REVIEW

Arterial bypass – a surgical method in treatment of peripheral arterial obstructive disease of the lower limbs

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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

Rezumat: În boala obstructivă arterială periferică, în stadii clinice avansate, în care regăsim pacienți cu durere de repaus, leziuni trofice arteriale, precum și în unele cazuri de claudicație intermitentă (claudicație invalidantă), tratamentul intervențional - chirurgical și endovascular - joacă un rol important. Ca și componentă a tratamentului chirurgical, bypass-ul arterial este o procedură valoroasă, cu rezultate bune, atât imediat cât și la distanță, la pacienți selectați. Poate fi de asemenea folosită în combinație cu tehnici endovasculare, în cadrul procedurilor hibrid moderne. Bypass-ul arterial prezintă numeroase indicații, fiind disponibilă o paletă largă de modalități tehnice de efectuare a acestuia. Articolul prezent trece în revista principalele tipuri ale bypass-urilor arteriale, acestea fiind discutate în funcție de materialul grafturilor folosite (biologic și sintetic), de nivelul fiecarui segment arterial: aortoiliac, infrainghinal (deasupra și sub nivelul genunchiului) și de indicațiile si complicațiile acestora.
Cuvinte cheie: bypass arterial, boală obstructivă aterosclerotică periferică, proceduri hibrid

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**).

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

LericheFontaine clinical classification		Rutherford clinical classification			
Stage	Clinical aspects	Grade	Category	Clinical aspects	
I	Asymptomatic	0	0	Asymptomatic	
IIa	Mild claudication	I	1	Mild claudication	
IIb	Moderate-severe claudication	I	2	Moderate claudication	
		I	3	Severe claudication	
III	Rest pain	II	4	Rest pain	Critical ischemia
IV	Arterial ulcer or gangrene	III	5	Minor trophic lesion	Critical ischemia
		III	6	Major trophic lesion	Critical ischemia

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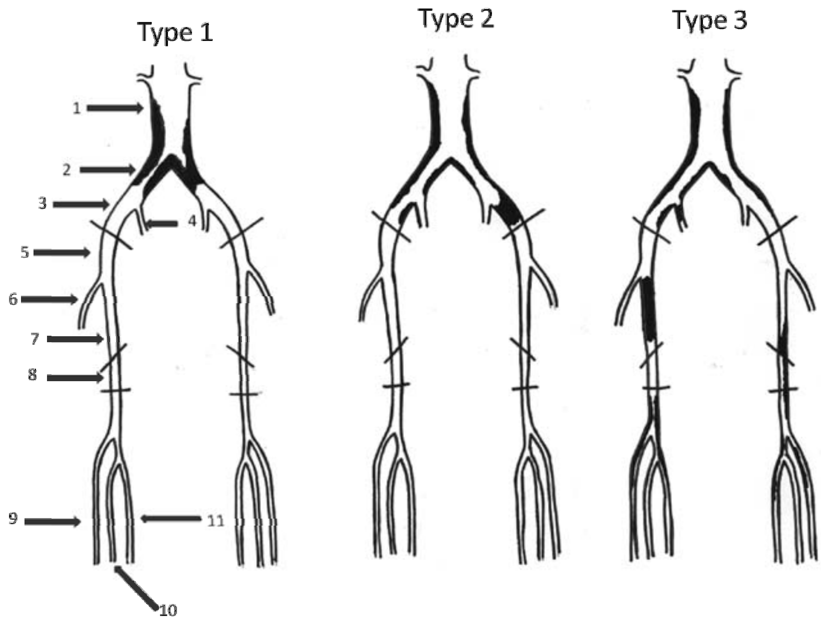
Arrows:

1 = infrarenal abdominal aorta
2 = common iliac artery
3 = external iliac artery
4 = internal iliac artery
5 = common femoral artery
6 = deep femoral artery
7 = superficial femoral artery
8 = popliteal artery
9 = anterior tibial artery
10 = peroneal artery
11 = posterior tibial artery



Type 1 aortoiliac obstructive disease = atherosclecrotic involvment of abdominal aorta and common iliac arteries
Type 2 aortoiliac obstructive disease = atherosclerotic involvment of infrarenal abdominal aorta, common iliac arteries, external iliac arteries and femoral (common femoral) bifurcation
Type 3 aortoiliac obstructive disease = infrarenal abdominal aorta, common iliac arteries, external iliac arteries, femoral (common femoral) bifurcation, popliteal, or tibial arteries

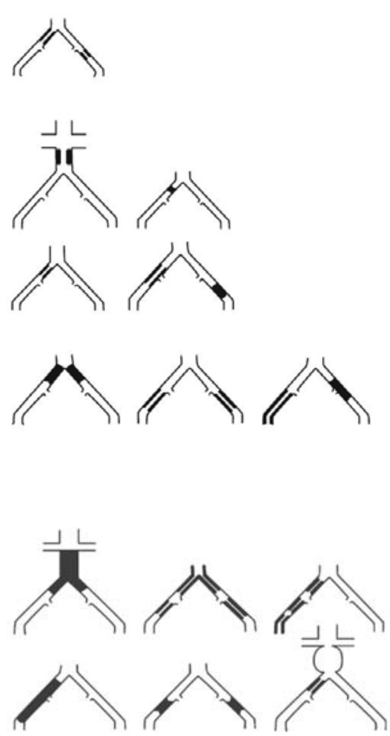
Figure 1. Aorotoiliac obstructive disease classification, from (1).

