Review article

Surgical revascularization techniques for diabetic foot

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ABSTRACT

Diabetes is an important risk factor for atherosclerosis. The diabetic foot is characterized by the presence of arteriopathy and neuropathy. The vascular damage includes non-occlusive microangiopathy and macroangiopathy. Diabetic foot wounds are responsible for 5–10% of the cases of major or minor amputations. In fact, the risk of amputation of the lower limbs is 15–20% higher in diabetic populations than in the general population. The University of Texas classification is the reference classification for diabetic wounds. It distinguishes non-ischemic wounds from ischemic wounds which are associated with a higher rate of amputation. The first principles of treatment are the control of pain of an eventual infection. When ischemia is diagnosed, restoration of pulsatile blood flow by revascularization may be considered for salvaging the limb. The treatment options are angioplasty with or without stenting and surgical bypass or hybrid procedures combining the two. Distal reconstructions with anastomosis to the leg or pedal arteries have satisfactory limb-salvage rates. Subintimal angioplasty is a more recent endovascular technique. It could be suggested for elderly patients who are believed to be unsuitable candidates for a conventional bypass or angioplasty. The current article would focus on the various revascularization procedures.

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1. Introduction

Diabetic foot is one of the challenging diseases in vascular surgery. This disease is based on the neuropathic gangrene due to microangiopathy as well as macroangiopathy such as peripheral arterial occlusive disease. Therefore, the strategy for diabetic foot is as follows: The first step includes infection control by minor amputation and/or drainage, the second step involves assessment of the limb ischemia, and the final is to complete vascular reconstruction such as distal bypass to the crural arteries. To salvage the diabetic foot, it is important that doctors, who treat, should understand these strategies. They should also have a settled opinion for the diabetic foot. The current article focuses on the surgical revascularization of the diabetic foot. The different classifications used are cited. These classifications help in the diagnostic process to differentiate a non-ischemic foot from an ischemic one. In fact,

only the ischemic variety requires revascularization. The different surgical techniques are presented, with an emphasis on their indications and results.

1.1. Evaluation of diabetic foot: variations in signs and symptoms

Several classifications of diabetic wounds have been suggested. The classification of the University of Texas (UT) [Table 1] is easy to utilize.¹ It consists of four grades according to depth of the wound and four stages according to the presence or absence of an infection and/or an arteriopathy [Table 2]. It is most often used as the reference classification for diabetic wounds. A complementary classification of the wound infection has been defined in the International Consensus on Diabetic Foot.² This classification consists of four grades [Table 3].

1.2. Clinical evaluation

Clinically, the distinction of ischemic ulcer is not always easy. The decrease or the disappearance of the peripheral pulse confirms the diagnosis of obliterating arteriopathy of the lower limbs (OALL).

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Table 1
Classification of the University of Texas for diabetic foot.

		Grade 0	Grade 1	Grade 2	Grade 3
		Epithelial lesion (amputation in %)	Superficial wound (%)	Deep wound: Attack of tendon or capsule (%)	Osteitis or arthritis: Attack of bone or articulation (%)
Stage A	No ischemia, no infection	0A (0)	1A (0)	2A (0)	3A (0)
Stage B	No ischemia, infection	0B (12.5)	1B (8.5)	2B (28.6)	3B (92)
Stage C	Ischemia, no infection	0C (25)	1C (20)	2C (25)	3C (100)
Stage D	Ischemia, infection	0D (50)	1D (50)	2D (100)	3D (100)

The disappearance of the tibial pulse has a better positive predictive value than the disappearance of the foot pulse.³ Nevertheless, in particular instances, there can be severe ischemic signs (necrosis of the toe) while the distal pulses are present, as a result of the extreme distal nature of the vascular lesions. Intermittent claudication of the calf or the sole of the foot, pain of decubitus which eases on reclining have good diagnostic values. But an arteritis frequently associated with a peripheral neuropathy⁴ and the absence of pain does not exclude the diagnosis.

