Arterial bypass – a surgical method in treatment of peripheral arterial obstructive disease of the lower limbs
Sorin Băilă, Andrei Parnia, Codin Panaite, Mihaela Sălăgean

Abstract: In peripheral arterial obstructive disease, in advanced clinical stages, meaning patients with rest pain, trophic arterial lesions and in some cases of intermittent claudication (invalidating claudication), interventional treatment - surgical and endovascular - plays an important role. As a part of surgical treatment, arterial bypass is a valuable procedure, with good results, immediate and at distance in selected patients. It also may be used in combination with endovascular techniques in modern hybrid procedures. It has numerous indications and a large variety of technical methods is available in performing arterial bypass. Our article is reviewing main types of arterial bypass which are discussed regarding the material of bypass grafts (biologic and synthetic) on each arterial segment: aortoiliac, infrainguinal (above knee and below knee), their indications and complications.

Keywords: arterial bypass, peripheral arterial obstructive disease, hybrid procedures

INTRODUCTION

Chronic atherosclerotic arterial disease of the lower limb have a progressive evolution up to final clinical stages when rest pain and trophic lesions are dominant. These are stages 3 and 4 in Leriche-Fontaine classification, also known as critical ischemia, when the affected limb is threatened (Table 1). The treatment of election in these stages of disease is the interventional treatment (endovascular, surgical and/or hybrid procedures). In our department's experience on this type of pathology, bypass is the dominant procedure of arterial lower limb revascularization.

In terms of anatomoclinical classification the peripheral obstructive arterial disease of the lower limb takes two forms: aortoiliac arterial obstructive disease (affecting abdominal aorta and iliac arteries), and infrainguinal obstructive disease (affecting arteries below the inguinal ligament). Aortoiliac obstructive disease is also divided in three forms of disease (Figure 1).

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Table 1. Leriche - Fontaine classification; Rutherford classification (2)

<table>
<thead>
<tr>
<th>Leriche/Fontaine clinical classification</th>
<th>Rutherford clinical classification</th>
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<tbody>
<tr>
<td>Stage</td>
<td>Clinical aspects</td>
</tr>
<tr>
<td>I</td>
<td>Asymptomatic</td>
</tr>
<tr>
<td>IIa</td>
<td>Mild claudication</td>
</tr>
<tr>
<td>IIb</td>
<td>Moderate-severe claudication</td>
</tr>
<tr>
<td>III</td>
<td>Rest pain</td>
</tr>
<tr>
<td>IV</td>
<td>Arterial ulcer or gangrene</td>
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Critical Ischemia

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Figure 1. Aortoiliac obstructive disease classification, from (1).

Figure 2. The Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II) classification of aortoiliac lesions (1).

*Abbreviations: CIA = common iliac artery; EIA = external iliac artery; CFA = common femoral artery; AAA = abdominal aortic aneurysm
Along with the arterial bypass we also perform (thromb)embolectomies, (thromb) endarterectomies, angioplasties, depending on arterial lesions found and eventual thromboembolic complications (Figures 5-8, 14).

**Arterial bypass**

A. **Definition:**

Bypass is a shunt that goes round on an occluded artery, performed in a terminolateral (end-to-side) manner proximally and distally (in order to preserve collateral circulation), which provides blood flow to the vascular bed distally of occlusion. In the case of anatomic bypasses the shunt is parallel with the occluded vessel. Arterial bypass assumes the existence of terms such as “inflow (run in)”, the vascular conduct and “outflow (run off)”. Inflow is represented by the donor artery, by the debit and the hemodinamic quality of the blood flow which alimentates the bypass. The conduct is the connection element between the inflow and outflow. It can be manufactured of different materials, biologic or synthetic, and it can or cannot follow the traject of occluded artery (anatomic or extraanatomic bypass). Outflow is represented by the distal vascular bed alimented by the bypass2 (Figure 4).

