

Lower-Extremity Revascularization

The open approach to treating limb-threatening lower-extremity ischemia has proven to be an effective means of achieving revascularization.

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The goal of lower-extremity revascularization is to relieve pain, heal wounds, and prevent amputations by restoration of arterial perfusion. Open surgical procedures have long been the only option available to restore circulation to the lower extremity. However, there has been an explosion in the application of endovascular devices toward this end. There also has been additional interest in lower-extremity revascularization, often by physicians without formal training in arterial disease of the lower extremity, with its myriad diagnostic and therapeutic scenarios. There is much that can be learned by understanding the principles of open vascular surgical techniques. This necessarily brief overview will discuss the indications for vascular reconstruction, diagnosis of peripheral arterial disease, and the open vascular procedures used for revascularization.

INDICATIONS

The classic indications for revascularization are incapacitating claudication, rest pain, and tissue loss including gangrene and nonhealing ulcerations.¹ Claudication is rarely a limb-threatening situation, and a failed intervention can certainly result in possible limb loss. This must be clearly understood by patients and treating physicians. Claudication should be truly incapacitating to serve as an indication for vascular reconstruction, especially if tibial artery intervention is required. The majority of infrapopliteal revascularization procedures should be performed for patients in a limb-threatening situation with symptoms manifest as pain at rest and tissue loss (nonhealing ulcers or gangrene).

Rest pain due to arterial insufficiency is usually located in the toes and forefoot of the affected limb, and it is typically described by the patient as burning pain that is

worse at night in the recumbent position. This pain improves by placing the foot in the dependent position such as dangling the leg at the side of the bed, standing, or ambulating. Continuous pain that is unrelieved by dependency indicates that the ischemia is severe and limb loss is a possibility, warranting the need for intervention.

DIAGNOSIS

Patient history and physical examination remain important tools in management of the vascular patient. The history provides information about the indication for vascular intervention, as well as concurrent risk factors in other arterial beds. The physical examination (pulses, skin enve-

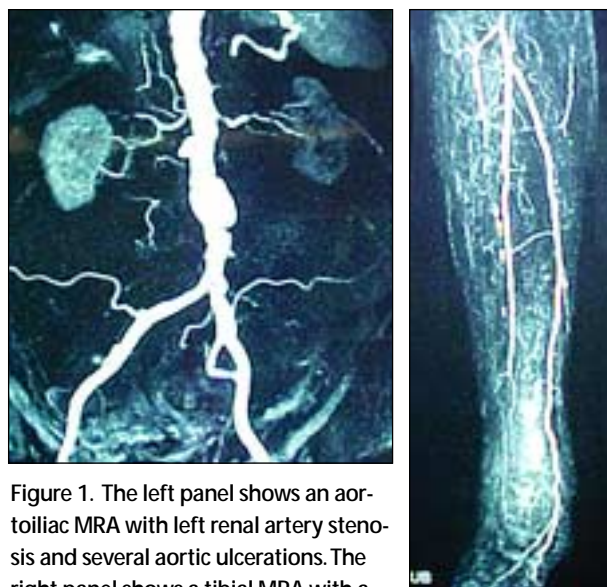


Figure 1. The left panel shows an aortoiliac MRA with left renal artery stenosis and several aortic ulcerations. The right panel shows a tibial MRA with a proximal occlusion of the anterior tibial artery, distal occlusion of the peroneal artery, and an intact posterior tibial artery with runoff into the plantar branches.

lope) provides an assessment of the extent of vascular involvement. The hand-held Doppler is widely used in the evaluation of ischemia. An experienced examiner can differentiate an acoustically normal signal from an abnormal Doppler signal. The presence of a Doppler signal indicates that there is blood flow in the examined artery; however, it does not indicate whether this flow is adequate. The severity of ischemic disease should be documented by noninvasive vascular lab testing prior to any intervention. These studies confirm the degree of ischemia and serve as a baseline for future postprocedural follow-up.

