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REVIEW

Infrainguinal open reconstruction: a review of surgical considerations and expected outcomes

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Abstract: Infrainguinal arterial occlusive disease can lead to potentially disabling and limb-threatening conditions. Revascularization may be indicated for claudication, rest pain, or tissue loss. Although endovascular interventions are becoming more prevalent, open surgeries such as endarterectomy and bypass are still needed and performed regularly. Open reconstruction has been associated with postoperative morbidity, both at the local and at the systemic levels. Local complications include surgical site infections (SSIs 0–5.3%), graft failure (12–60%), and amputation (5.7–27%), and more systemic issues include cardiac (2.6–18.4%), respiratory (2.5%), renal (4%), neurovascular (1.5%), and thromboembolic (0.2–1%) complications. While such outcomes present an additional challenge to the postoperative management of surgical patients, it may be possible to minimize their occurrence through careful risk stratification and preoperative assessment. Therefore, individualized selection of candidates for open repair requires weighing the need for intervention against the likelihood of adverse outcomes based on preoperative risk factors. This review provides an overview of open reconstruction, focusing on identifying the clinical indications for surgery and perioperative morbidity and mortality.

Keywords: infrainguinal bypass, outcomes, risk factors

Introduction

Peripheral arterial disease (PAD) is one of the leading causes of atherosclerotic morbidity in the US, affecting 8–10 million people.[1] As this number rises due to the persistence of cigarette smoking and the aging population, revascularization continues to play an increasingly important role in PAD management when medical therapy is insufficient or when there is critical limb ischemia (CLI).[2,3] Although endovascular intervention is becoming more common and is in many cases the first-line treatment, there is still a role for open surgical intervention.[4] Anatomic considerations as well as overall patient health and influence of comorbidities provide an integral role in guiding treatment[5,6]

Deciding on the optimal strategy for revascularization for infrainguinal PAD in symptomatic patients begins with a choice between endovascular and open approaches. While endovascular therapy is less invasive and has fewer perioperative risks, it is generally thought to produce diminished patency when compared with open procedures such as endarterectomy and bypass.[4,7–9] Without a definitive indication for one approach over the other, the choice depends on a consideration of patient- and disease-specific factors that stratify risk among operative techniques. In patients with major tissue loss, a good-quality venous conduit, and an anatomic pattern consistent with multilevel disease, defined as Trans-Atlantic Inter-Society Consensus Document on the Management of Peripheral Arterial Disease (TASC) C or D, open intervention

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is often advocated but still remains an issue of contention.[10] Nevertheless, patients chosen to undergo open operations experience perioperative mortality in excess of 2% and complication rates remain >20% in some cohorts.[11,12] This review aims to explore the current practice of infrainguinal reconstruction by providing an overview of open procedures and their associated outcomes.

Clinical indications for open revascularization

The decision to perform open repair of occlusive disease often begins with a consideration of the clinical manifestations of PAD. Symptomatic PAD presents as intermittent claudication, rest pain, or tissue loss. Intermittent claudication classically manifests as reproducible lower extremity aching or fatigue on exertion that is relieved with rest. Vascular origin of these symptoms, as opposed to musculoskeletal or neuropathic etiologies, is confirmed by an ankle brachial index <0.9, although this may be falsely elevated if there are calcified vessels.[13] Several studies have shown that outside of certain populations, claudication is unlikely to progress to more severe disease involving rest pain in the short term.[14–16] Therefore, patient education, exercise therapy, and medical treatment are offered initially, while surgical repair is reserved for individuals who fail conservative and medical therapy or for patients with severe disability.[6]

Surgical management of patients with PAD is the preferred method of treatment upon the development of CLI, which manifests as rest pain and, in more severe cases, tissue loss and gangrene. Although CLI presents in only 1–3% of PAD patients, its causation of restricted lower extremity tissue perfusion has a broad impact on local and global physiologic processes. This necessitates revascularization to avoid unremitting pain, limb amputation, debilitating infection, and death.[17–19] The Bypass versus Angioplasty in Severe Ischemia of the Leg (BASIL) trial has compared the outcomes of the two methods of revascularization.[20–22] Despite similar perioperative mortality and higher perioperative morbidity in the surgery group, data indicate improved outcome in open surgical intervention in patients expected to survive more than 2 years due to higher amputation-free survival and lower all-cause mortality when compared with endovascular methods. The BASIL trial was limited by a lack of advanced endovascular treatment and hemodynamic monitoring. The Best Endovascular versus Best Surgical Therapy in patients with Critical Limb Ischemia (BEST-CLI) trial, which is currently enrolling, seeks to clarify which patients will benefit from open versus endovascular options.[23] Open surgical options include endarterectomy, often the treatment of choice for the common femoral artery (CFA) and bypass.

