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A systematic approach to the failed plastic surgical reconstruction of the diabetic foot

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Plastic reconstruction for diabetic foot wounds must be approached carefully and follow sound micro-surgical principles as it relates to the anatomy of the designated flap chosen for coverage. First, the surgeon always needs to evaluate the local and general conditions of the presenting pathology and patient, respectively when considering a flap for reconstruction. The flap that is chosen is based on the vascularity, location, and size of the defect. Salvage of the failed flap and revisional reconstructive procedures are very challenging. Often, adjunctive therapies such as hyperbaric oxygen, negative pressure wound therapy, vasodilators, and/or vascular surgery is required. In certain case scenarios, such as patients with poor general health and compromised local vascularity in which revisional flap coverage cannot be performed, the above mentioned adjunctive therapies could be used as a primary treatment to potentially salvage a failing flap.

Keywords: *pedicle flaps*; *muscle flaps*; *diabetic foot*; *osteomyelitis*; *plastic surgery*

Soft tissue coverage for most diabetic foot wounds represents a challenge to the reconstructive surgeon. In our experience, patients suffering with diabetic foot and ankle soft tissue defects that require plastic reconstruction could be divided into two broad categories concerning their etiological mechanism: (1) traumatic wounds with a 'pathological evolution' such as degloving injuries, burns, and/or open fractures to diabetic patients and (2) chronic wounds that could be related to decubitus ulcerations in a diabetic background such as heel 'pressure' wounds, wounds associated with peripheral neuropathy including Charcot foot deformity or an osseous prominence with ulceration, with or without diabetic foot infections. Wounds could be associated with peripheral arterial disease or vascular insufficiency in diabetic patients. Concerning the nature and the morphological aspect of the wound we recommend the University of Texas Health Science Center San Antonio diabetic wound classification system (1) that presents the depth, quality, level of maturity and healing, and the involvement or not of any local infectious factors (Table 1).

The most important initial step in treating soft tissue defects related to the diabetic foot is to perform a timely and complete surgical debridement. This entails the surgical excision of all non-viable and/or infected soft tissue and bone so that the wound margins and base of the soft tissue defect are healthy and viable. This does not imply that débridement should be limited because of the size or location of the index wound since proper soft tissue reconstruction can only be performed after successful débridement and wound preparation regardless of size, depth, or location. If there is exposed bone or suspicion for underlying osteomyelitis, then bone cultures and biopsies are obtained and empiric systemic antibiotic therapy is started and eventually tailored to the identified pathogen. It is common for a patient to be brought back to the operating room several times for débridement before the wound is optimized for flap coverage. Failure to have an adequately débrided wound will most likely lead to failure of any attempt at flap coverage (2–9).

In addition to adequate soft tissue and bone debridement, the utilization of an external fixator is applied to stabilize significant osseous defects and/or unstable

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Table 1. The University of Texas Health Science Center, San Antonio, diabetic wound classification system (1)

Grade	0	I	II	III
A	Pre- or postulcerative lesion completely epithelialized	Superficial wound, not involving tendon, capsule, capsule or bone	Wound penetrating to tendon or capsule	Wound penetrating to bone
B	Pre- or postulcerative lesion, completely epithelialized with infection	Superficial wound, not involving tendon, capsule, or bone with infection	Wound penetrating to tendon or capsule with infection	Wound penetrating to bone or joint with infection
C	Pre- or postulcerative lesion, completely epithelialized with ischemia	Superficial wound. not involving tendon, capsule, or bone with ischemia	Wound penetrating to tendon or capsule with ischemia	Wound penetrating to bone or joint with ischemia
D	Pre- or postulcerative lesion, completely epithelialized with infection and ischemia	Superficial wound, not involving tendon, capsule, or bone with infection and ischemia	Wound penetrating to tendon or capsule with infection and ischemia	Wound penetrating to bone or joint with infection and ischemia

fractures. The utilization of external fixation allows access to the soft tissue defect and the performance of plastic surgical reconstruction. The management of Charcot foot deformity, if present, needs to be coordinated with a specialist that can adequately reconstruct the deformity to ensure the success of plastic surgical reconstruction. Often, Charcot foot and/or ankle deformities require deformity correction by performing complicated arthrodesis procedures prior to plastic surgical reconstruction.