The noninvasive vascular lab uses Doppler ultrasound to measure the ankle/brachial index (ABI), segmental pressures, and waveform analysis, and to generate Duplex images. Other important tests include pulse volume recordings (PVR), transcutaneous oxygen tension ($TcPO_2$), and photoplethysmography (PPG). The ABI is measured as the ankle pressure divided by the brachial pressure with a normal value of 1. In intermittent claudication, an ABI of 0.5 to 0.8 is usually obtained, whereas in severe ischemia the ABI is usually less than 0.5. Noncompressible arteries lead to falsely high ankle pressures in more than 30% of diabetic patients;² therefore, in diabetics with ischemia, other noninvasive studies should be added to determine the adequacy of blood flow.³

Segmental pressure and waveform analysis can help localize vascular occlusive disease. PVRs reflect a change in limb volume in response to arterial pulsation. The PVR wave is recorded, and its contour and amplitude are studied. Foot pain is ischemic if the amplitude of the PVR waveform is less than 15 mm. Ulcerations are unlikely to heal if the PVR amplitude is less than 5 mm. These requirements are the same for diabetic and nondiabetic patients.⁴ The $TcPO_2$ measures the partial pressure of oxygen that diffuses through heated skin.⁵ $TcPO_2$ is accurate in predicting healing. Healing is likely if $TcPO_2$ is above 35 to 40 mm Hg and is unlikely below 20 to 26 mm Hg. A $TcPO_2$ regional index can be used to account for changes in systemic arterial oxygen tension.⁶ To obtain the regional index, the $TcPO_2$ of the leg is divided by the $TcPO_2$ measured at a reference point (chest). Wounds with a $TcPO_2$ index below 0.4 are unlikely to heal, whereas those with $TcPO_2$ above 0.6 are likely to heal.⁷

After it has been determined that revascularization is indicated, an imaging study is needed to plan the appropriate procedure. Arteriography is the most common method of arterial imaging. However, new modalities such as magnetic resonance angiography, CT angiography, and duplex ultrasound are being used with increasing frequency. These new modalities avoid the complications of arterial puncture and possible renal dysfunction associated with arteriography (Figure 1). However, they are still

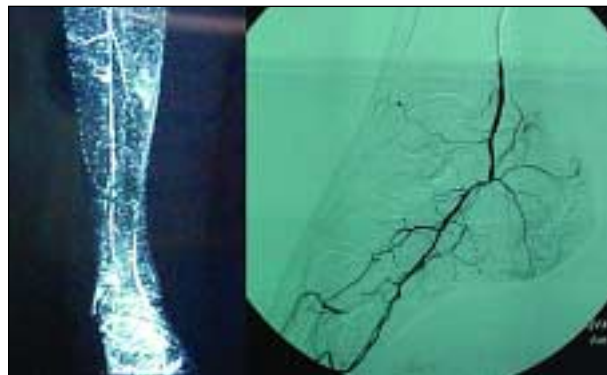


Figure 2. The left panel shows a suboptimal result from a lower-extremity MRA. The right panel is the intraoperative arteriogram demonstrating a posterior tibial artery suitable for bypass.

being refined and require the involvement of physicians dedicated to obtaining precise images (Figure 2). Therefore, arteriography remains the gold standard for lower-extremity arterial imaging.

VASCULAR RECONSTRUCTION

Arterial endarterectomy was the first vascular reconstruction to gain popularity and be performed with any degree of success, but this technique was limited to short, focal disease. Surgical bypass became favored as a means of revascularization for diffuse, severe disease. Bypass techniques have been the workhorse for lower-extremity revascularization for the past 30 years, with continuing refinements along the way. In 1964, Charles Dotter, MD, performed the first dilation of an atherosclerotic stenosis by sequentially passing larger catheters through the lesion.⁸ Andreas Gruentzig, MD, then developed the double-lumen, polyvinyl balloon catheter, thereby greatly increasing the ease and effectiveness of arterial dilation. These advances have led to an explosion of intraluminal devices for the treatment of lower-extremity lesions. Although these devices can be applied percutaneously, they are invasive and should be implemented in appropriate clinical situations by those familiar with the treatment of vascular disease. As a general rule, endovascular methods have success in proximal, short, arterial stenoses. Surgical bypass techniques have proven successful for the treatment of distal, diffuse arterial occlusions.

