RECONSTRUCTION IN THE REVASCULARIZED DIABETIC FOOT

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Abstract:
With an ongoing epidemic, the diabetic population with a neuroischemic diabetic foot is ever increasing. Advances in podiatry with refinements in microvascular reconstructive surgery in the last two decades have paved the way for the best functional reconstruction in neuroischemic diabetic feet. Salvage rate of the critically ischemic foot with revascularization and subsequent reconstruction has resulted in a shoeable and stable foot or its remnants in many patients. A standardized algorithm for reconstruction in a revascularized diabetic foot was developed by our department yielding predictable results. An evolving protocol in terms of the timing of reconstruction in revascularized diabetic feet and the best reconstructive flap techniques, based on the understanding of pathologies of regional vascular insufficiency and that of the immediate revascularized state are described. Rapid advances in the field of tissue engineering and stem cell therapy are expected to make a radical change in the field of reconstructive surgery in dysvascular limbs.

Key words: Neuroischemic diabetic foot, functional reconstruction, functional microangiopathy, microvascular reconstruction, like tissue reconstruction, stem cell therapy.

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Introduction

The World Health Organization estimates that currently more than 135 million people are diagnosed with diabetes mellitus in the world and this number expected to increase to 300 million by the year 2025. Approximately 25% of this population is expected to develop foot lesions during their life time (1). By 2030, an estimated 366 million persons will be affected by diabetes (2). Losing this limb can lead to a profound loss of productive life for patients in the Indian economy. India has one of the largest, if not the largest population of diabetic persons in the world. Reconstruction in the revascularized diabetic foot with a complex wound is a challenging job. Reconstructive surgeons should work with devotion to the basic principles of wound care. This is accomplished by understanding the functional reconstruction, rehabilitation potential, and careful knowledge of existing altered vascular anatomy and pathology. Basic steps of reconstruction are technically the same as in non-diabetic patients, but the approach is different. Our reconstruction procedures were carried out in seventy eight revascularized diabetic feet by the Department of Plastic Surgery, Government General Hospital from January 2003 to January 2010.
AIM OF RECONSTRUCTION

Reconstruction should result in a useful foot or remnant of the foot that renders patients ambulant. We termed this "functional reconstruction" which means to reconstruct the structures of mechanical design for weight bearing from skin envelope to bony skeleton in the foot or remnant foot. This should be achieved after the vascular insufficiency has been addressed by either a revascularization procedure or after adequate medical treatment of the vascular insufficiency. Failure to recognize the ischemic diabetic foot or attempted reconstructions without revascularization will lead to more progressive proximal amputations due to recurring necrosis at the sutured site as shown in Figure 1.

The first step is the recognition of critical vascular insufficiency that would prevent the normal wound healing process. The second step is to address that critical vascular insufficiency by revascularization. Once the wound healing potential is reestablished, labile regional circulation is stabilized and regional vascular insufficiency is corrected, the reconstruction procedure can be carried out. The ultimate and compelling aim of reconstruction is to salvage the foot and limb, especially when there is contralateral limb loss. This will allow the patient to have a socially and economically productive life (2). (Figure 2)

APPROACH TO THESE PATIENTS

Our approach to these patients involves the services of a plastic surgeon who is the primary physician, but should also consists of a vascular surgeon to revascularize the critical ischemic limb. Other team members include: interventional radiologists for angioplasty; radiologist for pre and post operative Magnetic Resonance Angiogram/conventional intra-arterial digital subtraction angiogram; endocrinologist for metabolic control; microbiologist for infection control; prosthetist / orthotist for footwear and offloading devices; and nurses for education and...
recurrence prevention. The interdisciplinary team integrates their services together for treatment plans, but carries out individualized treatment for each patient. In a multispecialty-integrated approach, the patient should also be made an important member of this team. In order to reduce the recidivism of foot lesions, patient education is of utmost importance, especially with those patients who do not “feel” their disease because they have both dysvascularity and concomitant neuropathy. Neuropathy is distributed peripherally in the same location as Peripheral Arterial Disease (PAD) and may also be associated with compromised vision from retinopathy and age related cataracts. These patients are not aware of their loss of protective sensation or reflexes and tend to walk barefoot, especially in our country. Education with repeated counseling goes a long way in preventing the recurrences of foot lesions (3). In order to avoid amputation and poor patient satisfaction, the patient and the caregivers are involved in prolonged discussions with the multidisciplinary team before embarking on the arduous task of revascularization followed by reconstruction. The complexity and composition of the wounds in the post revascularization stage requires critical analysis in terms of the following factors: whether it is in the weight-bearing or non weight-bearing areas; if it is in a regional vascular insufficiency zone; if there are any underlying bony deformities causing increased pressure; presence of any abnormal biomechanics causing abnormal muscle recruitment or imbalance. These factors should be considered for planning of the reconstructive and adjunctive procedures. Prior authors have performed combined distal bypass and microvascular tissue transfers but results have been associated with considerable morbidities and failures. We have found good results with the use of this protocol by performing reconstructions only after improving the wound’s healing potential and optimizing the patient’s general condition.

