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Lower extremity bypass in patients with diabetic foot ulcers

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Worldwide, diabetes has become an epidemic. In the United States, the incidence of diabetes is increasing 1% per year. Presently there are approximately 16 million people (6% of the population) who have diabetes, half of whom do not even know they have the disease. Although no one is immune, African Americans, Hispanics, and Native Americans are at greater risk. In the United States, diabetes is the seventh leading cause of death, mainly secondary to cardiovascular complications.

Foot problems are an associated complication and an increasing problem among individuals with diabetes. Of diabetics, 15% develop a foot ulcer during their lifetime, and foot ulcers precede 85% of all nontraumatic amputations [1]. Half of lower extremity amputations in the United States occur in people with diabetes (86,000 last year). Amputation is one of the diabetic's greatest fears, with documented decreased physical, emotional, and social function. Amputation rates are greater with increasing age; in men compared with women; and among members of racial, ethnic, and socioeconomic minorities. Despite best efforts, the incidence of lower extremity amputation in patients with diabetes continues to rise. Access to care and the quality and comprehensiveness of the care delivered are major variables affecting the outcome of diabetic foot care and amputation prevention [2]. Half of amputations may be preventable through better education of patients, families, and health care professionals; following evidence-based diagnosis and treatment algorithms for diabetic foot problems; and routine and regular foot care.

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Why diabetics are different

The cause of foot problems and faulty wound healing in patients with diabetes can be attributed to three predisposing factors: peripheral neuropathy, vascular disease and tissue hypoxia, and abnormal cellular and inflammatory pathways [3]. Peripheral neuropathy is the most common complication afflicting diabetics. There are several components, but the loss of protective sensation to pressure, pain, and temperature reduces or removes the warning signals of a potentially dangerous condition or event. Motor neuropathy results in weakness and atrophy of the intrinsic and skeletal muscles of the foot, altering foot structure and leading to deformity and altered biomechanics. Autonomic neuropathy can affect the extremities, heart, and other major organs. Autosympathectomy leads to arteriovenous shunting and impairs the normal maintenance of skin integrity and vascular tone. Neuropathy also impairs the neuroinflammatory response, the hyperemic response, and a proper thermoregulatory response important for normal wound healing.

When a person sustains an acute wound, the body responds with an orderly and predictable process of healing phases dependent on cellular and humoral components. Abnormalities in cellular function, particularly among neutrophils and fibroblasts, have been found in diabetics. The humoral responses to wound healing, such as extracellular matrix and cytokine production, are affected adversely by advanced glycosylation end products and disrupt this orderly sequence of healing. With neuropathy and microvascular dysfunction impairing several of the regulatory mechanisms, diabetic wound healing frequently gets "stuck" in the inflammatory/proliferative phase, allowing for repeated injury, infection, and further inflammation.

Lower extremity peripheral vascular disease (PVD) is one of the most important reasons for pain, nonhealing ulceration, gangrene, and amputation in individuals with and without diabetes. It also is a marker for systemic atherosclerosis affecting the coronary and cerebral arteries. The incidence of PVD in diabetic patients is at least four times that of nondiabetic individuals and increases with age and duration of diabetes. Women are affected similarly to men. Critical ischemia has been shown to be associated with 62% of cases in which there has been nonhealing ulceration and a causal factor of 46% of amputations [1]. It is essential that any algorithm for wound healing in the diabetic include assessment for vascular insufficiency and proper management.

Diabetic peripheral vascular disease

The ultimate consequence of atherosclerotic PVD is diminished arterial perfusion to the lower extremity and foot. PVD contributes to limb pain, ulceration, and impaired wound healing and decreases the ability to fight infection by delaying or preventing the delivery of oxygen, nutrients, components of a proper immune response, and antibiotics to the affected area.