Type A lessions

Type B lessions

Type C lessions

Type D lessions



TYPE A LESIONS
• Unilateral or bilateral stenoses of CIA
• Unilateral or bilateral single short (3 cm) stenosis of EIA

TYPE B LESIONS
• Short (3 cm) stenosis of infrarenal aorta
• Unilateral CIA occlusion
• Single or multiple stenoses totaling 3−10 cm involving the EIA not extending into the CFA
• Unilateral EIA occlusion not involving the origins of internal iliac or CFA

TYPE C LESIONS
• Bilateral CIA occlusions
• Bilateral EIA stenoses 3–10 cm long not extending into the CFA
• Unilateral EIA stenosis extending into the CFA
• Unilateral EIA occlusion that involves the origins of internal iliac and/or CFA
• Heavily calcified unilateral EIA occlusion with or without involvement of origins of internal iliac and/or CFA

TYPE D LESIONS
• Infrarenal aortoiliac occlusion
• Diffuse disease involving the aorta and both iliac arteries requiring treatment
• Diffuse multiple stenoses involving the unilateral CIA, EIA, and CFA
• Unilateral occlusions of both CIA and EIA
• Bilateral occlusions of EIA
• Iliac stenoses in patients with AAA requiring treatment and not amenable to endograft placement or other lesions requiring open aortic or iliac surgery

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 aneurism

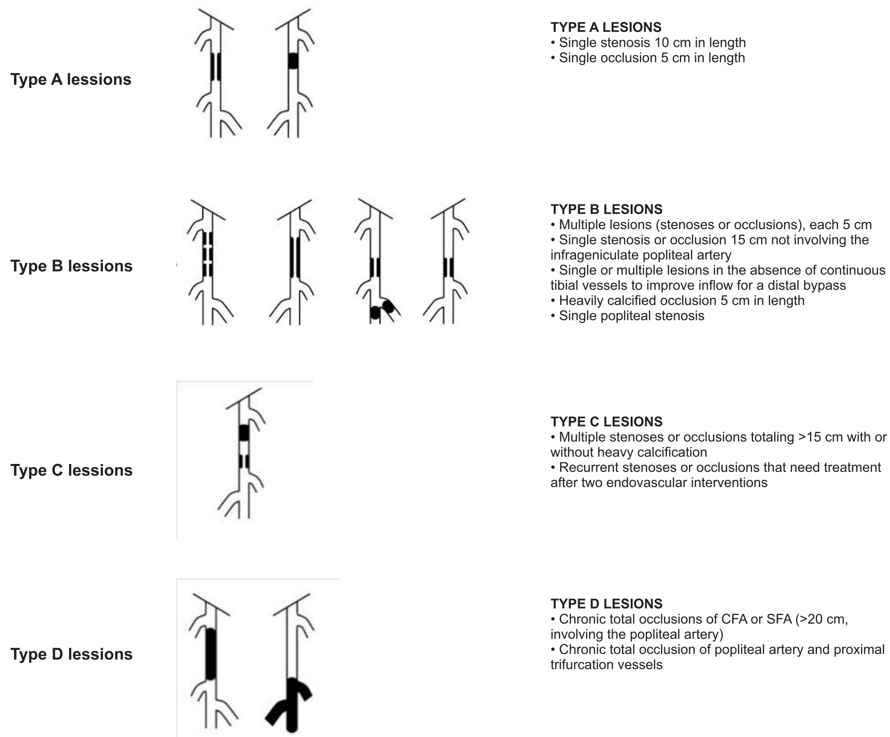


Figure 3. The Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II) classification of infrainguinal obstructive disease (1).
*Abbreviations: CFA = common femoral artery; SFA = superficial femoral artery.

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**).

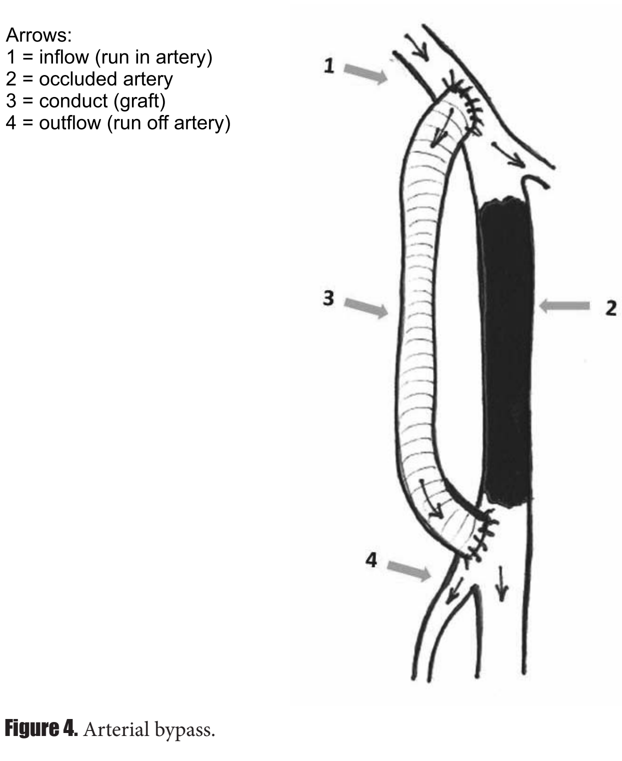


Figure 4. Arterial bypass.

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 sinthetic, 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 bypass[2] (**Figure 4**).

