Use of Vascular Conduits in Peripheral Vascular Disease Surgery: A Review

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ABSTRACT

When performing peripheral vascular disease (PVD) bypass surgery, vascular surgeons use a variety of conduit types to save limbs that might otherwise require amputation. Long-term limb salvage rates, improvement of walking distance, and thus the improvement of the patient's quality of life depend substantially on how long the implanted conduit remains free of occlusion. Autologous veins taken from the patient's body are considered the conduit of choice for PVD bypass surgery, but the need for alternative options has led to the development of biological and synthetic substitute grafts. Although results with existing conduits are currently less than satisfactory, recent developments in tissue engineering provide hope for an improved selection of alternative vascular grafts in the near future.

The purpose of this article is to provide an overview of the conduit options available for peripheral vascular disease bypass surgery and to summarize their application as well as their advantages and disadvantages in the clinical setting.

INTRODUCTION

It is estimated that peripheral vascular disease affects as many as 12 million people in the United States, most of them over the age of 50 years. Peripheral vascular disease (PVD), also known as peripheral artery disease (PAD), refers to the narrowing of the blood vessels outside of the heart and brain. PVD can affect the blood vessels of the legs, arms, lower abdomen, and neck.

Atherosclerosis is the most common cause of PVD, which progressively leads to occlusion (blockage) of the arteries that carry blood to the legs, feet, or arms. In most cases, PVD is an indicator of systemic atherosclerosis, which means that these patients are generally also at high risk for myocardial infarction (heart attack), stroke, and cardiovascular death.

The most common symptom of PVD of the lower extremities is claudication or pain while walking that may even occur during rest in late stages of the disease. Other symptoms can include cold legs or feet, changes in the skin color, numbness, cramping or weakness of the legs, and non-healing ulcers of the legs or feet. If left untreated, insufficient blood flow to the extremities may cause gangrene (tissue death), which requires amputation.

Fortunately, less than 10% of PVD patients need amputation. In more than 70% of patients, medication and lifestyle modifications, such as controlling weight, blood pressure, diabetes, and cholesterol levels as well as exercise programs and smoking cessation lead to stabilization or even improvement of the symptoms within five to ten years. However, the remaining 20 to 30% of PVD patients develop increasingly severe symptoms and require intervention either through percutaneous transluminal angioplasty (PTA) or bypass surgery.

A review of the various conduits options available for bypass surgery for PVD of the lower extremities and discussion of the results achieved with cryopreserved saphenous vein allografts in this surgical procedure are provided in this article.

LOWER EXTREMITY PVD BYPASS SURGERY -- AVAILABLE GRAFT OPTIONS

Narrowing or occlusion of the arteries in the lower extremities most commonly occurs in the femoral artery (infrainguinal disease) or in the popliteal artery (infra popliteal disease). In either case, claudication pain is usually localized to the calf of the leg. The second most frequent sites at which PVD can occur are the distal aorta and the two iliac arteries. PVD in these arteries can lead to pain in the buttocks or thighs as well as the lower legs.

When treating PVD, conservative options such as lifestyle modifications and medication are usually attempted first. Only when more severe symptoms develop are angioplasty and bypass surgery taken into consideration as possible treatment options.

Angioplasty, the dilation of a narrowed artery using a small balloon, has several advantages including faster patient recovery and the fact that it is a less costly intervention. On the other hand, arteries that have been opened using angioplasty tend to have lower long-term patency (freedom from blockage). In a five-year study examining the long-term patency of percutaneous transluminal angioplasty (PTA) performed on the femoral artery to treat claudication, a patency rate of 60% was reported. When used for limb salvage, the five-year patency rate was only 7%. Clinical outcomes demonstrate better success using PTA on the iliac arteries than on the femoral or popliteal arteries. Likewise, the best outcomes are achieved with PTA if the arterial disease is limited to a single vessel segment less than 10 cm in length.

THE USE OF VASCULAR CONDUITS IN PERIPHERAL VASCULAR DISEASE SURGERY

PVD surgical bypass is indicated only in patients with severe arterial occlusion who are at risk of losing a limb or have non-healing ulcers or gangrene. The success of the surgical bypass procedure is determined by:

- Patency: how long the vascular graft used for bypass remains free of occlusion
- Limb salvage: how long the limb can be retained before amputation and a prosthesis is needed
- Patient survival

Since the arteries below the knee have a small diameter (less than 6 mm) and are prone to spasm or thrombosis (blood clot formation), the use of angioplasty on the infrapopliteal arteries is generally described as high risk and prone to failure in the medical literature. Below the knee, especially in the case of limb salvage, revascularization with vascular grafts is preferred. Vascular grafts commonly used for PVD bypass surgery can be placed in one of three groups:

- Autografts
- Allografts (also known as homografts)
- Other conduits, which include such options as synthetic grafts, xenografts, and human umbilical vein