In planning a surgical bypass, three components must be considered: arterial inflow, target outflow, and the conduit for bypass. Appropriate inflow and outflow sites are determined by preoperative imaging. Inflow lesions may need to be addressed, often with endovascular techniques, prior to performing an infrainguinal bypass. Although the distal anastomosis is preferentially per-

formed to arteries with intact runoff to the foot, bypasses to isolated segments of the tibial and peroneal arteries result in acceptable patency and limb-salvage rates.⁹

Inflow Procedures

Inflow procedures address occlusive disease in the aorta and iliac arteries proximal to the inguinal ligament. Symptomatic aortoiliac disease is usually manifest as claudication in the calf with extension to the thigh and buttock area. Rest pain and tissue loss are unusual with isolated aortoiliac disease because significant collaterals develop maintaining distal perfusion. Limb-threatening ischemia (rest pain and tissue loss) most commonly occur when multilevel disease involves combined aortoiliac and infrainguinal disease. Claudication and rest pain may be relieved by treating the inflow problem; tissue loss, however, requires the addition of a distal revascularization.

The standard bypass for diffuse aortoiliac disease is the aortobifemoral bypass (Figure 3). Unilateral aortofemoral bypasses are performed, but aortoiliac disease severe enough to require surgery is commonly bilateral. The operation involves placement of a synthetic graft from the infrarenal abdominal aorta to each femoral artery. The most commonly used graft materials are Dacron, in a knitted or woven fashion, and polytetrafluoroethylene (PTFE). Results of aortobifemoral bypass are excellent, with close to 100% immediate patency and 5- and 10-year patency >80% and 75%, respectively.¹⁰ Postoperatively, >80% of patients are symptom free after 5 years, and 50%

of patients can return to employment.¹¹ Operative mortality rates are <5%. Recognized complications include colonic ischemia, retrograde ejaculation, graft thrombosis, graft infection and hemorrhage, as well as cardiopulmonary and renal problems.

An iliofemoral bypass is an excellent option for the patient with unilateral inflow disease, especially for those at increased risk for an abdominal aortic procedure (Figure 4). The operation is performed through a flank approach with a retroperitoneal dissection, often under regional anesthesia. The bypass extends from the common iliac artery to the femoral artery using Dacron or PTFE graft material. The graft is tunneled in an anatomic position in the retroperitoneum and brought under the inguinal ligament into the groin for anastomosis to the femoral artery. Results are excellent, with 5-year patency reported between 75% and 90%.¹²

Extra-anatomic bypasses do not follow the normal anatomic course of the arterial tree. These operations are performed when the risk of an anatomical procedure is excessive due to the patient's medical condition or infected tissue planes. The procedures can be performed using regional and/or local anesthesia, minimizing the cardiopulmonary risk of general anesthesia and intubation. Examples of extra-anatomic procedures include femoro-femoral and axillofemoral bypass.

Femorofemoral bypass is appropriate for unilateral aortoiliac disease in a patient considered a poor operative risk for an intra-abdominal procedure (Figure 5). The

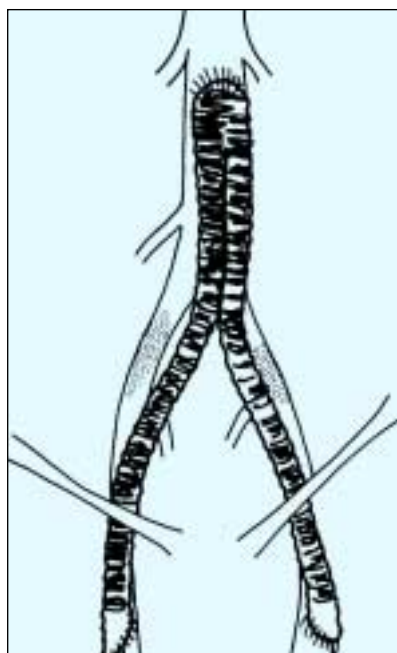


Figure 3. Schematic drawing of an aortobifemoral bypass.