B. History:

In 1896, Jaboulay made first exerimental 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-

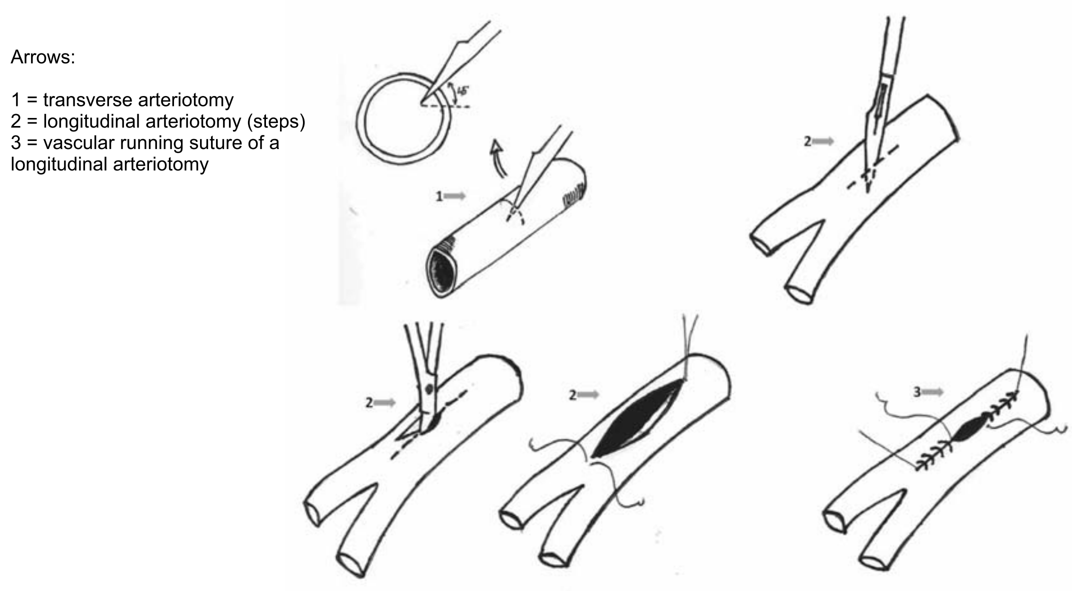


Figure 5. Basic techniques in vascular surgery (18).

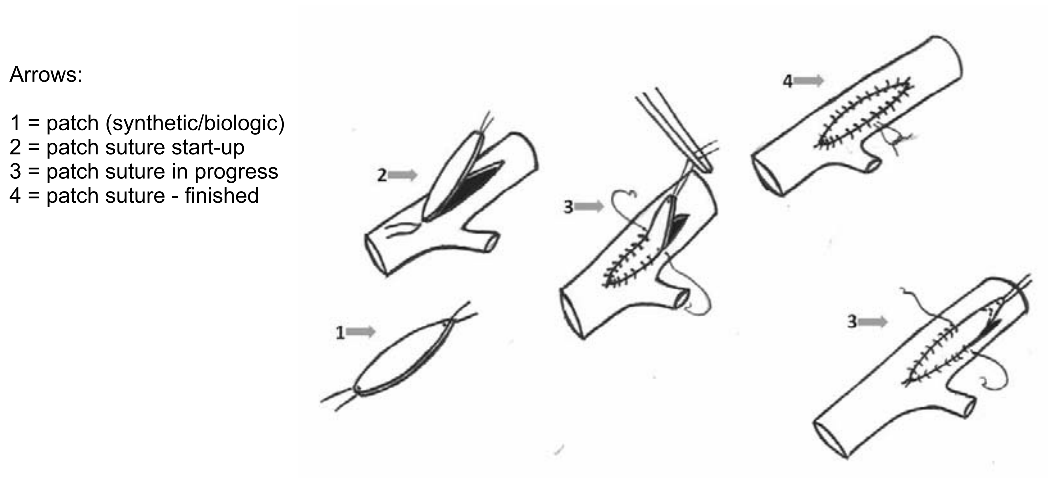


Figure 6. Patch angioplasty (18).

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[20].

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

In the history of arterial bypass surgery, at most importance has the evolution of grafts materials. In 1906, Goyanes performs first autologous vein transplant in human. In 1948 Gross uses arterial human allografts. Vorhees uses the first sinthetic fabricated grafs, Vinyon N (polivynil chloride) in 1952. Edwards uses politetrafluorethilene (Teflon) grafts in 1957, DeBakey uses poliesther (Dacron) grafts in 1957, Soyer uses expanded polytetrafluorethilene (ePTFE) grafts in 1972 and Parodi starts the use of vascular endografts (covered stents) in 1991[2].