Common femoral endarterectomy (CFE)

Endarterectomy is the most common modality to revascularize the CFA and the profunda femoris artery in the treatment of PAD. Although CFE was previously the gold standard for artherosclerotic lesions of the CFA, there has recently been a shift toward endovascular therapy for revascularization of the CFA.[4,7] Endovascular therapy has shown decreased patency but similar perioperative morbidity and mortality for common femoral disease.[8,9,24] However, endovascular therapies may compromise blood flow to the profunda femoris, which originates at the femoral bifurcation. Endovascular stents at the CFA are also susceptible to fracture and kinking due to frequent flexion and movement at the inguinal ligament.[25,26] Stenting in the CFA has been associated with high risk of intervention in a recent study, although there remains a lack of consensus with conflicting published data.[24,27,28] The American College of Surgeons' National Surgical Quality Improvement Project database demonstrated that CFE is well tolerated by patients with PAD, showing a 30-day mortality rate of 1.5% and at least one complication in 7.9% of patients. The most common complications were superficial surgical site infection (SSI; 6.3%), urinary tract infection (1.7%), and deep vein thrombosis (DVT; 0.5%).[29] These rates were comparable to those seen in endovascular intervention, revealing similar perioperative outcomes but favorable long-term postoperative outcomes in patients undergoing CFE. When comparing CFE to hybrid procedures involving endovascular repair, no difference in patency was observed between the two groups.[30] At 1 year postoperatively, freedom from intervention in the ipsilateral limb is reported as 82% and survival rate as 89% for CFE.

Bypass and expected outcomes

Surgical bypass uses autologous or prosthetic vein grafts to reroute blood flow to poorly perfused distal sites, circumventing vessel occlusions. The efficacy of reconstruction is heavily influenced by the anatomic location of the occlusion, as different arteries face varying hemodynamic stresses dependent on vessel size. Definitions of patency and stenosis can vary depending on the study and the type of intervention (bypass or endovascular). This makes direct comparison of retrospective studies challenging.

Femoral–popliteal disease

Bypass of the femoral and popliteal arteries has generally proven to be durable and successful in suitable patient populations. Maximal hemodynamic supply and minimal risks for infection are achieved by the use of a greater saphenous vein (GSV) graft, producing 5-year patency at 70%.[31] However, studies have found that ~40% of patients do not have an ipsilateral vein of sufficient length to use for the procedure.[32,33] In the absence of a history for PAD in the other limb, contralateral saphenous vein may be used instead. Arm vein, either single segment or composite, is also an option for conduit if there is not any GSV or if the contralateral leg has PAD and good vein.[34] Prosthetic grafts are used in the absence of suitable autologous vessels, although they exhibit mildly lower long-term durability, especially with distal vessel location.[35,36] Despite high overall patency, femoral–popliteal bypass surgery is associated with a number of complications including lower extremity lymphedema, wound infection, graft occlusion, respiratory failure, acute kidney injury (AKI), stroke, and cardiovascular accident, contributing to a 30-day morbidity rate of 37%.[37,38] Identification and prevention of patient risk factors is essential to minimize such high rates of these perioperative complications.