Moreover, in the study of Apelqvist et al,⁵ half of the patients with gangrene did not have pain of decubitus. The examination of the skin and the exoskeleton of the wound could support additional arguments in favor of arteritis:

- Fine, atrophic, pinkish, smooth, and shiny skin
- Distal coldness of the foot
- Erythrosis of declivity (declining erythrosis)
- Cyanotic appearance
- Depilation
- Thickened, stratified, and swarthy-colored (dark) nails with onychomycosis
- Wounds which are localized in the areas of rubbing (lateral and dorsal parts of the foot)
- Necrotic appearance.^{6,7}

1.3. Diagnostic process

The clinical examination, with the help of a stylet, specifies the depth and extent of the trophic disorder. It investigates for a bony contact or an articular surface. The infection initially manifests as cellulitis. It could progress toward an abscess (gangrene) or lymphangitis. It is imperative to investigate for fever and an increase in the amount of C-reactive protein, associated with leukocytosis. Bacteriological samplings are only indicated in case of a clinically established infection.⁸ The microorganisms responsible for the infection should be isolated and identified from the sample. Contamination by commensal flora, which colonize the skin, should be avoided. There is no consensus as to the best technique that is to be applied. Before taking any sample, the wound must be prepared. A superficial swab of the wound is the most utilized method since it is the easiest, but saprophytic germs could be found which have no relation to the infection. Deep swabbing, curettage, of an ulcer

Table 2
Stages of diabetic foot.

Stage A	Non-ischemic, non-infected wound. There is secondary hyperkeratosis with diabetic neuropathy
Stage B	Non-ischemic, infected wound. There is perforation. If follows, a cracking of the hyperkeratosis corn which gets superinfected in depth in comparison to a zone of hyper-pressure such as the head of the metatarsals
Stage C	Non-infected, ischemic wound. The trophic disorder is secondary to an ischemia and a perforating illness (Stage B). This stage corresponds to dry necrosis
Stage D	Infected, ischemic wound. It involves gangrene following the infection of stage C. There is wet necrosis

could be carried out with the help of a curette or a sterile scalpel. Tissue biopsy, which is rendered possible by neuropathy, is a method to be favored. Finally, fine needle aspiration is a good method for deep wounds. In case of an unfavorable development, repeated samplings are advised.⁸

The histological characteristics of the arterial lesions do not have specificity in diabetes. OALL in diabetic patients preferentially involves the sub-inguinal arteries, in particular the deep femoral arteries and the arteries of the leg. It often saves the arteries of the foot, specially the pedal artery, whereas the trophic disorders predominate in the foot and in the toes.⁹

1.4. Radiological evaluation

X-rays of the foot for investigating the signs of osteitis or arthritis are carried out in the first place. The signs suggestive of a deep penetrating wound include periosteal reaction, osteopenia, and osteolysis. But these signs become evident only after the destruction of 30–50% of the bone.⁹ At the outset of progression, the X-ray plates could be normal. Therefore, one must repeat them for every 2–4 weeks. Magnetic resonance imaging could be done. This examination seems to have a good sensitivity and specificity, especially for attacks of the fore-foot. The anatomical description pinpoints the diseased bony are as and is very useful in guiding a possible surgical intervention.

1.5. Echo Doppler and measurement of the systolic pressure index (SPI)

The measurement of the SPI is an indispensable standard investigation. It is carried out with the help of a continuous Doppler probe. It corresponds to the ratio between the systolic pressure measured at the ankle in mmHg and that in the arm (humeral). An index between 0.7 and 0.9 translates into a compensated OALL, whereas a value less than 0.5 manifests as severe ischemia.¹⁰ An SPI greater than 1.4 signifies that the distal arteries are calcified and incompressible (medialcalcosis seen in 30% of diabetics).¹¹ An SPI >1.4 could therefore be associated with endoluminal lesions. This measurement is therefore only reliable in 70% of the cases, but it refines the clinical process.

1.6. Transcutaneous measurement of the partial oxygen pressure (TcPO₂)

It is an indirect measurement for quantifying the severity of cutaneous ischemia. The pressure obtained is an indicator of the

Table 3
Classification by international consensus on diabetic foot.