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 aneurismal disease. End stages of obstructive arterial disease correspond to the clinical term of critical ischemia. This includes patients with rest pain, those with trophic

Steps of performing end-to-end vascular anastomosis:
1: vessel ends with suture start
2: anastomosis in course
3: end-to-end finished anastomosis
4: design of vessel ends for oblique end-to-end anastomosis
5: oblique end-to-end anastomosis (one side of suture and suture complete)

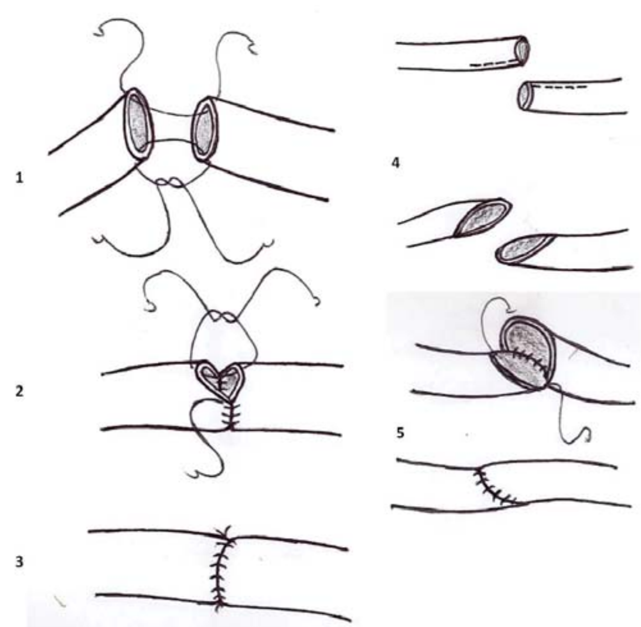


Figure 7. Basic techniques in vascular surgery: end-to-end vascular anastomosis (18).

Steps of performing end-to-side vascular anastomosis
1: design of the lateral end of anastomosis
2: anastomosis suture start-up
3: anastomosis length adjustment technique

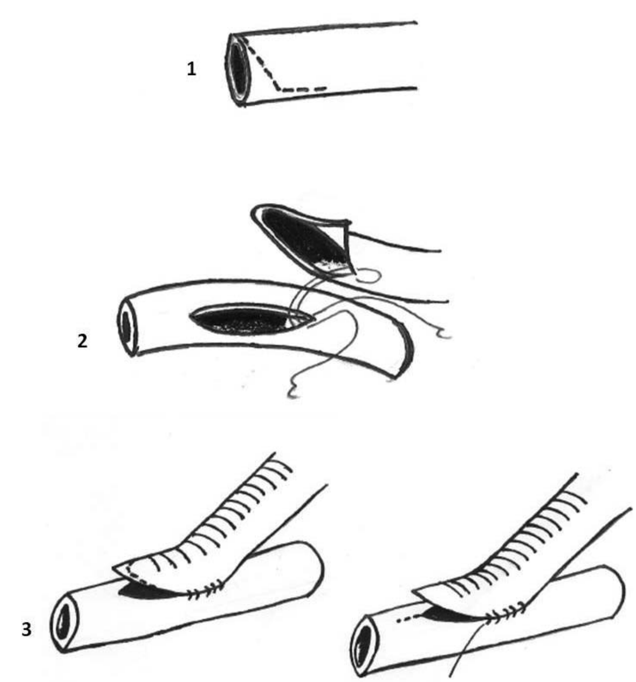


Figure 8. Basic techniques in vascular surgery - end-to-side vascular anastomosis (18).

lesions (arterial ulcers, necrosis, gangrene), but it also includes patients with incapacitating claudication (intermittent claudication at distances of less than 50 meters)[2].

Morphopatologically, 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 lessions have endovascular treatment indication[1] (**Figures 2, 3**).

Contraindications of surgical revascularisation are represented by general surgical contraindications, as well as very short life expectancy[2].

D. Arterial bypass classification:

1. Anatomical criteria:

i. Anatomic bypasses: the bypass conduct follows a traject parallel with the occluded vessel. In aorto-iliac obstructive disease there can be made aortobifemoral, iliofemoral anatomical bypasses. In infrainguinal obstructive diease there can be performed femuropopliteal (above or below knee) bypasses, popliteopopliteal bypasses or even infrapopliteal bypasses in distal forms of the disease, with involvment of calf arteries[2] (**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 lessions that cannot be solved by endovascular means; active abdominal septic process, surgically hostile abdomen[13,14]. 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[15-17] (**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:

Steps of performing aortobifemoral bypass

1: infrarenal aortic clamping, transversal complete aortotomy and suture of the distal aortic end
2: aorto-prosthetic end-to-end anastomosis
3: aortobifemoral bifurcated graft with aorto-prosthetic proximal anastomosis (end-to-end) and distal prosthetico-femoral bilateral anastomoses (end-to-side)

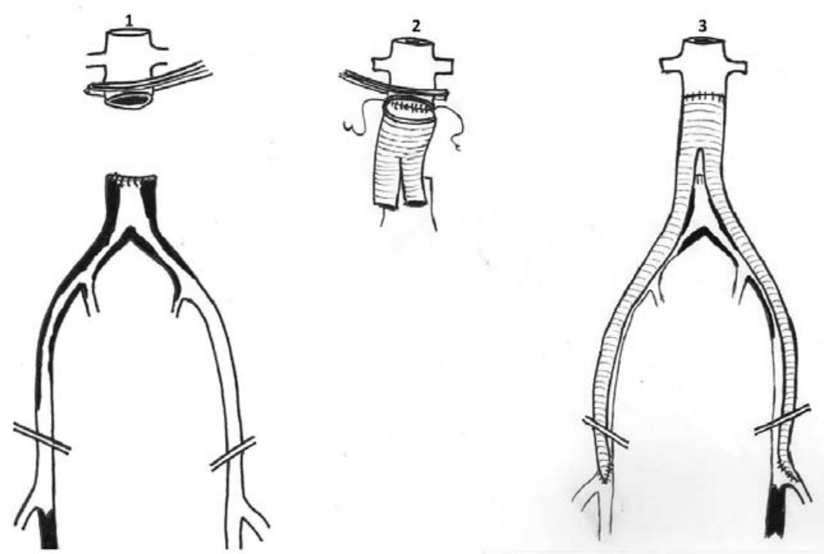


Figure 9. Anatomic aortobifemoral bypass (19).