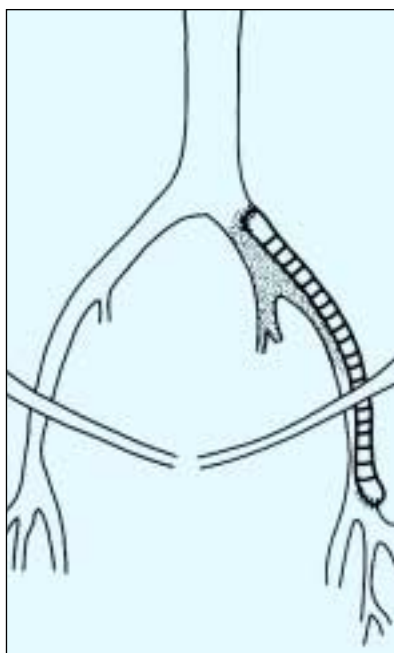


Figure 4. Schematic drawing of an iliofemoral bypass.

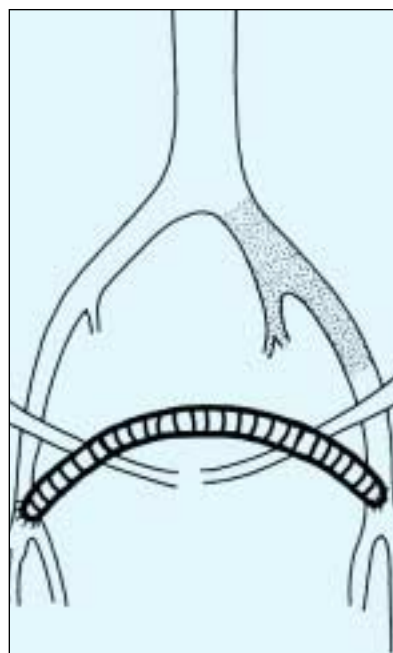


Figure 5. Schematic drawing of a femoro-femoral bypass.

bypass requires a contralateral femoral artery with good flow. Blood is routed from the femoral artery with sufficient flow to the femoral artery on the symptomatic side by means of an 8-mm, externally reinforced PTFE graft. The graft is placed through a subcutaneous tunnel in a suprapubic position on the anterior abdominal wall in a C configuration. Patency rates for crossover femorofemoral bypass are 60% to 80% at 5 years.¹³ Progression of disease in the donor iliac artery can occur; however, it is relatively uncommon. Axillofemoral bypass is performed in patients with aortic or bilateral iliac disease who are at high risk for an intra-abdominal procedure (Figure 6). The proximal anastomosis is performed at the first portion of the axillary artery. Externally reinforced PTFE is tunneled in a subcutaneous position along the anterior axillary line to the ipsilateral femoral artery.

Patency rates in axillofemoral bypasses are 70% at 5 years, but are inferior to those of aortofemoral, iliofemoral, and femorofemoral bypasses.

Outflow Procedures

Infrainguinal bypasses aim to restore circulation to the popliteal, anterior tibial, posterior tibial, peroneal, pedal, or plantar arteries. The majority of these bypasses are performed for limb-threatening situations, such as rest pain and tissue loss. The most commonly used inflow artery for infrainguinal bypasses is the common femoral artery, but reports support the use of the superficial femoral and popliteal arteries for inflow in the absence of proximal occlusive disease.¹⁴ Seemingly, shorter bypasses result in better patency and limb salvage rates. However, the bypass should not originate distal to a hemodynamically significant lesion. If preoperative imaging demonstrates a hemodynamically significant proximal stenosis, it should be treated or the bypass should originate proximal to the lesion.