Risk factors and prevention

Diabetic PVD is more common, occurs at a younger age, and advances more rapidly with a roughly equal male-to-female ratio compared with nondiabetic PVD. Diabetes is not the only risk factor for PVD; other risk factors are hypertension, smoking, hyperlipidemia, hyperhomocystinemia, obesity, and family history. Prevention of or delaying the onset of PVD in the diabetic is best achieved by elimination of the associated risk factors, especially proper and tight control of diabetes. Periodic clinical vascular examination, including noninvasive testing when appropriate, identifies diabetic patients at risk so that they can be observed more carefully or referred to a vascular specialist.

Pathophysiology

Diabetic PVD has several distinguishing features in contrast to PVD in nondiabetic patients. Although atherosclerotic occlusive disease can involve any artery in the diabetic patient (especially in smokers), there is a predilection for the process to involve primarily the tibial and peroneal arteries between the knee and the foot. The foot vessels, especially the dorsalis pedis artery, the distal posterior tibial artery, and the plantar arteries, usually are spared. It is a persistent misconception that there is an occlusive microvascular disease affecting the diabetic foot arteries that precludes revascularization necessary for wound healing. This misconception leads to inappropriate or no vascular evaluation and care extended to many diabetic patients who need aggressive revascularization for proper wound healing. Because the atherosclerotic disease spares the foot arteries, tissue perfusion in the ischemic diabetic foot can be restored by appropriate vascular reconstructions.

Peculiar to the diabetic is the development of microvascular dysfunction, which begins early in diabetic life. It frequently is seen in the capillaries and arterioles of diabetic kidneys, retinae, and peripheral nerves but spares no organ. It begins as increased microvascular pressure leading to endothelial injury with basement membrane thickening and results in a limited capillary capacity with loss of autoregulatory function, including the abolition of a vasoconstrictor response. Basement membrane thickening may impede leukocyte migration and impair oxygen diffusion, resulting in a metabolic blockage of oxygen use. Increased arteriovenous shunting, an impaired hyperemic response to heat and inflammation, a loss of a postural vasoconstrictor response, increased capillary permeability leading to edema formation, and a diminished or loss of neurogenic regulatory response alters the diabetic patient's ability to respond to wounding with a proper and orderly sequence of healing.

Diabetic patients with atherosclerotic peripheral vascular disease also show a diminished ability to establish collateral circulation, especially around the infrageniculate arterial branches at the knee level. This diminished ability is another reason why it is better to bypass directly to an artery that has continuity all the way down to the foot when one is trying to heal extensive tissue loss.

Although the pathology of atherosclerosis is similar for diabetic patients and nondiabetic individuals, peculiar to the diabetic patient is the development of calcification involving the intimal plaque and media (medial calcinosis/Mönckeberg's sclerosis) that frequently involves diabetic arteries at all levels. Medial calcinosis is the most common reason why noninvasive testing results are frequently erroneous and are only complementary to clinical judgment in assessing the severity of diabetic PVD. Medial calcinosis leads to falsely high segmental pressures and an erroneously elevated ankle/brachial index. Medial calcinosis also can complicate revascularization techniques, including balloon angioplasty and surgical bypass.

Clinical presentation and evaluation

The clinical presentation of diabetic patients with major artery occlusions or hemodynamically significant stenoses varies depending on their activity level and the adequacy of collateral pathways. Claudication, the inability to walk a given distance (usually described in blocks) because of an aching or pain in the muscles of the leg, is the earliest symptom of PVD. It is easily reproducible, made worse by an incline, and always relieved by rest. The arterial blockage or stenosis is usually one level higher than the group of muscles involved in the symptoms. For the nondiabetic patient, calf claudication usually means superficial femoral artery disease, and thigh, hip, and buttock claudication implies atherosclerotic occlusive disease involving the aorta and iliac arteries. Because of the predilection for tibial and peroneal artery involvement, diabetics may describe foot pain or tightness when walking or, because of neuropathy, may state that they just have to stop and not be able to describe classic claudication. As PVD worsens, rest pain occurs and is described similarly for diabetics and nondiabetics with a deep, aching pain in the muscles of the foot at rest or at night. It is relieved by hanging the feet in a dependent position or walking. As the disease process progresses further, tissue ulceration or gangrene or both develop. Because of neuropathy, diabetic patients often present with tissue loss or gangrene or both as the first sign of PVD.