Arrows

1: inflow artery= axillary artery (with proximal anastomosis)
2: bypass graft
3: outflow artery= femoral artery (with distal anastmomoses) unilaterally (A) or bilaterally (B)
C: different types of distal anastomoses in axilobifemoral bypass

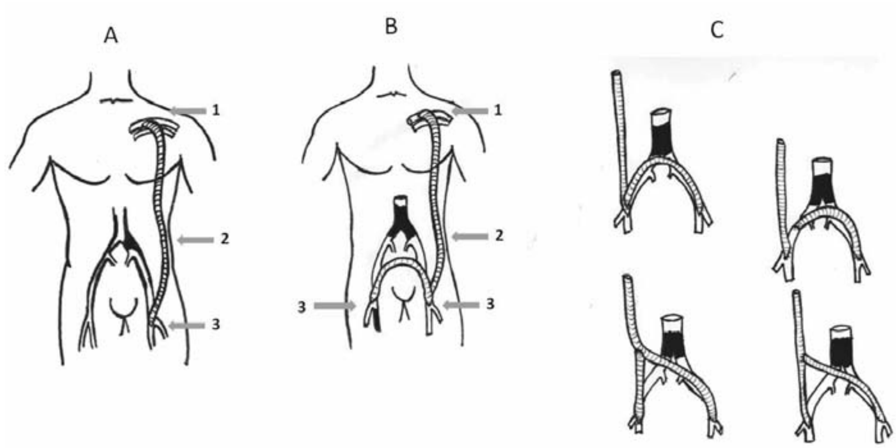


Figure 10. Extraanatomic axilo(bi)femoral bypass (2).

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.

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

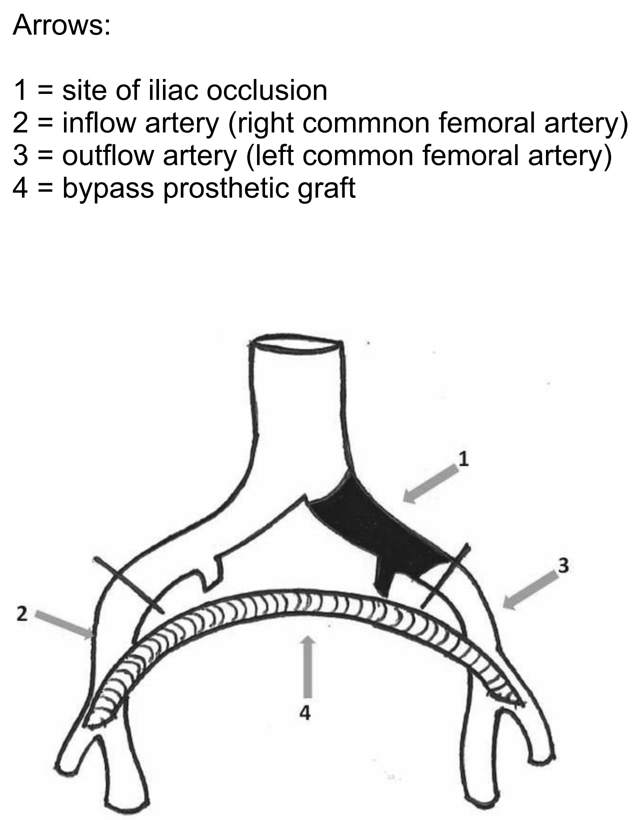


Figure 11. Extraanatomic femorofemoral bypass (4).

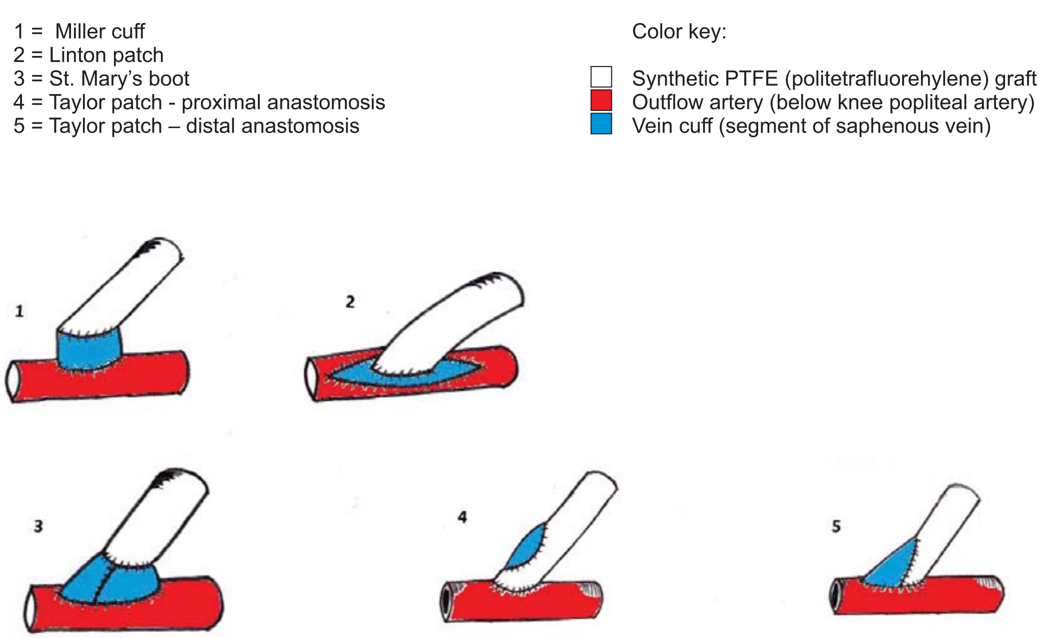


Figure 12. Several types of distal "vein cuff".

are: renal revascularization in renal fibrodisplasia; surgical treatment of peripheral arterial aneurisms, vascular trauma, arterial reconstructions after infected synthetic vascular graft removal, mycotic aneurisms[2] (**Figure 21**).