Plastic reconstructive options for diabetic foot and ankle wounds

Generally, plastic reconstruction involves free skin grafts (3) or flaps. Soft tissue defects that are present in the diabetic foot often need flap reconstruction. It is our opinion that skin grafts are not usually recommended for a majority of the extremely deep and severe wounds encountered forms B, C, D; grades II, III (Table 1); and especially when they are located at the weight-bearing aspect of the foot and without enough subdermic soft tissue (fat or muscle) between the skin graft and the underlying bone. Dorsal and some plantar soft tissue defects and non-weight-bearing donor site defects are usually the only diabetic foot wounds we elect to cover with a skin graft.

The flaps could be random-local (advancement, transpositional, or rotating) (4) or vascularized. Vascularized flaps could be free, pedicled, fasciocutaneous, or muscle derived. Pedicled fasciocutaneous flaps could be axial reverse or orthrodromic or perforator based. Another, traditional flap that can also be used for the above mentioned cases is the cross leg distant flap. The most effective choice for soft tissue flap coverage typically depends on multiple factors including but not limited to the location, size, appearance, and depth of the wound in conjunction with the vascularity of the limb and the presence of underlying pathology.

The location of the defect is described according to the surface (dorsal, plantar, medial, and/or lateral) and the functional character of the injured area (weight-bearing area, peri-articular, non-weight–bearing, etc.). The wound depth is critical for the procedure selection. A superficial wound can be treated with surgical debridement, non-weight-bearing, and secondary healing or skin grafting (2). For deeper wounds, a fasciocutaneous, adipofasciocutaneous, or muscle flap is indicated. Local random flaps include transpositional, advancement, and rotational flaps that incorporate the skin, subcutaneous tissue, and sometimes the fascia for transfer. These flaps are geometrically designed and based primarily on the location of the defect. The flaps may be random in nature or based on a specific arterial inflow. Plantar defects, such as sub-cuboid ulcerations from Charcot neuroarthropathy and sub-metatarsal head ulcerations are especially well suited to this type of flap coverage so as to cover 'like with like' tissue. Modifications of bilobed and V-Y random advancement flaps are typically utilized for the coverage of sub-metatarsal ulcers and plantar defects as long as no underlying osteomyelitis is present (5, 6).

Local intrinsic muscle flaps are another option for closure of plantar weight-bearing wounds or to cover osseous defects after surgical management of osteomyelitis. Most frequently used muscle flaps in the foot are the flexor digitorum brevis, abductor hallucis, abductor digiti minimi, and the extensor digitorum brevis muscles (7). In the diabetic foot, remote pedicle island flaps are commonly utilized for the weight-bearing surface and to restore sensation. Pedicle flaps involve the local transposition of skin, subcutaneous tissues, and the associated neurovascular supply to cover a soft tissue defect and may be designed with retrograde or anterograde vascular inflow. Pedicle flaps are indicated to salvage failed local-random flaps, failed muscle flaps, and for larger soft tissue defects particularly over previous pedal amputations or heel defects. Pre-operative planning for these flaps involves meticulous evaluation of the vascular

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supply and its anatomic variations. The most common pedicle flaps utilized in the diabetic foot include the digital artery flap, medial and lateral plantar artery flaps, and reverse flow sural artery flap. In cases of using a vascularized flap (pedicled or free), it is preferred to utilize a neurovascular pedicle flap (medial plantar artery flap or reverse flow sural artery flap) if feasible and in order to restore sensation on the weight-bearing surface (Figs. 1 and 2).