Clinical evaluation, judgment, and experience are the most important means for identifying diabetic PVD and determining its severity. Noninvasive testing by whatever means is only complementary to clinical evaluation. As already mentioned, segmental systolic pressures in the lower extremity may be falsely high because of medial calcinosis and result in a falsely elevated ankle/brachial index. A systolic arterial ankle pressure of less than 50 mm Hg (ankle/brachial index <0.6) suggests critical ischemia. Medial calcinosis frequently spares the foot and toe arteries with a toe pressure normally 10 mm Hg lower than the arm pressure. An absolute toe pressure of less than 30 mm Hg is considered inadequate for wound healing. Arterial waveforms derived from using either a Doppler or pulse volume recordings (PVR) also frequently are used. The waveform is normally triphasic, and hemodynamically significant stenoses result in either a biphasic or monophasic waveform. Transcutaneous oxygen tension ($TcPO_2$) also is used to measure the degree of ischemia. Normal $TcPO_2$ is defined as 55 mm Hg or greater. In general, if the $TcPO_2$ is 30 mm Hg or greater, the arterial blood supply should be adequate for wound healing in the nondiabetic patient. If it is less than 30 mm Hg, wound healing is questionable and supports the clinical evaluation leading to further vascular evaluation and treatment. Measuring $TcPO_2$ depends on many variables and, similar to other noninvasive tests, is complementary to clinical judgment, especially when one is trying to heal extensive tissue loss, foot-sparing surgery, or a local amputation.

Experienced vascular consultation and contrast arteriography or magnetic resonance (MR) angiography are indicated when there is a question of ischemia complicating a diabetic wound. Consultation and imaging also are indicated when one has followed an appropriate treatment algorithm for diabetic wound care and healing is still problematic: "Reevaluate for ischemia."

Arteriography and magnetic resonance angiography

Arteriography still is considered the gold standard for defining the anatomic location and extent of atherosclerotic occlusive disease affecting the arteries of the lower leg and foot of diabetic patients. More than 90% of diabetic patients presenting with ischemic foot ulcerations and gangrene have shown surgically correctable occlusive disease with current arteriography techniques, especially digital subtraction arteriography. Remembering that diabetic PVD more typically affects the tibial and peroneal arteries, arteriography remains the most cost-effective modality when one visualizes the arterial tree all the way down and includes the foot vessels. Contrast-induced acute renal insufficiency remains a concern for the diabetic patient, but proper hydration minimizes the chances of this complication occurring. The use of nonionic contrast material has not eliminated the complication, and newer medications, such as fenoldopam, may be beneficial, although further clinical studies are needed. For patients with renal insufficiency, proximal carbon dioxide angiography and pressure measurements may reduce the amount of contrast used.

MR angiography provides an excellent alternative for patients with renal compromise. Because of the peculiar involvement of diabetic PVD, there must be ongoing communication between the vascular surgeon and interventional radiologist to ensure that there is visualization of the arterial tree, including the foot vessels, especially when one is trying to heal extensive tissue loss, reconstructive foot surgery, or local amputation.

Treatment initiatives

Similar to the nondiabetic patient, the treatment of the diabetic patient with PVD depends on its severity as determined by the patient's symptoms and physical examination, including a detailed vascular evaluation. Important in this decision making is the patient's general medical condition and associated risk factors and the patient's interpretation of his or her functional status and well-being. Motivation and compliance are important [4].