2. Humbilical vein allograft - may be used as an alternative to synthetic grafts in below knee revascularization[2].
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[2].
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 excellent patency (75-80% 5 year patency)[1,6,8] (**Figure 20**).

Synthetic grafts. Nowadays there is a very large variety of synthetic grafts available. For exam-

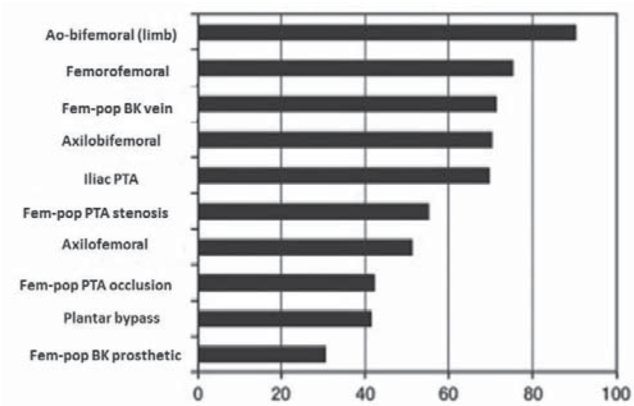


Figure 13. 5 year % patency in main vascular interventional procedures (1). Abbreviations: Fem-pop = femoropopliteal; BK = below knee; PTA = Percutaneous Transluminal Angioplasty.

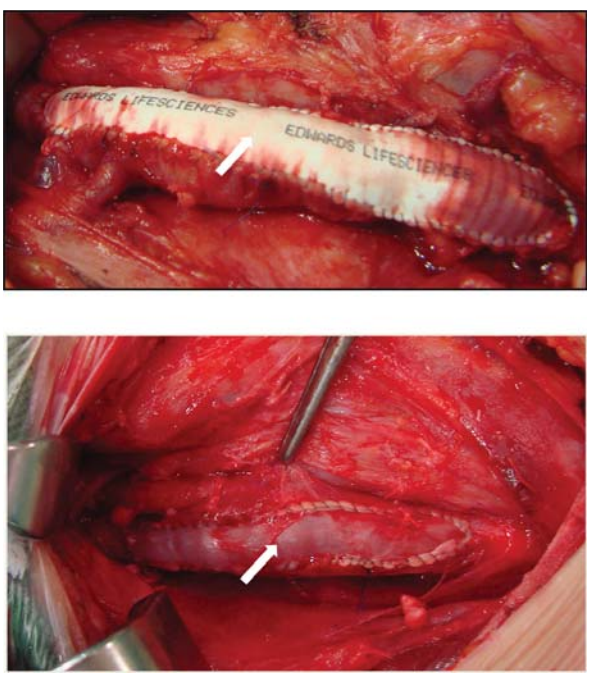


Figure 14. Sinthetic polytetrafluorethylene patch angioplasty (arrow). Venous patch angioplasty (arrow).

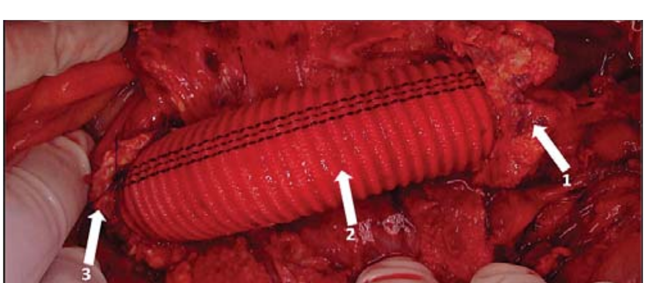


Figure 15. Aorto-aortic Dacron (polyesther graft) interposition
Arrows:
1. Infrarenal aorta and proximal end-to-end anastomosis
2. Dacron graft
3. Terminal aorta and distal end-to-end anastomosis

ple: textile grafts – 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[2,7] (**Figure 15**).