In general, the management of diabetic foot and ankle soft tissue defects must be based on the safer flap according to the vascularity of the limb, patient's co-morbidities and if a flap failure occurs, a more complicated flap could follow. For example, if closure with a local-random flap is feasible, it should be attempted first. The second tier of treatment typically involves pedicle and/or perforator flaps. Free tissue transfers with vascular anastomosis may be performed with skepticism and after a thorough evaluation of the vascular status of the diabetic limb with angiography. Free tissue transfer utilized for complex diabetic foot and/or ankle wounds typically require harvest of the latissimus dorsi or gracillis muscle with microvascular anastomosis to a patent artery of the lower extremity (8, 9) (Fig. 3).

Failure and complications in plastic surgery for the diabetic foot management

Regardless of the plastic surgery reconstruction chosen, numerous complications are possible, with flap necrosis being the most common. Flap necrosis is classified as partial/superficial or full thickness (Figs. 4 and 5). In addition, the percentage of the flap compromised must be assessed and considered. The causes for flap necrosis are numerous and need to be understood particularly when attempting to salvage a flap that developed necrosis. Additionally, patient-related factors in the diabetic population contribute significantly to flap complications; therefore careful patient selection and co-management of the patient's co-morbidities is of utmost importance.

Fig. 1. Intra-operative view of a harvested reverse flow sural artery flap.

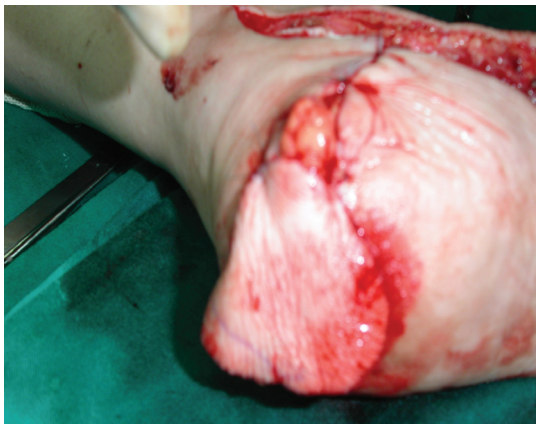

Fig. 2. Intra-operative view of a pedicled medial plantaris flap.

Technical errors such as compromise to the angiosome, pedicle, or vascular anastomosis and excessive tension on the flap should be avoided in order to decrease the chances of flap ischemia and necrosis. Meticulous hemostasis is paramount to prevent hematoma formation that can lead to venous congestion and flap necrosis. In addition, addressing pre-existing conditions such as osteomyelitis and vascular disease often have to be re-evaluated to determine if further intervention are required that may be jeopardizing the overlying flap. Regardless of the circumstances, the patient should be monitored closely in the postoperative setting so that complications can be recognized and treated early. Frequently, local wound care, hyperbaric oxygen therapy, adequate off-loading, as well as continuance of antibiotic therapy might be necessary during the patient's recovery period.

Fig. 3. Intra-operative view of a harvested gracillis muscle for eventual free tissue transfer.

Fig. 4. Clinical view of superficial necrosis of a reverse flow sural artery flap.

Rational approach to management of the failed plastic surgical reconstruction

The goal of revisional surgical treatment for failed soft tissue coverage is to eradicate infection if present, reassess and address any vascular compromise to the extremity, re-evaluate the underlying osseous structure and correct it if needed, and perform delayed soft tissue coverage when all of the previous factors are addressed. Deciding which patients are proper candidates for revisional and reconstructive surgery depends on the above mentioned factors. Before performing a second plastic reconstruction or another type of treatment, the surgeon needs to address the failure reasons that lead to the flap complication. A multidisciplinary team approach is taken to ensure optimization of the patient's systemic condition(s). Glycemic control is extremely important and must be addressed by the internists and/or endocrinologists so that blood sugars are normalized during the perioperative period. If patient non-compliance is the primary cause for the flap failure and patient education with eventual compliance cannot be established, the patient may be better served with amputation of the affected extremity or continuation of prolonged wound care modalities.