Mild-to-moderate claudication is treated best by controlling risk factors and an active and aggressive exercise program. Protective footwear and continual foot inspection are important during and after exercise. Diabetic patients may have significant PVD without showing a problem until some type of traumatic event initiates a blister or ulcer. This event most commonly occurs with improperly fitting shoes. Some type of athletic sneaker must be worn during exercise, and foot inspection and routine care are mandatory. The use of hemorrheologic agents and antiplatelet agents are individualized. Proper glycemic control is key to any success.

The indications for arteriography or MR angiography and vascular reconstruction include disabling claudication, ischemic rest pain and night pain, tissue ulceration, gangrene, or an inability of a surgical procedure to heal because of associated ischemia. If the clinician is managing a diabetic foot wound and the wound is not responding despite providing the appropriate care, the clinician should reassess for diabetic PVD complicating wound healing.

Revascularization techniques

Endovascular procedures

Endovascular procedures include percutaneous transluminal angioplasty (PTA) with and without stent placement, atherectomy, and laser-assisted angioplasty. PTA with and without stent placement remains the most common endovascular revascularization procedure because the results of laser angioplasty and atherectomy have been disappointing. The success of PTA depends on the location of the disease being treated, the length of the disease being treated, whether the disease is localized or diffuse, and the amount of calcium complicating the plaque. PTA results are best with short, isolated stenotic areas of narrowing in high-flow arteries, such as the aorta and iliac arteries. Diminishing success is associated with more extensive or distal occlusive disease, especially if it is diffuse and heavily calcified. Diabetic arterial occlusive disease frequently is complicated by all of these conditions, especially the involvement of the infrainguinal arteries. The author's most frequent use of PTA is to manage short, isolated stenotic segments in the aortoiliac arteries, especially before a distal revascularization. The routine use of stents after balloon angioplasty may improve patency, but further clinical studies are needed before it is recommended for routine treatment of diabetic infrainguinal (outflow) disease. Gene therapy is still investigational and unproven for routine use. If angioplasty with or without stent placement is the only alternative for infrainguinal revascularization, one must accept an earlier failure rate and higher recurrence of disease, especially in the infrapopliteal arteries.

Vascular reconstruction

Surgical revascularization procedures in diabetic patients are tolerated extremely well with excellent outcomes and morbidity and mortality rates equal to those of nondiabetic patients and no greater than those of major amputation. Inflow (aortoiliac/femoral) procedures and outflow (femoral, popliteal, tibial/peroneal, and pedal) procedures can be tailored to an individual diabetic patient's needs depending on the location and extent of disease and what the bypass is being asked to do, associated risk factors, and the patient's overall well-being. Age is no contraindication to revascularization. It is important to assess the patient's functional status, motivation, compliance, and general medical condition, including risk factors and comorbid conditions that might affect patency and overall success.

The preoperative assessment and preparation help determine what particular procedure a patient may tolerate successfully. Patients with extensive tissue infection or destruction with questionable limb salvage, even if circulation was restored, must be evaluated carefully as to whether they may be served better by performing a primary amputation. All active infection must be controlled before any surgical revascularization. Infected wounds must be probed carefully, and all necrotic tissue and pus must be débrided and dependently drained [5]. Appropriate adjunctive intravenous antibiotics are administered throughout the preoperative and perioperative periods. Dressings are appropriate for the wound being treated. Coronary artery disease and left ventricular dysfunction are the leading causes of morbidity and mortality in all major revascularization procedures. Diabetics may have underlying asymptomatic cardiac disease because of sensory and autonomic neuropathy. Preoperative cardiac consultation and possible stress testing are indicated when the patient has an abnormal electrocardiogram, a history of significant coronary artery disease, or left ventricular dysfunction with prior congestive heart failure. Pulmonary function should be evaluated and treated because it may influence the type of revascularization procedure recommended and the anesthesia needed to carry out the bypass. Medications are reviewed and adjusted, especially those affecting the clotting cascade. Blood glucose control is a prerequisite to any elective revascularization procedure. Renal function needs to be assessed, especially if it has been affected by arteriography, and surgery postponed until renal function returns to baseline if possible.