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

Nontextile synthetic grafts (e.g.: expanded

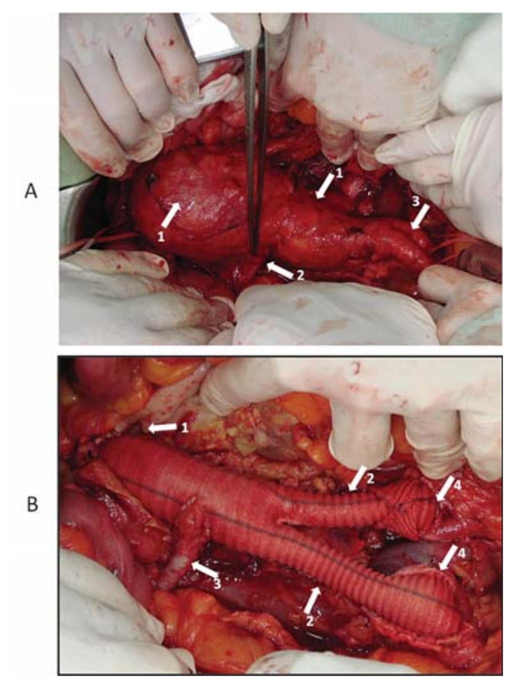


Figure 16. A: Infrarenal abdominal aortic aneurysm
Arrows:
Bisaccular aortic anurysmal dilatation
Inferior right polar renal artery
Normal common iliac arteries (right and left)
B: Infrarenal abdominal aortic aneurysm after surgical resolution (aortobiiliac interposition + reimplantation of a right inferior polar artery)
Arrows:
Dacron graft common body, anastomosed end-to-end to infrarenal aorta
Dacron graft limbs
Reimplanted right inferior polar renal artery
Distal end-to-end anastomoses between right and left Dacron graft limbs and common iliac arteries

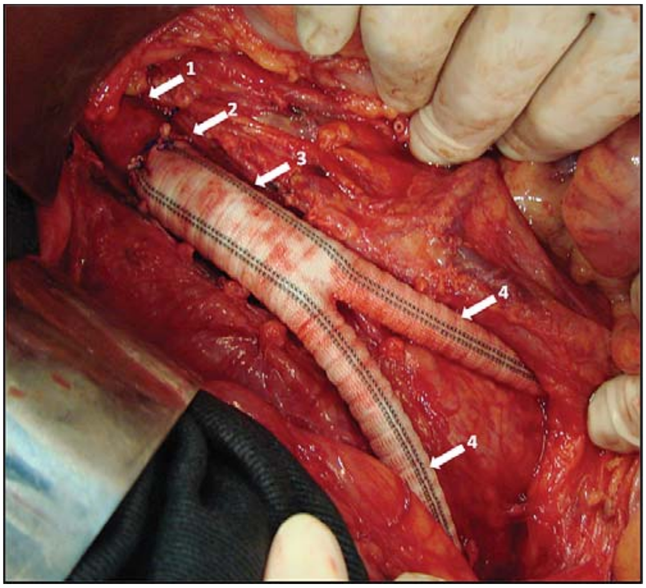


Figure 17. Aorto-bifemoral Dacron graft.
Arrows:
1. Normal infrarenal aorta
2. End-to-end aorto-prosthetic anastomosis
3. Dacron graft common body
4. Dacron graft limbs, passing through retroperitoneal tunnels towards femoral arteries

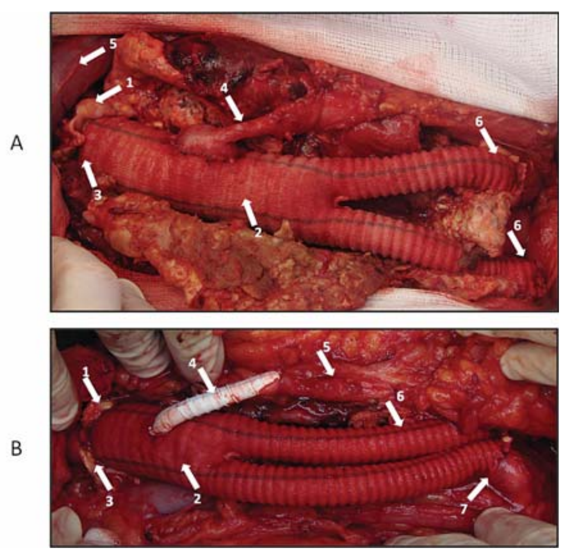


Figure 18. Aorto-biiliac Dacron graft.
A: Arrows:
1. Infrarenal aorta anastomosed end-to-end to a bifurcated Dacron graft
2. Dacron bifurcated graft
3. End-to-end aorto-prosthetic anastomosis
4. Reimplanted inferior mesenteric artery in an end-to-side manner
5. Left renal vein
6. Prosthetico-iliac end-to-end anastomoses
B: Arrows:
1. Infrarenal aorta anastomosed end-to-end to a bifurcated Dacron graft
2. Dacron bifurcated graft
3. Termino-terminal aorto-prosthetic anastomosis
4. Prosthetico-inferior mesenteric reinforced polytetrafluorethylene bypass graft
5. Inferior mesenteric artery
6. Left prostetic limb
7. Right prosthetico-iliac end-to-end anastomosis

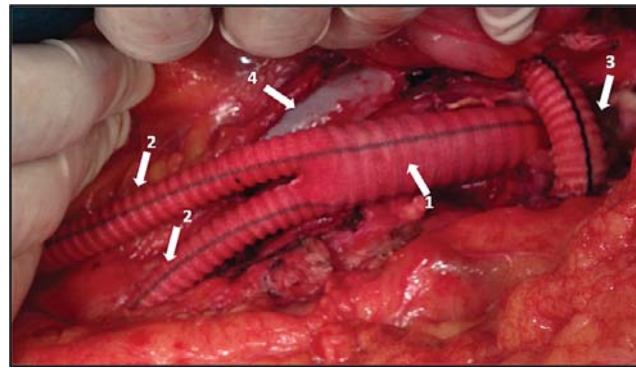


Figure 19. Aorto-bifemoral Dacron graft.
Arrows:
1. Aorto-bifemoral Dacron graft common body
2. Dacron graft limbs, passing through retroperitoneal tunnels towards femoral arteries
3. Reconstructed left renal vein after tactical section (interposition of a Dacron graft)
4. Inferior vena cava