![Figure 1. Vascular system of the lower extremities](image-url)
The autogenous greater saphenous vein (GSV) is the graft of choice for revascularization of lower extremity PVD. The GSV, which runs the length of the leg, is either completely dissected and reattached in reversed orientation to the occluded artery or left in situ, whereby the vein is left in place and both ends are detached and reattached to create a bypass at the arterial occlusion site. If the GSV is left in situ, the valves in the vein must be obliterated using a valvulotome, so that blood flow in the opposite direction is not hindered. Both in situ and reversed saphenous vein graft orientations are equally successful with four-year post-operative patency of 70% or better and limb salvage rates approaching 80%.7,8

Other autologous grafts that are used for PVD bypass surgery include the lesser saphenous vein (from the posterior calf of the leg) and the arm vein. These grafts are generally considered the best alternatives for bypass surgery below the knee when the GSV is not available. Using these grafts for infrapopliteal arterial bypass surgery, Caggiato and colleagues9 could demonstrate an average limb salvage rate of 76% after two years. In another study, the autogenous arm vein was used to bypass occlusions that had occurred in various locations in the lower extremities of 72 patients. Overall five-year patency and limb salvage rates were 54% and 76%, respectively.10

ALLOGRAFTS

The use of the GSV allograft has been extensively studied and much has been published on its use in the medical literature. Saphenous vein allografts present an attractive alternative when satisfactory autogenous veins cannot be obtained, for example, if the autogenous saphenous veins had previously been used for coronary artery bypass surgery or if the patient is suffering from varicose veins. Cryopreservation is the most common method of preservation for this type of vascular graft. The techniques of vein handling, preservation, and thawing are critical for satisfactory performance after implantation.11,12,13 It is common clinical practice to match saphenous vein allografts to the recipient by ABC/HR blood type; however, the importance of blood type matching and the mechanisms involved in maintaining allograft patency have not yet been fully established.14,15,16,17,18

The primary patency rate of cryopreserved saphenous vein allografts, which is the uninterrupted patency of a graft without any interventions such as angioplasty, is reported to be rather poor in most studies as shown in Table 1. Likewise, secondary patency, which is the patency of a graft after repair through intervention, is not significantly higher. Despite these discouraging patency results, acceptable limb salvage is observed after implantation of cryopreserved saphenous vein allografts. The hypothesis that allografts, during the period that they are patent, provide sufficient blood flow to the lower extremities to promote ulcer healing and tissue death is generally accepted.14,16,19

A number of variables have been evaluated for their effect on the patency of saphenous vein allografts in PVD bypass surgery including age, gender, renal dysfunction, hypertension, smoking, and indication for surgery. None of these factors were found to correlate with poor patency, although diabetes and composite grafts (grafts spliced together of several shorter lengths of vein) were found to negatively affect graft patency in individual studies.16,17 In most studies, anticoagulants such as aspirin or warfarin could not be shown to improve graft patency.14,15,16,17

In addition to their use in the treatment of peripheral vascular disease, saphenous vein allografts play an accepted role in coronary artery bypass graft (CABG) surgery. In coronary artery bypass surgery one or more of the blocked arteries responsible for supplying oxygen-rich blood to the heart are bypassed to restore normal blood flow. CABG surgery is performed to relieve the symptoms of coronary artery disease such as chest pain (angina) and to lower the risk of heart attack or other cardiac problems. As with PVD procedures, saphenous vein allografts are an acceptable choice when no suitable autologous tissue is available or its use is not feasible.20,24

OTHER CONDUITS

A variety of prosthetic grafts are available for clinical use in the United States today. Synthetic conduits, manufactured of polytetrafluoroethylene (PTFE, also known as Gore-Tex®) and Dacron®, are routinely used for bypass surgery above the knee with satisfactory results.25 These grafts are not suitable for the reconstruction of small diameter arteries below the knee, however, since they carry a substantial risk for thrombosis.26,27 In a study using PTFE conduits, reconstructions above the knee showed five-year patency rates of 63%, whereas the patency rate after five years for below-knee reconstructions was only 44%.28 As stated by Budd et al29, “vein should always be used, if available, below the knee joint”. Glutaraldehyde-preserved human umbilical veins have also been used for PVD bypass surgery, but routinely demonstrate poor long-term patency and limb salvage rates. In a study involving 78 infrainguinal reconstructions using human umbilical vein, the five-year patency rate was 29% and the limb salvage rate was 58%.30 Increased bypass graft thromboses resulting in major amputations within 30 days and late aneurismal degeneration have been observed in patients who have received a human umbilical vein graft.27,31 For these reasons, human umbilical vein has fallen out of favor with the surgical community in recent years.