Grade 1	Absence of infection
Grade 2	Minimal dermatocellulitis
Grade 3	Dermatocellulitis>2 cm or deep abscess, lymphangitis, osteitis, septic arthritis, or fasciitis
Grade 4	Presence of general signs (fever, tremors, hypotension, tachycardia, confusion, hyperleukocytosis, and acidosis)

oxygenation of the superficial layer of the skin. It reflects the nutritional efficacy of microcirculation. It is a simple, non-invasive, and reproducible method even in case of mediocalcosis. The sites of measurement are the back of the foot and the first inter-bone space and avoiding a positioning on a tendinous zone. The normal TcPO₂ for a diabetic patient is around 50 mmHg as against 65 mmHg for a non-diabetic patient.¹²

A TcPO₂ less than 35 mmHg is a manifestation of a hypoxia at rest and points to the non-healing characteristics of trophic disorders. A measurement which is <10 mmHg signifies impossibility of healing since tissue viability is totally compromised. The measurement could be sensitized through a measurement of the dangling legs. However, infection and edema of the back of the foot lead to falsely lower measurements. Hence, TcPO₂ is contraindicated.¹³

1.7. Other investigations: measurement of the systolic pressure at big toe

The significance of this measurement in diabetics lies in the lesser frequency of mediocalcosis at the level of the toes.¹⁴ It is therefore indicated in cases of neuropathy which is accompanied by mediocalcosis with SPI >1.4.^{15–17} Previously, plethysmograph-based measurement of systolic pressure necessitated a sophisticated and costly equipment. A completely automatic and easy-to-use photo-plethysmograph is in the process of evaluation.¹⁸ An OALL is defined by a toe/arm index of less than 0.55. Systolic pressure at big toe greater than 30 mmHg raises the hope for curability of an ulcer. At values less than 30 mmHg, ischemia is critical and a revascularization must be envisaged.

1.8. Management of an infected trophic disorder

Abscesses must be drained immediately. A cellulitis, which does not respond quickly to antibiotic treatment or which could progress toward a phlegmon, should be surgically incised. A superinfected gangrene of the toe or a fore-foot should be treated by amputation while leaving the wound open. If not addressed adequately, the infection of trophic disorders aggravates ischemia due to interstitial edema and could suddenly affect the prognosis of the limb. Treatment of the infection (discharge, incision, and antibiotic therapy) must be initiated without delay. Revascularization should be aimed only when the infectious condition is controlled. In all cases, where an amputation is carried out, it is important to do a prior vascular assessment in order to avoid the setbacks of non-healing and repeated amputations.

1.9. Indications for revascularization

Once severe ischemia (critical ischemia) is confirmed by coldness of the feet, paleness, decreased pulse, necrosis, and some evocative signs from a vascular investigation (arterial pressure <50 mmHg or TcPO₂ <30 mmHg), then every attempt must be made for revascularization of the limb. The aim of revascularization is to ensure salvage of the limb by healing of the trophic disorder. A satisfactory support bed with at least a receiving arterial axis, a distal artery of a good caliber, and the presence of a plantar arch is a mandatory prerequisite.

The evaluation of the arterial network is carried out with the help of the following:

- An angio-tomodensitometry or
- An angio-magnetic resonance.

If there is a renal insufficiency, an arteriograph is necessary if the support bed is not clearly visualized. The benefits from revas-

cularization should be more than its risks. Complete evaluation about the operability is carried out without delaying this step in fragile patients. The investigation of other arterial diseases revolves around the exploration of the supra-aortic trunks and coronaries. Finally, the indication of a surgical revascularization loses much of its significance in bedridden patients.

1.10. Surgical management

The vascular surgeon can choose between bypasses, endovascular techniques as follows:

- Transluminal angioplasty which may or may not be associated with the placement of a stent
- Subintimal recanalization. This is a more recent approach.

Hybrid techniques include both. The choice of a revascularization technique is a similar to that of non-diabetic patients.¹⁹ It depends on the type of lesion, the presence or absence of stenosis and thrombosis as well as their length.

The recommendations of the Transatlantic Intersociety Consensus (TASC),²⁰ updated in 2007 (TASC II)²¹ classifies aortoiliac or femoro-popliteal lesions into four types:

- For TASC A, endovascular treatment is the treatment of choice and for TASC D, surgery
- For TASC B, endovascular treatment is to be favored, while for TASC C lesions, surgery is to be favored.