Tibial disease

With high amputation and 1-year mortality rates, patients with infrapopliteal occlusive disease represent a particularly challenging cohort to manage.[1,39] Much of this stems from the anatomically distal site of occlusion and necessitates a longer venous conduit when compared with femoral–popliteal disease. The use of autologous veins are preferred and have been shown to produce similar long-term outcomes compared to the more proximal surgeries with 5-year patency rates at 47%.[6,40] Meanwhile, the use of spliced or prosthetic grafts has been linked to diminished durability and higher rates of complications, and they may not be ideal for distal reconstruction.[41] Furthermore, tibial disease is often associated with diabetes, which may compromise revascularization efforts and negatively impact graft patency.[42] Careful selection of patients, use of appropriate operative techniques, and vigilant postoperative management are especially important to ensure clinical success in this cohort.[43]

Conduit

The type of conduit used for bypass can heavily influence surgical outcome and should be selected on a patient to patient basis. The GSV is an ideal conduit due to its ease of harvest, vessel length, and inconsequential removal.[38] Primary patency rates at 1, 5, and 10 years are 85%, 72%, and 55%, respectively.[44] In infrainguinal disease, such durability has proven to be higher than with other conduits. Furthermore, GSV grafts have been associated with superior amputation-free survival in comparison to prosthetic grafts.[9,20]

In the absence of suitable GSV, other autologous veins such as superficial arm veins may be considered. Although the cephalic and basilic veins may be used as a single segment, they are often combined into a composite conduit to provide sufficient length in the setting of infrainguinal surgery. Single-segment cephalic vein has been shown to have the best durability of the three options.[45] One long-term study revealed 5-year patency and limb salvage rates of 55% and 72%, respectively.[34] These rates are still above those for comparable prosthetic conduits.[46]

Prosthetic grafts are used when autologous conduits are not available or suitable. Of these, expanded polytetrafluoroethylene (ePTFE), polyethylene terephthalate (Dacron), and heparin-bonded ePTFE grafts are most common. Generally, their use in infrainguinal bypass has been shown to have inferior results compared to autologous GSV. Four-year patency rates for infrainguinal bypass with ePTFE and GSV are 54% and 76%, respectively.[47] Prosthetic grafts to tibial vessels have particularly poor outcomes, with 36-month primary patency rates at 20% and limb salvage rates of 55%.[41] Meanwhile, heparin-bonded grafts have demonstrated improved long-term outcomes and show promise as a prosthetic option.[48,49]

Surgical site complications

While patency is the primary measure of long-term success for bypass revascularization, it can be affected by a number of perioperative complications at the site of surgical repair that compromise technical success and quality of life (Table 1). Although there are a number of local complications, SSI, graft occlusion, and limb loss will be reviewed here. Each complication discussed is associated with risk factors that should be considered prior to surgery to avoid poor outcomes (Table 2).

SSIs occur frequently in infrainguinal bypass in the 30-day perioperative window, presenting in as many as 11% of cases regardless of bypass origin.[50] The common pathogens involved include *Staphylococcus epidermidis* (37%), methicillin-sensitive *Staphylococcus aureus* (26%), and *Enterococcus* (10%).[51] SSI often presents as graft infection. Reported rates of graft infection after bypass involving the femoral artery are 3.8%. Independent risk factors, such as female sex, diabetes mellitus, active infection at the time of bypass, and redo bypass, are shown to be associated with graft infection. In patients with prosthetic grafts, the rates of graft infection

Table 1 Postoperative complications

Complications	
Surgical site	
Infection*	0–5.3%[37]
Graft failure**	12–60%[80]
Amputation**	5.7–27%[81]
Systemic	
Cardiovascular*	2.6–18.4%[66]
Respiratory failure*	2.5%[69]
Renal failure*	4%[71]
Cerebrovascular*	1.5%[11]
Venous thromboembolism*	0.2–1%[76]
Death*	0–6.3%[82]

Notes: *30-Day postoperative range. **1-Year postoperative range.

associated with the above risk factors are 6.8%, 6.5%, 11.7%, and 11.5%, respectively. As prosthetic grafts are susceptible to infection, autologous conduits for infrainguinal bypass or endovascular revascularization are recommended in high-risk patients.[51] Although graft infections may not increase postoperative mortality, they often contribute to lower limb amputation and may require removal or attempts at rescue with vacuum-assisted devices and rotational muscle flaps.[52–55]