B. **History:**

In 1896, Jaboulay made first experimental succesful repair of a carotid lesion by eversed suture. Between 1904 - 1906 Carrel si Guthrie, in Chicago, develop numerous progress in suture and vascular anastomosis technique vasculare, during the first attempts of organ transplan-
Indication for surgical revascularization is to be made in final clinical stages of peripheral arterial obstructive disease, in vascular trauma and in peripheral aneurismatic disease. This includes patients with rest pain, those with trophic

tation: triangulation technique in vascular anastomoses; first interpositions of inverted venous segments in arterial circulation with demonstration that they do not degenerate in high pressure conditions; the Carrel patch.

In 1913, Jeger proposes the principle of arterial bypass as treatment of peripheral aneurismal disease

In 1948, Kunlin performs first arterial bypass for atherosclerotic obstructive disease.


C. Indications:
Indication for surgical revascularization is to be made in final clinical stages of peripheral arterial obstructive disease, in vascular trauma and in peripheral aneurismatic disease. End stages of obstructive arterial disease correspond to the clinical term of critical ischemia. This includes patients with rest pain, those with trophic
lesions (arterial ulcers, necrosis, gangrene), but it also includes patients with incapacitating claudication (intermittent claudication at distances of less than 50 meters). Morphopathologically, surgical treatment indication is made following the classification of the The Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II). Type C and D lesions of this classification in both aortoiliac and infrainguinal localisation, have surgical revascularisation indication. In contrast, type A and B lesions have endovascular treatment indication (Figures 2, 3).

Contraindications of surgical revascularisation are represented by general surgical contraindications, as well as very short life expectancy.

D. Arterial bypass classification:
1. Anatomical criteria:
   i. Anatomic bypasses: the bypass conduct follows a traject parallel with the occluded vessel. In aortoiliac obstructive disease there can be made aortobifemoral, iliofemoral anatomical bypasses. In infrainguinal obstructive disease there can be performed femuropopliteal (above or below knee) bypasses, popliteopopliteal bypasses or even infrapopliteal bypasses in distal forms of the disease, with involvement of calf arteries (Figures 9, 16-19).
   ii. Extraanatomical bypasses: the bypass conduct does not follow the traject of occluded artery. Indications for extraanatomical bypass include: those cases at high risk for more complex surgical interventions of anatomic reconstruction (e.g. aortobifemoral bypass) and which have vascular lesions that cannot be solved by endovascular means; active abdominal septic process, surgically hostile abdomen. Most used extraanatomical bypasses in aortoiliac obstructive disease are axilofemoral, axilobifemoral and femurofemoral bypasses. There are described other types of extraanatomical bypasses, such as transobturatory iliofemoral bypass, indicated in cases with groin infection (Figures 10, 11).

2. Type of bypass graft:

Nowadays there is a large variety of vascular graft available. The characteristics of ideal vascular graft are:
Types of vascular grafts:
a. Biological grafts:
1. Arterial allograft (or homograft). It assumes transplantation of a biological material from one individual to another of the same species. Indication of arterial allografts usage

it must be available in a large variety of dimensions and shapes; high durability; lack of reactivity (toxicity or allergenicity); good elastic properties, easy maneuverability; malleability and folding capacity; inner lining atraumatic for blood cells and nonthrombogenic; infection resistance; low cost; easily purchasable; unlimited resterilization capacity.
Arrows:

1 = site of iliac occlusion
2 = inflow artery (right common femoral artery)
3 = outflow artery (left common femoral artery)
4 = bypass prosthetic graft

Figure 11. Extraanatomic femorofemoral bypass (4).

Color key:

- Synthetic PTFE (polytetrafluoroethylene) graft
- Outflow artery (below knee popliteal artery)
- Vein cuff (segment of saphenous vein)

Figure 12. Several types of distal "vein cuff".

are: renal revascularization in renal fibrodisplasia; surgical treatment of peripheral arterial aneurisms, vascular trauma, arterial reconstructions after infected synthetic vas-
cular graft removal, mycotic aneurisms (Figure 21).

2. **Humbilical vein allograft** - may be used as an alternative to synthetic grafts in below knee revascularization.

3. **Bovine heterografts** (a type of xenograft): present the advantage of a biological material, but also the great disadvantage of high immunogenicity. They can only be used enzymatically treated or tanned. Bioengineered shell may be the solution for reducing their immunogenicity.