The result of revascularization of the limbs is evaluated according to the primary permeability and secondary permeability after a supplementary treatment of a restenosis or an occlusion after the initial action. Another factor to be taken into consideration includes percentages of limbs that are saved.

1.10.1. Bypass

They are indicated in case of stage III or IV of Leriche et Fontaine associated with stenosis and/or extended arterial thrombosis (TASC C or D).^{20,21} There must be a receiving trunk. Bypasses must be only carried out once the infection is controlled. Use of autologous venous material (mostly the homo or contralateral great saphenous vein) is preferred. This vein is either inversed so that the valves are not opposed to the arterial flux or utilized *in situ* with a devalator. This vein must be of good caliber, with a diameter of 3 or 4 mm at least and of a good quality (absence of varicosity).

If there is an indication for revascularization, a venous echo Doppler of the two limbs is carried out as a pre-operative measure to evaluate this vein. If the vein is insufficient or of a bad quality, one can either use an allograft or a composite bypass (anastomotic prosthesis distal to a venous graft) which enables one to pass the flexible tube from the knee. An entirely prosthetic bypass with cuff can be utilized. These bypasses often involve the sub-inguinal level. They are either supra-articular or sub-articular femoro-popliteal, or femoro-distal. Some fundamental principles which govern to carry out bypasses are as follows:

- The shorter the bypass, the better will be its permeability
- The permeability of a sub-articular femoro-popliteal prosthetic bypass is less than that of a venous bypass due to the flexible tube from the knee.²²

Aleatory bypass is considered when the receiving arterial axis is single. In effect, the occurrence of an occlusion of the bypass is deleterious for the sole remaining axis. Because this aggravates ischemia, which sometimes necessitates amputation. The

inconvenience of this technique is that it requires general anesthesia on a diabetic and poly-vascular terrain. Sometimes, especially in women, the surgical procedure cannot be carried out because of too small or highly calcified distal artery in the pre-operation stage. Also, one must fear the delays of healing inherent in the distal wide routes in the ischemic area, the infectious complications, and above all the delay of the verticalization of the patient which is very harmful in the aged subject. In a prospective study which involved 795 arterial bypasses (87% sub-articular) carried out on account of trophic disorders in diabetic patients, the amount of limbs saved at 5 years was 87.5% which corresponded to a secondary permeability of 76% for femoro-distal bypasses.²³

1.10.2. Transluminal measurement with or without stent

It is indicated in case of stenosis or brief arterial thrombosis (TASC A and B).^{20,21} The endovascular procedure needs technical equipment which comprises a brilliance amplifier, a radio-transparent table, a stock of guides and initiators, angioplasty balloons and stents of different sizes and calibers for the iliac arteries, the superficial femoral arteries, the popliteal arteries, and the arteries of the legs. The principal advantage of all these procedures is the possibility of their being carried out under local anesthesia, which permits a quick emergence from the following day onwards. Besides, it does not compromise the possibility of a further surgical intervention in case of failure. Diabetic patients have less primary permeability after angioplasty than non-diabetics. However, at the cost of repetitive procedures, the secondary permeability and the amount of limbs saved 1 year do not present any significant difference whether the patients are diabetic or not.²⁴ There are a certain number of complications: Hematoma at the point of puncture in 2% of the cases. Some peripheral embolism with blue-toe, or a syndrome of blue nails, occurs in 1–2% of the cases. Finally, a dilatation could be the case of a dissection which necessitates the placement of a stent.²⁴

In a study which reported 66 angioplasties carried out in diabetic patients, the amount of limbs saved at 2 years was 85% with a secondary permeability of 69% for angioplasties.²⁵ However, a study which compared the results of the angioplasty vis-a-vis those where amputations are carried out at once in case of a critical ischemia in inoperable patients gave only a very slight advantage to the endovascular treatment. There was no significant difference in the mortality at 1 month, or for survival at 2 years.²⁶

1.10.3. Subintimal recanalization

The technique was described by Bolia in 1994.^{27,28} The principle is to carry out a subintimal dissection at the thrombosis with the help of a guide for making it re-enter into the arterial lumen just below the occlusion [Fig. 1].