Bypass vessels are often monitored for occlusion at regular intervals postoperatively.[56] Over time, venous conduits are prone to undergo neointimal hyperplasia and ultimately vessel restenosis caused by hemodynamic stresses of the physiological environment.[57] This is particularly true for prosthetic grafts, as discussed previously. Other factors predisposing to neointimal thickening include patient hypertension, diabetes, and hyperlipidemia[58] Meanwhile, infrainguinal bypass patients are susceptible to developing graft occlusions due to enhanced local hypercoagulability in the perioperative setting, with rates reaching up to 4.5%.[59] Various patient- and surgery-specific predictors for perioperative graft hypercoagulability include age, preoperative ambulatory status, advanced PAD, long duration of surgery, and intraoperative local trauma. Technical errors such as small vein diameter, inappropriate conduit selection, and graft length >50 cm are also associated with early graft failure.[33]

Impending graft failure can be identified using clinical symptoms, segmental blood pressures, and particularly duplex ultrasound.[60] When performed early postoperatively and assessed alongside aforementioned risk factors for graft occlusion, duplex ultrasound may be useful in identifying grafts at high risk of failure.[61] Occlusion may necessitate graft revision, which can be accomplished through either endovascular methods or a second open intervention. Open reintervention has been shown to be more durable than endovascular repair in thrombosed grafts undergoing salvage, with 12-month amputation rates of 75% and 56%, respectively (p=0.006).[62] Furthermore, endovascular-revised grafts require higher rates of reintervention to maintain patency, although they are less invasive.[8]

After lower extremity bypass, due to graft failure, persistent infection, or necrosis, amputation may still be necessary. Overall, 1-year postoperative freedom from major amputation and amputation-free survival has been reported as 87% and 76%, respectively.[63] Despite patent bypass grafts, some patients do not achieve limb salvage, and studies have demonstrated similar 1-year amputation rates in patients with patent (6.3%) and occluded (5.7%) grafts.[64] Thus, identification of patient comorbidities contributing to amputation in patent grafts in addition to prevention of graft failure is essential in limiting limb loss. Patients with diabetes, end-stage renal disease, previous amputations, peripheral neuropathy, preoperative gangrene, postoperative SSI, and abnormal wound healing are at an elevated risk for amputation.[64,65] For this

Table 2 Preoperative risk factors for poor outcomes

Surgical site complications	**Adverse systemic events**
Graft infection	**Cardiovascular**
Female sex, diabetes mellitus, active infection at time of bypass, and redo bypass.[51]	Dependent functional status, smoking history, diabetes, heart failure, prior percutaneous coronary intervention or cardiac surgery, angina ≤1 month before surgery or myocardial infarction ≤6 months, and emergent case status.[12]
Graft failure	**Respiratory**
Acute: age, preoperative ambulatory status, advanced PAD, long duration of surgery, and intraoperative local trauma.[59]	Smoking status, recent MI, CHF, COPD requiring oxygen, and low body weight.[69,70]
Chronic: prosthetic graft, hypertension, diabetes, and hyperlipidemia.[58]	**Renal failure**
	Male sex, CHF, diabetes, and angiotensin-converting enzyme inhibitor or angiotensin receptor blocker use.[71]
	Cerebrovascular accident
	Preoperative ventilation, previous CVA, postoperative MI, and return to operating room.[73]
	Venous thromboembolism
	Dependent functional status, metastatic cancer, surgical site infection, postoperative CVA, preoperative ventilation, and return to operating room.[76]

Abbreviations: PAD, peripheral arterial disease; MI, myocardial infarction; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident.

cohort, management of the underlying conditions is vital to improved outcomes postoperatively.

Adverse systemic events

Infrainguinal bypass is also associated with certain adverse systemic events including, but not limited to, cardiovascular injury, respiratory failure, and death (Table 1). As for local outcomes, a number of patient characteristics and comorbidities have been shown to predict increased global morbidity and mortality (Table 2).

Of all global morbidity associated with infrainguinal bypass, cardiac complications are the most common, occurring in 6.3% of patients.[66] Much of this is tied to the similarity in the pathophysiology of PAD and cardiac events, where patients undergoing lower extremity bypass are prone to the same risk factors for cardiac injury. Such factors include dependent functional status, smoking history, diabetes, heart failure, prior percutaneous coronary intervention or cardiac surgery, angina ≤1 month before surgery or myocardial infarction (MI) ≤6 months, and emergent case status.[12] The predisposition for cardiac injury often manifests during the physiologic stress caused by surgery, resulting in cardiovascular accident such as MI, arrhythmia, and congestive heart failure (CHF). Prognostication tools such as the Revised Cardiac Risk Index can be used to assess probability for perioperative cardiac events and determine a patient's indication for surgery.[67] This type of risk stratification allows for better informed consent, closer postoperative monitoring, and better assessment of outcome retrospectively. Antiplatelet and antilipid therapies have not been shown to decrease the risk for perioperative cardiovascular accident.[68]