Fig. 5. Clinical view of a full necrosis pedicled flap.

The patient's peripheral circulation needs to be thoroughly evaluated when flap necrosis and soft tissue loss is evident. Smoking cessation should be enforced immediately if not already addressed. The necessity of immediate vascular work up consisting of non-invasive and invasive vascular studies is performed to determine whether conservative vascular intervention through the administration of vasodilators and/or anticoagulation is sufficient. For more complicated arterial occlusions, endovascular intervention, arterial-venous bypass with a saphenous vein, sympathectomy, and/or lower extremity bypass is required. It is also paramount to understand the importance of emergent diabetic foot surgery in the presence of a severe limb ischemia. However, vascular surgery should be consulted as early as possible especially in the face of flap compromise so that both disciplines can reach a consensus on the final treatment plan and to also perform any needed revascularization and revisional plastic surgery to obtain successful diabetic limb salvage. Delayed reconstructive plastic surgery procedures need to be coordinated with the vascular team to determine the best time for a definitive soft tissue closure of the diabetic foot.

Once the patient is optimized, a hierarchy of available options for soft tissue reconstruction in the diabetic foot is applied based on the size and location of the defect while considering the vascularity of the limb and what available local tissue can be utilized. If failure of a skin graft is observed, it is usually because the graft was too thin and/or hematoma, seroma or infection had developed. Once these underlying factors are addressed, a revisional skin graft can be performed. If skin graft failure was because of placement on an osseous prominence or on a weight-bearing aspect of the foot, then salvage is usually performed with a local random flap if the surrounding tissues are sufficient and a vascularized pedicle or perforator flap if they are not.

In the event of failure of a local random flap, a pedicle or perforator flap can be utilized. The pedicle or perforator flaps of the lower extremity can also be utilized to salvage failure of a free vascularized flap and should be attempted, if feasible, before performing a revisional free vascularized flap. Another option that exists is to utilize a pedicle flap from the contralateral extremity, the cross-leg flap, if options are limited. In addition, a combination of flaps can also be utilized

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including a local random flap combined with a pedicle or perforator flap to cover larger soft tissue defects.

The modified Papineau technique (10, 11) provides another alternative for management of both soft tissue and bone defects especially in recurrent osteomyelitis in diabetic severe lesions (forms B, C, D and grades II, III) (1). This technique allows for secondary wound healing and has been described with increased popularity over the last decade, as a solution for persistent osteomyelitis and as a salvage procedure. The modified Papineau open grafting procedure (10) consists of a radical treatment procedure of the recurrent osteomyelitis following severe lower limb trauma or infection and the secondary reconstruction of bone and soft tissue defects without closing the skin when other procedures have already failed (bone grafting, negative pressure wound therapy, and a free or regional flap performance) after, of course, a meticulous debridement and curettage. While in the classical Papineau technique the surgeon uses cortico-cancellous bone chips, our modifications consist of the use of only cancellous bone that is harvested from the iliac crest with a minimal invasion technique.

The modified Papineau procedure is not the first treatment choice but a salvage solution, which in some cases, is very effective. As with any other surgical technique, it is imperative to perform a meticulous debridement and resection of the septic osseous segment before performing the Papineau technique. It is also essential to immobilize the osseous segments preferably with an external fixator. This technique can also be performed repeatedly if initial failure occurs. This Papineau technique is utilized often when major free tissue transfer or pedicle flaps are not feasible as a final attempt for salvage prior to amputation.

Conclusion

Many possibilities exist for surgical reconstruction of soft tissue defects in the diabetic foot. The frequent co-morbidities in this patient population necessitate careful pre-operative planning and a multidisciplinary approach for optimal outcomes. A hierarchy of available options for soft tissue reconstruction in the diabetic foot is applied based on the size and location of the defect in conjunction with the vascularity of the limb.

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