The necessary material is identical to that of the angioplasties. This re-entry could be carried out with the help of a guide or a dedicated device which would optimize the accomplishment of this delicate phase. An injection of iodized contrast, by a descending guided probe, controls its correct positioning in the arterial lumen upstream of the thrombosis. Next, an angioplasty is carried out by flattening the atheromatous thrombosis. In the initial technique, the placement of a stent was carried out only in the case of a residual stenosis which is greater than 30%. The significance of the placement of a stent after recanalization is controversial because its rigidity would decrease its primary permeability. In effect, the criterion for success is not the obtaining of a perfect radiological image but that of a dynamic one, with a good flow. This technique is the one that is most often indicated in case of critical ischemia (pain of decubitus, trophic disorders) in the presence of extensive arterial thrombosis (TASC C and D).

Fig. 1. Subintimal recanalization. A. Beginning of the subintimal dissection. B. Subintimal dissection. C. Intraluminal re entry. D. Angioplasty.

Some practitioners carry it out for severe claudications. Initially carried out in a femoro-popliteal,²⁹ this procedure has been extended to the arteries of the legs due to the utilization of angioplasty balloons of a small caliber. The placing of a stent in the leg is to be avoided because of the very weak caliber of the arteries. The inconvenience lies in its higher failure rate. One must deplore 14% technical failure and 20% of clinical failure which necessitate either an amputation or a short-term bypass.^{27–31} At 1 year, the rate of limbs saved is 80–90%. The primary permeability was 45–50% and the secondary permeability was 76%. At 3 years, the rate of limbs saved was 75% with a primary permeability of 25% and a secondary permeability of 50%. There was no significant difference between the diabetic and the non-diabetic groups.²⁹ The poor results of the primary permeability are therefore counterbalanced by a satisfactory rate of limb-saving. This is the concept of a temporary bypass: The important thing is to get over the worst, in order to obtain the healing of the limb.

Its advantage is to suggest an alternative to bypass which helps avoid general anesthesia and wide routes. It enables the re-establishment of a flow by an endovascular route in case of a long arterial thrombosis. One can therefore suggest this technique in the first place for elderly patients and/or inoperable stage C or stage D of the UT classification. However, the results for an immediate amputation in inoperable patients do not show any significant difference in terms of survival or independence at 2 years.²⁶

1.10.4. Combined procedure

It combines angioplasty and subintimal recanalization. A study, which only involved ischemic ulcers of diabetic patients found similar results.³² The rate of initial technical failure is 16%. The primary and secondary permeability at 1, 2, 3, and 4 years are 62%, 45%, 41%, and 38% and 80%, 69%, 66%, and 66% respectively. The rate of limb-saving at 1, 2, 3, and 4 years is 89%, 83%, 80%, and 80%, respectively. The results for limb-saving are satisfactory.

1.10.5. Hybrid procedures³³

It combines bypass and endovascular techniques or two endovascular techniques. For example, angioplasty of the superficial femoral artery combined with a femoro-distal bypass or an angioplasty of an external iliac artery combined with a femoro-

popliteal bypass. The principle of this technique is to have recourse to shorter bypasses and, therefore, bypasses which are permeable for a longer period. Studies on the treatment of critical ischemia published between 2003 and 2006 confirm the decrease in the carrying out of surgical bypasses in favor of endovascular technique, without an increase in the rate of amputation.³⁴

2. Conclusion

The main difficulty in the management of the diabetic foot is to appreciate the indications of revascularization. For this, there must be an ischemia combined with a diabetic neuropathy. If there is an ischemia, the indication for revascularization for saving of a limb is carried out on condition that the upstream bed is correct (at least a receiving axis). It is important to define a strategy with every available therapeutic arsenal: Surgical bypass, angioplasty, or the more recent subintimal recanalization: a technique of the future which has been tried and tested. This technique is to be suggested for very old and/or inoperable patients. Finally, any hope of healing after revascularization is illusory without a multi-disciplinary management. Once the leg is healed, prevention is fundamental for avoiding any recurrence.

Conflicts of interest

All authors have none to declare.

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