The most commonly recognized lower-extremity bypass is the femoral-popliteal bypass. In our practice over the past 5 years, however, only 22% (147 of 657) of lower-extremity bypasses were femoral-popliteal. The most common bypass in our vascular surgical practice is a tibial bypass. Patency rates of femoral-popliteal bypass are better to the above-knee popliteal (90% at 6 months, 74% at 2 years, 60% at 4 years) than those performed to

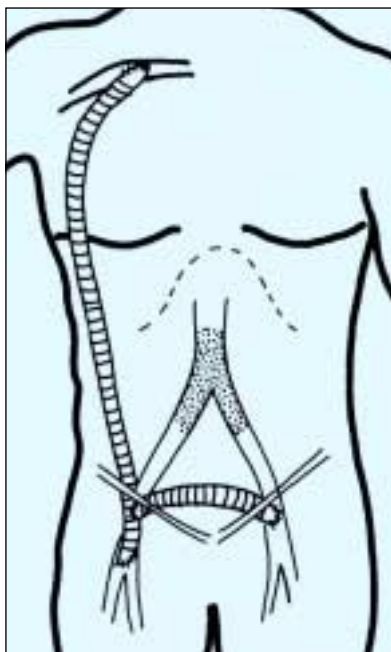


Figure 6. Schematic drawing of an axillofemoral bypass.

the below-knee popliteal segment (80% at 6 months, 65% at 2 years, 40% at 4 years) if prosthetic material is used as the conduit.¹⁵ Autogenous saphenous vein is superior to PTFE in bypasses to the above-knee (90% at 6 months, 85% at 2 years, 70% at 4 years) and below-knee popliteal artery (3 yrs, 76% vein vs 54% PTFE).¹⁶ Empirically, one would expect that better runoff to the foot would result in a more durable bypass. However, acceptable patency rates can be obtained in bypasses performed to an isolated popliteal segment lacking runoff to the foot if autogenous venous material is used for the conduit, indicating that the isolated popliteal artery may have acceptable runoff via collaterals.¹⁷

Bypasses to the tibial and peroneal arteries are primarily used for limb salvage in patients with rest pain or tissue loss. When vein is the

conduit, these bypass procedures are successful and durable, with 5-year patency rates >80%.^{18,19} Although the peroneal artery does not directly continue to the foot and connects via terminal branches, the peroneal artery offers the same limb salvage rates as bypasses performed to the anterior or posterior tibial arteries. The excellent patency and limb salvage rate reflects the value of tibial artery reconstruction. Bypasses can also be performed to the dorsalis pedis and plantar branches of the foot when needed to heal foot lesions and achieve limb salvage (Figure 7). The results obtained with dorsalis pedis bypass in diabetics are very favorable, with a limb salvage rate of 87%, while those reported for plantar bypasses are also excellent.²⁰

Therefore, the conduit of choice for infrainguinal bypasses is definitely autogenous vein. The most commonly used vein is the greater saphenous vein. Other autogenous vein sources include arm vein and lesser saphenous vein. The vein can be reversed so its valves do not interfere with blood flow. In this configuration the vein's distal end is used for the proximal anastomosis and the proximal vein for the distal anastomosis. The vein can be used *in situ* to obtain a better size match between the ends of the vein and the arteries. Disruption of the valves during *in situ* bypass must be done either blindly or under direct vision. After preparation of the vein, the proximal anastomosis is performed between the proximal vein and the inflow artery. The valves are then dis-



Figure 7. Incision on dorsum of the foot for the distal anastomosis of a dorsalis pedis bypass with vein (top panel). Anastomosis between a vein graft and the dorsalis pedis artery (bottom panel).

rupted by introducing a valvulotome (valve cutter) at the distal end of the vein. This can be done by unroofing the vein or by leaving the overlying skin intact, except in areas where branches are to be ligated. A vein bypass can also be performed with the vein in a translocated configuration. The vein is completely harvested from its bed, its branches tied, its valves disrupted, and it is then used in nonreversed prograde fashion. This method also allows a better size match between the vein and the arteries and allows the vein to be moved into the ideal position and location for the bypass. This is currently our most commonly used configuration. At the end of infrainguinal bypass procedures, an intraoperative arteriogram is often obtained. This arteriogram evaluates the distal anastomosis, the distal arterial runoff, and looks for intact venous valves and arteriovenous fistulae (*in situ* bypass) (Figure 8A,B). If any problem is found on the operative arteriogram, it is corrected while in the operating room to obtain optimum results.