SELECTION CRITERIA

A biological or synthetic substitute conduit that is readily available, easily stored, and easy to construct as necessary would undoubtedly be the ideal situation for peripheral vascular disease bypass surgery. However, the alternatives to autograft tissue that are available at present have proven less than optimal.14,15,21,29

Although autogenous conduits remain the implant of choice, situations do arise that require the use of alternative grafts when all options using autografts have been exhausted. While the generally accepted opinion is that non-autografts should only be used when a limited number or no autografts are available, saphenous vein allografts are the preferred alternative option based on their demonstrated safety and efficacy.17,19 Good limb salvage rates, dramatically lower infection rates than synthetic conduits, and repopulation of the vessel with the patient’s own cells to form a new endothelium lining are observed with saphenous vein allografts.14,31 The surgeon must be aware, however, that the quality of the saphenous vein prior to implantation as well as the storage and thawing procedures affect the patency of the vein graft.23

LifeNet, the largest full-service non-profit Organ Procurement Organization (OPO) and Tissue Bank and a leader in the cryopreservation of human allograft tissue, has been providing cryopreserved heart valves to the surgical community since 1986. Cryopreserved saphenous veins were added to LifeNet’s product line in 1987. Cryopreservation requires the use of special equipment such as special liquid nitrogen chambers and heat sinks to ensure grafts are frozen at a slow, constant rate. LifeNet’s cryopreservation process encompasses freezing vascular grafts at a controlled rate with a cell protective chemical. This protective maintains the matrix structure of the graft, allowing donor cells to repopulate the graft upon implantation.31,32
THE FUTURE OF ALLOGRAFT CONDUITS — TISSUE ENGINEERING

Human tissue engineering combines various aspects of medicine, molecular biology, and material science for the purpose of regenerating, replacing, or repairing diseased tissue. At this time, methods are being explored to grow living tissue replacements for vascular applications using a patient’s own cells that would solve the existing problems of thrombosis and poor patency with vascular prostheses.

Recent advances in tissue engineering of vascular grafts indicate that the construction of a conduit that will remain patent in vivo for substantial periods of time is achievable. Two approaches are being intensely investigated: a graft based on a polymer or collagen-based scaffold that is populated with cultured vascular cells in a bioreactor and a completely acellular tissue matrix that retains its natural mechanical properties and promotes recellularization by the host.

LifeNet recognizes that this latter approach of tissue engineering of vascular grafts has pronounced potential for use in a clinical setting. As part of a major research effort, LifeNet has developed a patented devitalization process that allows the preparation of an acellular matrix that retains the physiological arrangement of its structural proteins. This process has been applied to non-valved pulmonary artery conduit allografts, which will be entering clinical studies in the near future, and will subsequently be utilized for the decellularization of saphenous veins. The acellular matrix—once recellularized—has the potential to become autograft tissue with performance and characteristics similar to those of autologous tissue.

CONCLUSION

Peripheral vascular disease is a widespread condition that is associated with the risk of loss of limb or even loss of life.1 PVD is a marker for systemic atherosclerotic disease, and patients with PVD have a 4 to 5 times higher risk of dying from a cardiovascular incident.2 Since autologous saphenous veins are the conduit of choice for coronary artery bypass graft surgery, non-autologous conduits may be required to bypass arterial occlusions in the lower extremities of patients suffering from PVD. When compared to other available options, cryopreserved human saphenous vein allografts have demonstrated the highest safety and efficacy and should therefore be the graft that is used in such situations. When evaluating alternatives to autografts based on published data currently available, consideration should be given to the following facts that might bias the data against allograft tissue:

- Alternative grafts are generally used only when autologous vessels are unavailable or unsuitable
- Alternative grafts are consistently used in the least favorable sites and under least favorable circumstances
- Most vascular surgeons may be more familiar with procedures using the patient’s own venous vessels or synthetic conduits than with allograft implantation.

In addition, it is important for the implanting physician to have confidence in the integrity of the tissue bank that provides the allograft as well in the safety and efficacy of the implanted tissue to assure the best possible outcome for the patient. LifeNet holds the longest running current American Association of Tissue Banks (AATB) accreditation and is registered to the International Standards Organization (ISO) quality standards. All tissue is recovered using aseptic recovery techniques to assure the quality and safety of the tissue, and LifeNet subjects each donor to infectious disease testing that meets or exceeds those required by the AATB and FDA (Food and Drug Administration). Since beginning distribution of cryopreserved cardiovascular tissue in 1986, LifeNet tissue has demonstrated a consistent safe track record.

While it is to be anticipated that use of autologous vascular tissue will remain the preferred option for peripheral vascular disease bypass surgery, demand for “off-the-shelf” alternative conduits is likely to grow based on rising awareness of PVD and its increasing prevalence in our aging population. LifeNet is dedicated to addressing this need with the development and impending introduction of an acellular human saphenous vein allograft.

REFERENCES