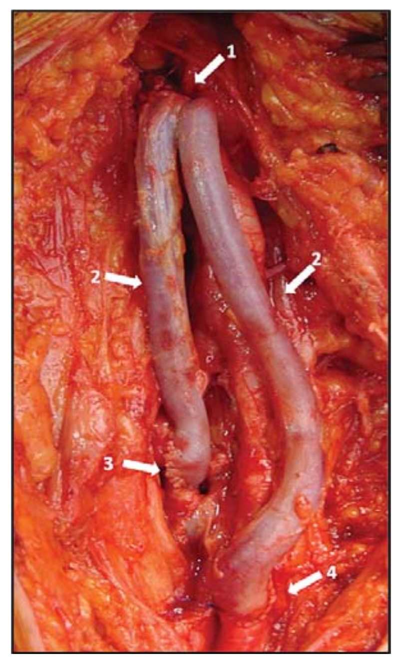


Figure 20. Reversed internal saphenous vein grafts in right femoral region.
Arrows:
1. Common femoral artery- saphenous end-to-side anastomosis
2. Reversed internal saphenous grafts
3. Anastomosis between one saphenous graft and deep femoral artery (end-to-side)
4. Anastomosis between other saphenous graft and superficial femoral artery (end-to-side)

polytetrafluorethilene) are hydrophobic; have a decreased integration in surrounding tissues; the endothelisation process is only present at anastomoses and they have low resistance[2].
Composite grafts are those grafts made out of more materials (especially out of a combination of synthetic and biologic grafts).

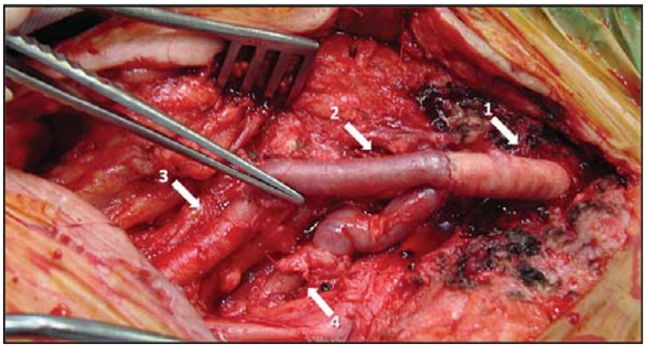


Figure 21. Reconstruction of femoral bifurcation with venous homograft.
Arrows:
1. Prosthetic graft (polytetrafluorethylene)
2. Bifurcated venous homograft with the two branches anastomosing end-to-end with superficial femoral artery and with the deep femoral artery
3. Superficial femoral artery
4. Deep femoral artery

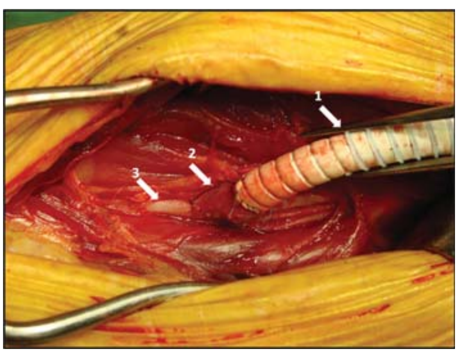


Figure 22. St. Mary's boot vein cuff.
Arrows:
1. Reinforced polytetrafluorethylene femuropopliteal graft
2. Vein cuff
3. Distal popliteal artery (below knee)

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 compliance[2].

In case of aortoiliac reconstruction the bypass graft of ellection is synthetic polyesther woven or knitted (Dacron) or expanded polytetrafluorethilene 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

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 patch[4,5, 21,22] (**Figure 12 22**).

Arterial bypass surgery complications:
- Direct complications: bypass thrombosis.
- Indirect complications: false aneurism, graft infection, distal embolization, fistulas or erosions in near organs[2] (**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 disease[23-25].

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 aneurism[9,10,11].

Mechanisms of graft occlusion have as basis:

- technical errors: restant or scarred venous valvulae; graft tunneling errors (graft entrapment); injured vein segments; sclerous veins; run-off artery thrombosis; thrombocite agregation; anastomotic stricture; intimal flap.
- postoperatory lessions: miointimal hyperplasia, aterosclerosis progresion, aneurismal degeneration[2]).

Postoperative treatment in patients outgoing arterial bypass surgery consists of: platelet aggregation inhibition (aspirine or clopidogrel - especially in cases with endarterectomy or balloon or stent angioplasties asociated); cilostasol is an phosphodiesterase III inhibitory agent which also have platelet aggregation inhibitory action and antiprolipherative effect on smooth muscle cell; the anticoagulant treatment (is selective); statins (which have a role in atherosclerotic plaque stabilisation); high blood pressure control[1,3].

In postoperative follow up after peripheral arterial surgical revascularization, are used objective end-points 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 necesitated an intervention (surgical or endovascular) in order to mentaining patency, but it was never fully thrombosed[2];

Secondary patency describes a thrombosed bypass successfully thrombectomised[2] (**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.

Results of below knee femuropopliteal bypass patency (2)

Conduct	Primary 4 year patency
Reversed great saphenous vein	77%
In situ great saphenous vein	68%
Human umbilical vein	60%
Polytetrafluorethilene graft	40%

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.

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