DYSVASCULARITY IN DIABETES MELLITUS PATIENTS

Ten percent of the diabetic patients in our study cohort were noted to develop peripheral vascular disease with a predilection towards the male gender. The author also found that 8% of the patients in this case series had end stage renal disease and 65% had medial wall sclerosis and calcification of vessels down to the digital vessels, diagnosed by plain radiography. All patients had multiple stenoses and occlusions involving both inflow and outflow vessels, in both lower limbs but asymmetrically affected. There was no predilection for the trifurcation or bifurcation of the popliteal artery in this series of cases as previously noted by Ukkola and Conrad. (4)
(5) Prior to the revascularization procedure, all of the patients had necrosis at the wound site without invasive infection. The patients also had no signs of wound improvement over a period of 48 to 72 hrs, a manifestation of dysvascularity in the lower limb. Fifteen percent were status post coronary bypass and 45% had eccentric stenosis in the iliac femoral segment. Those who were rendered fit by the central anesthetic assessment panel with optimization of cardiac and renal problems were taken up for surgery after high risk informed consent was obtained.

DIOSYNCRASIES OF REVASCULARIZED DIABETIC FOOT

There are many anatomical and pathological constraints in revascularizing limbs which reconstructive surgeons should have a thorough understanding of. Anatomically, there are few distal tissues available for reconstruction in the foot as it is an end organ and has a paucity of loose tissues. The first thing that the reconstructive surgeon should be aware of is the “regional vascular insufficiency”. Interestingly, after revascularization and re-establishment adequate flow in the macro vasculature, the reestablishment of wound healing potential does not always follow
immediately. After adequate revascularization, with distal bypass or endovascular procedures that render pulses palpable, persistent regional ischemic zones may persist. We termed this area the regional vascular insufficiency zones - (RVI) (Figure 3). These are many sequestered areas of soft tissues especially around the existing wounds due to “functional microangiopathy”

These areas have occult lactic acidosis due to the inability of capillaries to dilate or proliferate in response to ischemia and inflammation which results in local blockage of perfusion to tissues. This inability to respond, keeps the persistent ischemia at tissue level even after successful revascularization. It takes several weeks post revascularization for this area to show some granulation, which is the sign of wound healing potential. This is considered the latency period. During this latency period, the protocols practiced by the author are: continuing low molecular weight heparin, and as appropriate, with clopidogrel, aspirin, antidyslipidemic drugs, fluffy Owens three layered occlusive moist dressing and topical hydrogels on the wound in the presence of diffuse dry eschar (5). Topical negative pressure dressings were used in 60% of cases before definitive reconstruction, as this also effectively addresses the regional vascular insufficiency. Sharp debridement when needed is also performed with thoughtful incisions. If the debridement results in the exposure of tendons, bones, vessels and nerves, an intermediate preparatory dressing with collagen is applied. The opportunity for a free tissue transfer should be considered immediately, as this addresses the regional vascular insufficiency quite well. Most of the time these relatively ischemic and contaminated zones are approached with a free muscle flap from above the hip level as it resolves the infection effectively, due to the high vascularity of these flaps. Above-hip angiosomes are relatively free from atherosclerotic changes and by virtue of the robust blood supply, these free muscle flaps bring in tissues with adequate nutrition, oxygen, antibodies, and systemically administered antibiotics necessary for healing. To prevent invasive infection culture directed systemic antibiotics are used based on antibiograms.

