 1982;70(1):1–10.
53. Ecker ML, Jacobs BS. Lower extremity amputation in diabetic patients. Diabetes. 1970;19(3):189–95.
54. Goldner MG. The fate of the second leg in the diabetic amputee. Diabetes. 1960;9:100–3.
55. Kucan JO, Robson MC. Diabetic foot infections: fate of the contralateral foot. Plast Reconstr Surg. 1986;77(3):439–41.
56. Abdelfattah U, Power HA, Song S, Min K, Suh HP, Hong JP. Algorithm for free perforator flap selection in lower extremity reconstruction based on 563 cases. Plast Reconstr Surg. 2019;144(5):1202–13.
57. Adedeji R, Oragui E, Khan W, Maruthainar N. The importance of correct patient positioning in theatres

and implications of mal-positioning. J Perioper Pract. 2010;20(4):143–7.
58. Winfree CJ, Kline DG. Intraoperative positioning nerve injuries. Surg Neurol. 2005;63(1):5–18. discussion
59. Jeong HH, Hong JP, Suh HS. Thin elevation: a technique for achieving thin perforator flaps. Arch Plast Surg. 2018;45(4):304–13.
60. Goh TL, Park SW, Cho JY, Choi JW, Hong JP. The search for the ideal thin skin flap: superficial circumflex iliac artery perforator flap—a review of 210 cases. Plast Reconstr Surg. 2015;135(2):592–601.
61. Altiparmak M, Cha HG, Hong JP, Suh HP. Superficial circumflex iliac artery perforator flap as a workhorse flap: systematic review and meta-analysis. J Reconstr Microsurg. 2020;36(8):600–5.
62. Kim HB, Altiparmak M, Pak CJ, Suh HP, Hong JP. Reconstruction using free flaps for diabetic heel defects: outcomes and risk factor analysis. J Reconstr Microsurg. 2020;36(7):494–500.
63. McGregor IA, Jackson IT. The groin flap. Br J Plast Surg. 1972;25(1):3–16.
64. Daniel RK, Taylor GI. Distant transfer of an island flap by microvascular anastomoses. A clinical technique. Plast Reconstr Surg. 1973;52(2):111–7.
65. Koshima I, Nanba Y, Tsutsui T, Takahashi Y, Urushibara K, Inagawa K, et al. Superficial circumflex iliac artery perforator flap for reconstruction of limb defects. Plast Reconstr Surg. 2004;113(1):233–40.
66. Hsu WM, Chao WN, Yang C, Fang CL, Huang KF, Lin YS, et al. Evolution of the free groin flap: the superficial circumflex iliac artery perforator flap. Plast Reconstr Surg. 2007;119(5):1491–8.
67. Wei FC, Mardini S. Free-style free flaps. Plast Reconstr Surg. 2004;114(4):910–6.
68. Hong JP, Koshima I. Using perforators as recipient vessels (supermicrosurgery) for free flap reconstruction of the knee region. Ann Plast Surg. 2010;64(3):291–3.
69. Choi DH, Goh T, Cho JY, Hong JP. Thin superficial circumflex iliac artery perforator flap and supermicrosurgery technique for face reconstruction. J Craniofac Surg. 2014;25(6):2130–3.
70. Hong JP, Sun SH, Ben-Nakhi M. Modified superficial circumflex iliac artery perforator flap and supermicrosurgery technique for lower extremity reconstruction: a new approach for moderate-sized defects. Ann Plast Surg. 2013;71(4):380–3.
71. Suh YC, Hong JP, Suh HP. Elevation technique for medial branch based superficial circumflex iliac artery perforator flap. Handchir Mikrochir Plast Chir. 2018;50(4):256–8.
72. Hong JPJ, Goh TLH, Choi DH, Kim JJ, Suh HS. The efficacy of perforator flaps in the treatment of chronic osteomyelitis. Plast Reconstr Surg. 2017;140(1):179–88.
73. Suh HS, Jeong HH, Choi DH, Hong JP. Study of the medial superficial perforator of the superficial circumflex iliac artery perforator flap using computed tomographic angiography and surgical anatomy in 142 patients. Plast Reconstr Surg. 2017;139(3):738–48.
74. Fuse Y, Yoshimatsu H, Yamamoto T. Lateral approach to the deep branch of the superficial circumflex iliac artery for harvesting a SCIP flap. Microsurgery. 2018;38(5):589–90.
75. Yoshimatsu H, Iida T, Yamamoto T, Hayashi A. Superficial circumflex iliac artery-based iliac bone flap transfer for reconstruction of bony defects. J Reconstr Microsurg. 2018;34(9):719–28.
76. Yoshimatsu H, Steinbacher J, Meng S, Hamscha UM, Weninger WJ, Tinhofer IE, et al. Superficial circumflex iliac artery perforator flap: an anatomical study of the correlation of the superficial and the deep branches of the artery and evaluation of perfusion from the deep branch to the Sartorius muscle and the iliac bone. Plast Reconstr Surg. 2019;143(2):589–602.
77. Baek SM. Two new cutaneous free flaps: the medial and lateral thigh flaps. Plast Reconstr Surg. 1983;71(3):354–65.
78. Song YG, Chen GZ, Song YL. The free thigh flap: a new free flap concept based on the septocutaneous artery. Br J Plast Surg. 1984;37(2):149–59.
79. Wei FC, Jain V, Celik N, Chen HC, Chuang DC, Lin CH. Have we found an ideal soft-tissue flap? An experience with 672 anterolateral thigh flaps. Plast Reconstr Surg. 2002;109(7):2219–26. discussion 27-30
80. Hong JP, Chung IW. The superficial fascia as a new plane of elevation for anterolateral thigh flaps. Ann Plast Surg. 2013;70(2):192–5.
81. Kehrer A, Sachanadani NS, da Silva NPB, Lonic D, Heidekrueger P, Taeger CD, et al. Step-by-step guide to ultrasound-based design of alt flaps by the microsurgeon—basic and advanced applications and device settings. J Plast Reconstr Aesthet Surg. 2020;73(6):1081–90.
82. Kim EK, Kang BS, Hong JP. The distribution of the perforators in the anterolateral thigh and the utility of multidetector row computed tomography angiography in preoperative planning. Ann Plast Surg. 2010;65(2):155–60.
83. Chen KT, Mardini S, Chuang DC, Lin CH, Cheng MH, Lin YT, et al. Timing of presentation of the first signs of vascular compromise dictates the salvage outcome of free flap transfers. Plast Reconstr Surg. 2007;120(1):187–95.
84. Ashjian P, Chen CM, Pusic A, Disa JJ, Cordeiro PG, Mehrara BJ. The effect of postoperative anticoagulation on microvascular thrombosis. Ann Plast Surg. 2007;59(1):36–9. discussion 9–40
85. Glicksman A, Ferder M, Casale P, Posner J, Kim R, Strauch B. 1457 years of microsurgical experience. Plast Reconstr Surg. 1997;100(2):355–63.
86. Hanasono MM, Butler CE. Prevention and treatment of thrombosis in microvascular surgery. J Reconstr Microsurg. 2008;24(5):305–14.
87. Suh HP, Jeong HH, Hong JPJ. Is early compression therapy after perforator flap safe and reliable? J Reconstr Microsurg. 2019;35(5):354–61.
88. Wraight PR, Lawrence SM, Campbell DA, Colman PG. Creation of a multidisciplinary, evidence based, clinical guideline for the assessment, investigation and management of acute diabetes related foot complications. Diabet Med. 2005;22(2):127–36.