4. **Venous autograft** is at most times represented by the great saphenous vein. It can be harvested and used in reversed manner or it may be used in non-reversed manner ("in situ"), after devalvulation. In cases when great saphenous vein is not available or cannot be used as bypass graft, there may be used other autologous veins such as: small saphenous vein, superficial femoral vein, as well as upper limb veins (cephalic or basilic veins). Great saphenous vein graft is the best choice in infrainguinal arterial reconstructions, especially in bellow knee bypasses with an ex-

Figure 20. Aneurism with celiac axis.

Figure 21. Umbilical vein allograft.
Arterial bypass

Sorin Baila et al.

Fig. 15. Aorto-aortic Dacron (polyester graft) interposition

Arrows:
1. Infrarenal aorta and proximal end-to-end anastomosis
2. Dacron graft
3. Terminal aorta and distal end-to-end anastomosis

Fig. 16. A: Infrarenal abdominal aortic aneurysm

Arrows:
1. Infrarenal aorta and proximal end-to-end anastomosis
2. Dacron graft
3. Terminal aorta and distal end-to-end anastomosis

Of nontextile grafts the most widely spread are: Teflon (expanded polytetrafluorethylene) grafts, Polyurethane grafts, and bioabsorbable grafts.

Nontextile synthetic grafts (e.g.: expanded polyester – the most representative and frequently used being polyester (Dacron) woven or knitted grafts. They may be biologically coated (Collagen, Albumin, Gelatin, Heparin), impregnated with antibiotic substances (Rifampicin) or with Silver ions (antibacterial role). Woven textile vascular grafts have following properties: low porosity and elasticity, they have tendency to unravel at their ends; they have lower tissue integration and a lower anchorage of neointima. On the other hand, knitted textile vascular grafts offer a higher elasticity and porosity, resulting in a better maneuverability, they have superior mechanical compliance, they do not unravel and have superior healing.

Figure 13. 5 year % patency in main vascular interventional procedures (1). Abbreviations: Fem-pop = femoropopliteal; BK = below knee; PTA = Percutaneous Transluminal Angioplasty.
polytetrafluorethilene) are hydrophobic; have a decreased integration in surrounding tissues; the endothelisation process is only present at anastomoses and they have low resistance. Composite grafts are those grafts made out of more materials (especially out of a combination of synthetic and biologic grafts).
Arterial bypass

allograft, or composite grafts. For infrainguinal localization of arterial obstructive disease, especially in infrageniculate reconstructions, venous saphenous autograft is of election. (Excellent patency, similar with those of above knee bypasses, in comparison with infrageniculate synthetic graft bypasses). In cases of below knee bypasses with synthetic grafts, there may be used technical procedures in distal anastomosis that improve graft velocity and patency. They are generically called vein cuffs and they are of several types: Miller cuff, Linton patch, St. Mary’s boot, Taylor patch⁴,⁵, 2¹,²² (Figure 12).

Arterial bypass surgery complications:

- Direct complications: bypass thrombosis.
- Indirect complications: false aneurism, graft infection, distal embolization, fistulas or erosions in near organs² (Figure 23).

Precocious graft occlusion have the following etiologic causes: distal intimal flap; kinking or twisting of the graft; incomplete thrombus evacuation; unexpected hypercoagulation, severe outflow disease²³-²⁵.

Late graft occlusion (<2 year) has as a main cause: anastomotic hyperplasia

Late graft occlusion (>2 year) etiology constitutes of progressive atherosclerosis or anastomotic false aneurism⁹,¹⁰,¹¹.

Mechanisms of graft occlusion have as basis:

Figure 21. Reconstruction of femoral bifurcation with venous homograft.

Arrows:
1. Prosthetic graft (polytetrafluorethylene)
2. Bifurcated venous homograft with the two branches anastomosing end-to-end with superficial femoral artery and with the deep femoral artery
3. Superficial femoral artery
4. Deep femoral artery

Figure 22. St. Mary’s boot vein cuff.