Monckebergs sclerosis is the medial wall calcification of the arteries which is another common pathology seen in the diabetic population especially in those with renal disease. This can make microvascular anastomosis difficult, and also unreliable ankle pressure indices due to non-compressibility of vessels involving even the digital vessels. (Figure 4 and 5). Even after revascularization the renal neuroischemic diabetic foot is more prone for progressive proximal ischemia if debridement is not carefully considered. These feet are also sensitive to pressure and prone to injury even from a pressure dressing that is carelessly applied.
“Functional microangiopathy” poses another hurdle for the reconstructive microvascular surgeon. This pathology makes even the staged reverse flaps fail in total or in part due to oscillating veins and choked arteries. (Figure 6)

Another contributing factor is absence of adequate perfusion pressure in the diseased sympathectomized perforators. The authors feel that these problems can be addressed by free tissue transfer that brings in the well vascularized tissue to reduce the regional lactic acidosis cause by regional vascular insufficiency.

The best perforators are chosen based on the angiogram and can be done to also exclude graft thrombosis cases. In all cases preoperatively, a hand held Doppler is used prior to reconstruction. All ischemic tissues are more prone to exposure desiccation and devitalization. The reconstructive surgeon must balance these factors against the maturation of regional vascular insufficiency following revascularization and seize the early opportunity of reconstruction that brings in well vascularized tissues to the recipient site. Diabetic wounds with regional vascular insufficiency areas are also incapable of mounting an inflammatory or immune response to surgical trauma and therefore are staggered in the inflammatory phase of delayed wound healing. In the authors’ experience, microvascular tissue transfer surgery solves these problems well. Nonetheless, as severe axonopathic neuropathy occurs in the neuroischemic limbs, the chances of providing sensate flaps to prevent recurrence are not possible.

In the immediate post-revascularization period, there may be an increased inflammatory response at the wound site. Careful discernment between inflammation and infection should be considered as this may lead to aggressive debridement and unnecessary loss of salvageable tissues (9).

**Systemic Review of our Work**

In the Government General Hospital, department of the plastic surgery department, this author (TMB) performed 78 cases of reconstruction in revascularized diabetic feet during the period of January 2003 to January 2010. Ten females and 68 males were included in this systemic review of our work (Table 1).
These procedures were performed only after a critical analysis by the multi-specialty team had determined that the patients would have high probability for success. Patients are selected for reconstructive surgery only after thorough information has been provided. Those cases with less chances of success were advised to undergo primary amputation. Revascularization procedures were performed prior to any reconstruction in all of our cases, as all had a critically ischemic limb with average ankle pressure indices of 0.55. Angioplasty was performed in 42 cases, usually in the common femoral artery. Bypass was performed in 36 cases, with 18 distal bypass and the remainder to the popliteal or proximal arteries. A hybrid procedure is performed when a percutaneous transluminal angioplasty is accomplished in an inflow vessel and a distal bypass was performed during one case. Latency period is defined as the period before embarking on reconstruction following revascularization which can be 45 days to 90 days after bypass and 20 days to 60 days after angioplasty. This main difference between the latency period with bypass and angioplasty procedure is that wound healing potential is reestablished earlier with fast maturation of regional circulation following angioplasty on the average 35 days. This is probably related to the minimally invasive nature of angioplasty. The author also found that adequate pressure of 40mm Hg pressure distally at the dorsum of the foot is established in an average of 35 days after angioplasty and stenting. This result is also noted with stenting of even one proximal stenotic inflow vessel despite the presence of more than one stenosis distally.

Prior to revascularization, all patients had marginal ulcers or wounds with no healing potential. Fifty percent of these patients had limited gangrene. Sixty-five percent were smokers. In the post revascularization stage, areas of regional vascular insufficiency are treated with dressings and appropriate offloading of the foot. It may take several days post procedure for the clear line of demarcation and separation to appear. In this time period it is important to optimize their systemic problems and improve the patient’s wound status with multiple wound debridements, as needed. These debridements are done under nerve blocks as necessary. If needed, the coagulation profiles can be optimized with whole fresh blood, fresh frozen plasma and platelet concentrates. These patients are systemically, psychologically, and regionally prepared as the average time for reconstructive operation is 2.3 hours. Wound biopsy for culture and sensitivity is done routinely in all cases preoperatively. Preoperatively, source vessels are routinely Dopplered with a 10 MHZ hand held Doppler to pick up suitable recipient vessels in microvascular reconstruction and perforators for perforator based local regional flaps. Counseling is given to address smoking habits.