The need for aggressive invasive intraoperative and perioperative monitoring is assessed individually. Careful preoperative preparation and perioperative monitoring have been associated with reducing operative and perioperative mortality to less than 2% and a morbidity of 5% (mainly cardiac in origin).

Nutritional replenishment, control of edema, and intensive blood glucose control are important adjunctive measures during the preoperative and perioperative periods. It is generally best to keep the blood glucose less than 200 mg/dL during the perioperative period. For patients with open dependent ulcers or wounds or patients who have had reconstructive foot surgery or local forefoot amputation, weight bearing is delayed until healing is ensured. Sensory neuropathy puts the diabetic foot at risk. Active and passive physical therapy is important. When weight bearing is allowed, it is progressed slowly to prevent the development of an acute Charcot foot, disruption of a local reconstructive foot procedure, or aggravation of a locally débrided wound or minor amputation.

Inflow procedures

The management of aortoiliac occlusive disease is basically the same for diabetic and nondiabetic patients and most often requires the use of synthetic bypass grafts. Restoring inflow is a priority before contemplating any type of infrainguinal lower extremity bypass. Endovascular inflow procedures play a definite role here.

Infrainguinal (outflow) procedures

The indications for infrainguinal revascularization include disabling claudication, rest pain, tissue loss, gangrene, and failure of healing. Unrecognized or untreated lower extremity PVD increases the risk for major amputation, especially in patients who have a wound.

Infrainguinal revascularization procedures can be tailored depending on the amount, size, and quality of vein available; the patient's indications; associated risk factors; and the actual anatomic setup as determined by arteriography or MR angiography. It is important to note whether the bypass is being performed to improve claudication or it is needed to restore foot perfusion to heal extensive tissue loss or a previously performed foot procedure. The simplest and most effective vascular bypass would be one that bypasses an occluded superficial femoral artery with restoration of flow into the popliteal and tibial and peroneal arteries all the way down and into

Box 1. Management of non–limb-threatening diabetic foot ulcers

Clinical Characteristics
- Superficial
- Minimal or no cellulitis
- No bone or joint involvement
- No significant ischemia
- No systemic toxicity

Patient Characteristics
- Reliable
- Confirms to treatment
- Vigilant support system

Therapy
- Rest of injured part (non–weight bearing)
- Culture and sensitivities
- Empirical broad-spectrum oral antibiotics; specific antibiotic based on culture and response of wounds
- Careful débridement
- Local wound dressings
- Intensive follow-up
- Podiatric appliances and modified footwear

the dorsalis pedis and posterior tibial and plantar arteries. This bypass is not often an option for diabetic patients, especially patients who need to heal extensive tissue loss. Remembering that diabetics have a predilection for tibial and peroneal arterial occlusive disease, restoration of pulsatile blood flow to the foot has been found to be more important to achieve the most rapid and durable healing of extensive tissue loss, gangrene, or incisions from local forefoot procedures. A more proximal infrainguinal bypass usually suffices to improve claudication and rest pain. The decision to place the vein in the reversed, nonreversed, or in situ position depends on the anatomy, size and quality of the vein, and amount of vein that is needed. In general, the larger end of the vein should be placed at the more proximal bigger artery, and the smaller end should be used for the distal anastomosis. The in situ technique (in which the vein is left in its anatomic position) or nonreversed vein technique requires vein valve lysis. A flexible approach (especially when there is limited vein) allows for the use of an inflow source that is most distal, such as the popliteal artery when there is patency all the way to it.

Because infection travels along the course of the lymphatics that lie adjacent to the superficial veins most commonly harvested for bypass grafts, all active infection must be controlled before any distal revascularization.