Arm veins can also be used for infrainguinal bypasses. The cephalic vein from the wrist to the shoulder can be harvested for bypass. The lesser saphenous vein on the posterior aspect of the lower leg can also be used for infrainguinal bypasses. The patency rates of arm vein (73% at 1 year) and lesser saphenous vein bypasses are reasonable²¹ and better than those of pure prosthetic material (PTFE or Dacron), which have limited patency rates to infrapopliteal arteries.

Prosthetic grafts to the tibial arteries should only be used as a last resort after autogenous vein sources have been exhausted. However, there is a growing group of patients who lack suitable saphenous vein for distal bypass. This group has been estimated at 30% of those needing distal reconstruction, with an increase to near 50% for those undergoing a repeat or secondary procedure.²² PTFE bypasses to tibial arteries have resulted in generally poor results. Clinical series report 1-year patency rates between 20% and 50%, with 3-year patency rates ranging from 12% to 40%.^{18,23} The major cause of graft failure involving PTFE bypasses to infrainguinal arteries appears to be myointimal hyperplasia at the outflow anastomosis. Thrombogenicity may also play a role at the interface between the high resistance outflow artery and larger prosthetic graft.

There have been many attempts to improve upon the results of PTFE bypasses to infrapopliteal arteries through the interposition of venous tissue between the PTFE and recipient artery. We have reported a series of tibial artery bypasses using PTFE and a distal vein patch (DVP) for patients in a limb-threatening situation.²⁴ This procedure interposes a segment of venous tissue between the tibial artery and the prosthetic graft material (Figure 9). The majority of patients (59%) were referred for treatment



Figure 8. Completion arteriogram after an *in situ* vein bypass showing two arteriovenous fistulas (arrows) that require ligation for optimal bypass function (A) and distal anastomosis with the posterior tibial artery (B).



Figure 9. Intraoperative picture of a tibial bypass performed with a PTFE/distal vein patch technique for the distal anastomosis. PTFE (A). Distal vein patch (B). Tibial artery (C).

after one or more previous attempts at bypass had failed. In our series, of 514 tibial bypasses performed, 80 used PTFE with a DVP. Indications for revascularization were rest pain (49%) and tissue loss (51%). Lack of adequate vein resulted from previous failed bypass, previous coronary bypass, unsuitable vein, and absent vein due to ligation and stripping. The DVP technique allowed PTFE bypasses to tibial arteries with acceptable 4-year patency (62%) and limb salvage (79%) in this very complex group of patients.

Profundaplasty is also a possibility for patients with limited bypass options. The profunda femoris gives rise to important branches that supply the thigh and eventually connect with the popliteal artery as an important source of collateral flow to the lower limb. Patch angioplasty of the profunda artery is called a profundaplasty. Profundaplasty can be performed in conjunction with an infrainguinal bypass, or less commonly, performed alone in symptomatic patients in whom infrainguinal bypasses are not feasible due to unsatisfactory vein or the absence of a suitable outflow artery for the distal anastomosis. The best results of profundaplasty are obtained when the profunda stenosis is severe, usually in patients with a patent popliteal artery and adequate distal runoff to the foot. In addition, restoring flow to a profunda femoris can lower the level of amputation and certainly allow a below-knee amputation to heal the vast majority of the time.

CONCLUSION

Patients suffering from lower-extremity ischemia require careful diagnosis and aggressive treatment. Treatment should be individualized based on presentation and arterial anatomy. Physicians involved with lower-extremity revascularization must utilize the most appropriate method available whether by an open or endovascular approach. When properly performed, vascular

reconstruction relieves pain, enhances healing, and prevents major limb amputation, thereby returning patients to active and productive lives. ■

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