Minimally invasive cardiac monitoring using central venous catheters and arterial catheters were used during anesthesia. Regional block anesthesia was administered in cases of regional

<table>
<thead>
<tr>
<th>Procedures done</th>
<th>Number of cases</th>
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<tbody>
<tr>
<td>Skin grafting</td>
<td>10</td>
</tr>
<tr>
<td>Local and regional flaps</td>
<td>30</td>
</tr>
<tr>
<td>Perforator flaps</td>
<td>10</td>
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<tr>
<td>Staged reverse superficial sural artery flap</td>
<td>7</td>
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<tr>
<td>Pedicle fasciocutaneous forward flow flaps</td>
<td>9</td>
</tr>
<tr>
<td>Retrograde fasciocutaneous flap</td>
<td>4</td>
</tr>
<tr>
<td>Free microvascular flaps</td>
<td>48</td>
</tr>
<tr>
<td>Anterolateral thigh flap</td>
<td>4</td>
</tr>
<tr>
<td>Lattissimus dorsi flap</td>
<td>19</td>
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<tr>
<td>Glacilis flap</td>
<td>6</td>
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<tr>
<td>Radial forearm flap</td>
<td>12</td>
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<tr>
<td>Medial plantar artery flap (from relatively disease free sole)</td>
<td>2</td>
</tr>
<tr>
<td>Para scapular flap</td>
<td>5</td>
</tr>
<tr>
<td>Charcot joint stabilization</td>
<td>2</td>
</tr>
<tr>
<td>Tendo-Achilles lengthening</td>
<td>4</td>
</tr>
<tr>
<td>Osteectomies and gap arthroplasties</td>
<td>6</td>
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flaps, skin grafting reconstructions and free tissue transfers using below-hip angiosomes. Both end to end and end-to-side anastomoses are performed depending upon the suitability of recipient arteries or veins. The author always avoided neuroaxial anesthesia, as they can produce hypotension and may produce thrombosis of microvascular anastomoses. The remaining operations are done under general anesthesia with assiduous perioperative cardiac monitoring.

Preoperatively, all cases are assessed for associated abnormal biomechanics or underlying deformities that may cause increased pressure. If necessary, adjunctive procedures such as ostectomies, tenotomies and percutaneous tendo-Achilles lengthening are done. In the cases of microvascular tissue transfer, these adjunctive procedures are done as part of the preparation of the recipient site, in order to reduce ischemia time. Pursuing the principle of “like tissue reconstruction” in two cases we used a free medial plantar artery flap from the relatively disease free opposite instep for reconstruction. (Figure 7)

If the excision of the plantar ulcer is performed and only muscle is preserved at that depth, then local flaps are used for reconstruction. If ostectomies are done, a local flap in conjunction with an abductor hallucis muscle rotation flap is completed to cover the defect and dead space. This procedure is based on the perforators from the medial plantar artery. The authors feel that this can prevent a calcaneal prominence from causing plantar ulcers or recurrences. Since the author has implemented this technique, the recurrence of plantar ulcers has not occurred (Figures 8, 9 and 10).
CONCLUSIONS

The orderly completion and thoughtfully conceived plan to perform reconstruction following revascularization is the key to salvage the ischemic foot. Maintaining the bacterial balance of the wound should be the key aspect of the latency period before embarking on reconstruction. The appearance of granulation tissue in the wound is the hallmark of wound healing potential.

RESULTS AND COMPLICATIONS

Minor complications like seroma and hematoma were encountered in only 5% of the cases. The key to successfully treat these complications lies in the fast recognition and rapid evacuation in the postoperative period. Preoperative screening and optimization of the patient’s coagulation status reduced these problems in our series. Forward flow pedicled flap procedures were uniformly successful. However, staging is necessary in all reverse flow flaps. In our series, there was one staged reverse flow flap, using the reverse superficial sural artery flap for a posterior calcaneal defect that failed due to infection. There was partial necrosis of one anterolateral thigh free flap that was treated later by skin grafting. The use of below hip angiosomes is usually associated with more problems, as they do not recruit more tissue at their boundaries, which happens in non-diabetic individuals. In this series, above hip angiosomes for microvascular transfer did not experience any complications, except one radial forearm flap salvaged by repeat arterial anastomosis. This was attributed to thrombosis which was repaired with a fresh anastomosis done with distal, relatively disease free vessel, and excision of the thrombosed distal graft. Reconstructed foot or partial foot is globally offloaded with a walker for 6 to 8 weeks postoperatively. The average follow-up was nine months. Only four percent of the cases had recurrence of ulcers in the reconstructed area. Recurrent ulcers occurred in two cases where latissimus dorsi with skin graft was used for reconstruction.