Postoperative respiratory events, defined as pneumonia and reintubation after initial extubation, are also prevalent in the perioperative window following infrainguinal bypass. Respiratory events are present in 2.5% of patients and are more likely to occur in patients who smoke, had a recent MI, have symptomatic CHF, and have chronic obstructive pulmonary disease (COPD) requiring oxygen.[69] Furthermore, respiratory adverse events are also tied to low body weight, indicating inadequate nutrition.[69,70] Thus, patient diet may signify a possible point of intervention in prevention of postoperative respiratory events. If left uncompensated, respiratory events often progress to death and are a major cause of postoperative mortality.

Infrainguinal bypass patients not on dialysis preoperatively have been shown to be at risk of developing AKI. AKI has been reported at rates of 4% perioperatively and is especially prevalent in patients predisposed to perioperative prescription of nephrotoxic medications such as antibiotics, systemic hypotension, and renal vessel hypoperfusion as a result of atherosclerosis.[71] Thus, management of patient volume status and renal perfusion is vital in preventing AKI and subsequent renal failure. Furthermore, development of AKI is associated with various preoperative demographics and comorbidities including male sex, CHF, diabetes, and angiotensin-converting enzyme inhibitor or angiotensin receptor blocker use.[71] Patients with postoperative AKI have a 90% increased risk of developing chronic renal insufficiency requiring life-long dialysis dependence and are also more likely to experience cardiovascular accident and mortality.[71,72]

Cerebrovascular accident (CVA) including stroke and transient ischemic attack may occur perioperatively in 1.5% of patients.[11] As for cardiac complications, many of the risk factors for CVA are the same as those that contribute to the development of infrainguinal occlusive disease. Independent predictors for CVA include preoperative ventilation, previous CVA, postoperative MI, and reoperation.[73] CVA following infrainguinal bypass is generally embolic in etiology, and cardioprotective medications such as antiplatelet therapy and statins have been shown to reduce occurrence of CVA in this cohort.[74,75] Appropriate medical prevention is critical because CVA results in markedly increased disability and mortality in bypass patients.[73]

Venous thromboembolism (VTE) occurs in 1% of infrainguinal bypass patients within the first 30 days postoperatively, with DVT shown to present at higher rates than pulmonary embolism (PE).[76] Postoperative venous duplex scanning is only recommended in symptomatic patients.[77] However, perioperative anticoagulation prophylaxis is normally offered in bypass patients and especially for those with increased predisposition for postoperative VTE. Risk factors include dependent functional status, metastatic cancer, SSI, postoperative CVA, preoperative ventilation, and return to operating room.[76]

The total rate of 30-day perioperative mortality following infrainguinal bypass is 2.9%, and the majority of deaths result from major organ system failure caused by sepsis (33%), cardiac complications (44%), and pulmonary complications (38%).[12] Furthermore, perioperative mortality is exceedingly high in patients who experience postoperative cardiac arrest requiring cardiopulmonary resuscitation (CPR), with rates at 73%.[78] These relatively high mortality rates in the perioperative setting, combined with the frequency of the aforementioned comorbidities, has increased the favorability of less invasive endovascular procedures over bypass in high-risk patients. Decreased perioperative mortality, adjusted for comorbidities, of endovascular procedures compared to bypass supports this movement.[79] However, there are still concerns about durability.

Conclusion

Open reconstruction remains an important tool in the treatment of infrainguinal occlusive disease. However, open repair can be associated with local and systemic complications, and the identification of patient- and disease-specific risk factors is critical in selecting appropriate methods of surgical management. High-risk patients may warrant an increased level of postoperative monitoring in the intensive care unit (ICU) as preoperative coronary and carotid interventions have not been shown to be of benefit. The use of less invasive percutaneous methods is an important consideration in high-risk patients if adequate results can be obtained.

Disclosure

The authors report no conflicts of interest in this work.

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