Box 2. Management of severe limb-threatening diabetic foot ulcers

Clinical Characteristics
- Deep ulcer
- >2 mo cellulitis/lymphangitis
- Bone or joint involvement
- Significant ischemia/gangrene
- Systemic toxicity+

Patient Characteristics
- Unreliable
- Immunocompromised
- Poor support system

Therapy
- Immediate admission and complete bed rest
- Control blood glucose and stabilize medically
- Appropriate culture and sensitivities
- Empirical broad-spectrum intravenous antibiotics; specific antibiotic based on sensitivities and response
- Plain x-ray
- Early surgical débridement, dependent drainage, open ampulation
- Meticulous wound care
- Early evaluation for ischemia
- Selected revascularization and foot-sparing surgery/ conservative amputations/revisions
- Intensive follow-up
- Podiatric appliances and modified footwear

All necrotic tissue must be débrided with the dependent drainage of pus. Diabetics do not tolerate undrained sepsis, and intravenous antibiotics are only adjunctive. When infection is controlled, the team must be prepared to perform immediate arteriography (or MR angiography) and revascularization to minimize any further ischemic necrosis. When foot perfusion is restored, more localized débridement, reconstructive foot surgery, or minor amputation can be performed. Dressings are appropriate for the type of wound the clinician is trying to heal and protect. By directly restoring a pulse to the foot, amputation-sparing surgeries, such as the local excision of ulcerations and infected bony prominences, osteotomies, and arthroplasties, have eliminated the need for even minor amputations in the diabetic foot [6]. This approach best allows the return of function and well-being [7].

Summary

The assessment and management of ischemia for the diabetic patient must be a part of an evidence-based treatment algorithm for wound healing. In 1999, the American Diabetes Association published a consensus position to provide guidance to health care professionals who manage foot wounds in patients with diabetes [8]. The consensus panel recognized six approaches that are supported by clinical trials or well-established principles of wound healing: off-loading, débridement, dressings, antibiotics, vascular reconstruction, and amputation or reconstructive foot surgery when necessary. Adjunctive medical therapies include normalization of blood glucose, treatment of comorbid conditions, control of edema, nutritional repletion, and physical and emotional therapy. Education and prevention of recurrence are essential in any treatment algorithm. Box 1 and Box 2 are algorithms developed by the author and used in clinical management of diabetic lower extremity wounds. The author's multidisciplinary team approach is evidenced based with documented healing and a reduction in amputation at every level. For the patient, it best allows a return to function and well-being. Focusing on quality maximizes the cost/benefit ratio.

References

[1] Pecoraro RE, Reiber GE, Burgess EM. Pathways to diabetic limb amputation: basis for prevention. Diabetes Care 1990;13:513–21.

[2] Mayfield JA, Reiber GE, Sanders LJ, et al. Technical review: preventive foot care in people with diabetes. Diabetes Care 1998;21:2161–77.

[3] Caputo GM, Cavanaugh PR, Ulbrecht JS, et al. Assessment and management of foot disease in patients with diabetes. N Engl J Med 1994;33:854–60.

[4] Gibbons GW. The diabetic foot. In: Becker KL, Kahn RC, editors. Principles and practice of endocrinology and metabolism. 2nd edition. Philadelphia: JB Lippincott; 1995. p. 1313–6.

[5] Grayson ML, Gibbons GW, Balogh K, et al. Probing to bone in infected ulcers: a clinical sign of underlying osteomyelitis in diabetic patients. JAMA 1995;273:721–3.

[6] Gibbons GW, Habershaw GM, Marccacio EJ. Management of the diabetic foot. In: Callow AD, Ernst C, editors. Vascular surgery: theory and practice. Norwich, CT: Appleton & Lange; 1995. p. 167–79.

[7] Gibbons GW, Burgess AM, Guadagnoli E, et al. Return to well-being and function after infrainguinal revascularization. J Vasc Surg 1995;21:35–45.

[8] Cavanaugh PR, Buse JB, Frykberg RG, et al. Consensus development conference on diabetic foot wound care. Diabetes Care 1999;22:1354–60.