Post micro-vascular transfers, low molecular weight dextran infusion, and decadron 8mg every 8 hours along with proton pump blocker with topical gastric mucosa protection are given for the initial 48 hours. Posterior popliteal slab immobilization with fluffy dressings is used in every case. Table 1 lists the variety of procedures performed in the authors’ series.
Other considerations that are not uncommon to use include, simple reconstruction options like toe filleted flap for the weight bearing area and skin grafting for other non-weight bearing instep regions (Figure 11).

Microvascular reconstruction is the best option for treating regional vascular insufficiency because it brings in well vascularized tissue, which can reliably deliver antibiotics, growth factors, oxygen and nutrients to the relatively ischemic wound and promotes wound healing (Figures. 12, 13, and 14).
The best way to solve the problem of finding the suitable recipient artery, in the regional vascular insufficiency for microvascular anastomosis, is to direct dissection towards the distal end of the arterialized vein bypass graft. Anastomosis is done in an end-to-side fashion using local vein for output flow. Careful selection of renal neuroischemic patients for reconstruction following arterial reconstruction is very important as these patients have high propensity for failure. It is usually due to diminished wound healing, increased rate of graft, perforator and microvascular thrombosis. If necessary, primary amputation should be suggested. To optimize success, the author follows the criteria that in all neuroischemic renal feet, post revascularization pressure index must be above 0.7 with palpable pedal vessels (10). In this author’s series, topical negative pressure dressings were utilized for wound bacterial balance for an average period of 25 days before the reconstruction, especially in regional vascular insufficiencies.

Preoperatively, a conventional angiogram is not always necessary. Even for local regional flaps a hand held Doppler assessment is often enough to understand the altered vascular anatomy. Tourniquets, tension sutures and tight dressings are avoided.

Prior to reconstruction and after revascularization, Doppler the source vessels and perforators increases the chance of success. Post revascularization pressure indices are not useful in deciding which form of reconstruction is needed (10). However, the status of vessels in the vicinity of the defect, quality of wound such as exposed vital structures, wound healing potential and amount of contamination are the main factors in determining the type of reconstruction. Adjunctive procedures must also be an integral part of reconstruction. Adjunctive procedures and like tissue reconstruction (reconstruction of sole defect with sole skin flaps) both have as high probability of reducing the recidivism of foot lesions. In calcaneal grade four ulcers, the use of muscle propeller flap with local rotation flaps reduces the recurrence risks. Three effective ways of monitoring the flaps are the evaluation for color, bleeding and warmth of free flap.

Patients’ motivation and compliance are the foundation for prevention of recurrences. Immediate postoperative compliance with global, then regional offloading with molded footwear and silicone gel socks along with proper care of the insensate foot by the patient will lead to success. Unequivocally, appropriate patient counseling and foot care education plays a pivotal role. Our protocol for management of the revascularized diabetic foot is illustrated in Figure 15.

![Figure 15 - Protocol for reconstructive management of the revascularized diabetic foot](image-url)
**Future**

The complex hurdle in dealing with patients with diabetes, for the reconstructive surgeon, is to overcome regional vascular insufficiency. Topical growth factors like platelet derived growth factor are neither cost effective nor address the critical point of regional vascular insufficiency or functional microangiopathy. Though the senescent organ of repair in the diabetic is revamped to some extent by the growth factors, they are not effective in ischemic tissues. Other considerations are the use of stem cell therapy which is believed to rejuvenate the functional microangiopathy. In India, stem cell therapy is costly and requires large-scale prospective trials to establish the effectiveness. Engineered tissue can be utilized in appropriately revascularized extremities (11). Primary microvascular flow through flaps is another concept slowly gaining acceptance in the reconstruction of the neuroischemic foot. These flaps provide cutaneous elements for wound coverage and at the same time provide vessel continuity with autogenous bypass vein grafts.

**REFERENCES**

1) Layne O. Gentry, Julia B. Garcia-Diaz, George A. Pankey. Contemporary diagnosis and management of Diabetic Foot Infections 2006; 1; 9


3) Althea VM Foster. Podiatric assessment and management of the diabetic foot. 2006; 168-170


5) Conrad MC, Large and small artery occlusion in diabetics and non diabetics with severe vascular disease. Circulation 1967; 36; 83-91