Arrows:
1. Reinforced polytetrafluorethylene femuropopliteal graft
2. Vein cuff
3. Distal popliteal artery (below knee)

Biological behavior of synthetic vascular grafts is marked by: outer fibrin deposit, multiplication of endothelial cells on the inner surface, but without realisation of a proper endothelial layer with its own known properties, outer invasion of connective tissue elements, and solidarisation of the fibrin layer. In order to achieve thrombosis resistance, and infection protection, there have been targeted the following: endothelial cell seeding, colloidal graphite lining, antibiotic impregnation, increasing the compliance².

In case of aortoiliac reconstruction the bypass graft of ellection is synthetic polyester woven or knitted (Dacron) or expanded polytetrfluorethilene as aortic grafts. In case of infrainguinal reconstructions there may be used: venous autografts, synthetic grafts (expanded polytetrafluorethilene, Dacron); human umbilical vein

Figure 23. Graft infection in femoral region.

Arrows:
1. Groin longitudinal incision in Scarpa triangle, exposing the infected graft
2. Nonintegrated polytetrafluorethylene infected graft, easily detachable from surrounding tissues
- technical errors: restant or scarred venous valvulae; graft tunneling errors (graft entrapment); injured vein segments; sclerous veins; run-off artery thrombosis; thrombocyte aggregation; anastomotic stricture; intimal flap.
- postoperative lesions: miointimal hyperplasia, atherosclerosis progression, aneurismal degeneration²).

Postoperative treatment in patients undergoing arterial bypass surgery consists of: platelet aggregation inhibition (aspirine or clopidogrel - especially in cases with endarterectomy or balloon or stent angioplasties associated); cilostasol is an phosphodiesterase III inhibitory agent which also have platelet aggregation inhibitory action and antiproliferative effect on smooth muscle cell; the anticoagulant treatment (is selective); statins (which have a role in atherosclerotic plaque stabilisation); high blood pressure control¹,³.

In postoperative follow up after peripheral arterial surgical revascularization, are used objective endpoints such as patency, limb salvage, survival rate, but also subjective end-points (quality of life)²,¹².

Primary patency describes a functional bypass without further interventions on the conduct or anastomoses (there are not included interventions proximally or distally of the bypass)²;

Primary assisted patency describes a bypass which has necessitated an intervention (surgical or endovascular) in order to mantaining patency, but it was never fully thrombosed²;

Secondary patency describes a thrombosed bypass successfully thrombectomised² (Figure 13).

Our department experience: In a period of time of 17 months (between January 2014 to May 2015), we have had treated and operated in our department 375 patients with peripheral obstructive arterial disease. Of these patients, 131 were amputated per primam (major amputation) and 244 were surgically revascularized. There were performed 126 surgical revascularization interventions for aortoiliac obstructive disease and 118 interventions for infrainguinal obstructive disease. We have had a combined (aortoiliac and infrainguinal) total rate of major amputation of 16,8% after surgical revascularization, with no perioperative deaths in chronic patients. After emergency revascularization we have had a mortality rate of 8,1% for aortoiliac localisation and of 1,8% for infrainguinal localisation.

**CONCLUSION**

Arterial bypass is a classic, yet a very efficient surgical method of treatment for peripheral arterial obstructive disease in critical ischemia patients, with good results on limb salvage, on improvement of quality of life and on survival rate in this category of patients. A very careful assessment of vascular patients perioperatively and good surgical strategy and technique lead to good patency in time for this procedure. These end-points are also found in our department’s experience, measured by low postoperative mortality and amputation rate, which subdue to results published in literature.

**Conflict of interest:** none declared.

**References**


**Results of below knee femoropopliteal bypass patency (2)**

<table>
<thead>
<tr>
<th>Conduct</th>
<th>Primary 4 year patency</th>
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<tbody>
<tr>
<td>Reversed great saphenous vein</td>
<td>77%</td>
</tr>
<tr>
<td>In situ great saphenous vein</td>
<td>68%</td>
</tr>
<tr>
<td>Human umbilical vein</td>
<td>60%</td>
</tr>
<tr>
<td>Polytetrafluorethilene graft</td>
<td>40%</td>
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