Eur J Vasc Endovasc Surg **35**, 61–67 (2008)
doi:10.1016/j.ejvs.2007.08.004, available online at http://www.sciencedirect.com on ScienceDirect

Human Umbilical Vein versus Heparin-bonded Polyester for Femoro-popliteal Bypass: 5-year Results of a Prospective Randomized Multicentre Trial

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Purpose. *To compare long-term patency of Heparin-Bonded Dacron (HBD) and Human Umbilical Vein (HUV) vascular prostheses in above-knee femoro-popliteal bypass surgery.*
Design. *A prospective randomized multi-centre clinical trial.*
Patients and methods. *Femoro-popliteal bypasses were performed in 129 patients between 1996 and 2001. After randomization 70 patients received an HUV and 59 an HBD prosthesis. Patients were followed up every three months during the first postoperative year and yearly thereafter. The median follow-up was 60 months (range 3–96 months). Graft occlusions were detected by duplex scanning, angiography or surgical exploration.*
Results. *The cumulative primary patency rates were 79%, 66% and 58% at 1, 3 and 5 years postoperatively. Primary patency rates for HUV were 74%, 64% and 58% at 1, 3 and 5 years and 84%, 68% and 58% for HBD, respectively (log-rank test,* $p = 0.745$*). Overall secondary patency rates were 82%, 72% and 61% at 1, 3 and 5 years postoperatively. The overall cumulative limb salvage at 5 years follow-up was 89% (CI 80%–91%) and was not dependent on graft type. Smoking* ($p = 0.019$*), number of patent crural arteries* ($p = 0.030$*) and previous cerebro-vascular events* ($p = 0.030$*) were significant predictors of graft occlusion.*
Conclusion. *There was no difference in long-term graft performance between HUV and HBD for above knee infrainguinal bypass.*

Keywords: Peripheral arterial occlusive disease; Femoro-popliteal bypass; Peripheral bypass; Dacron; Heparin-bonded polyester; Human umbilical vein; Claudication.

Introduction

The choice of graft material for prosthetic femoro-popliteal bypass has been a controversial matter over the past decades. Many trials have been conducted to investigate and compare graft adequacy for this procedure.[1] Despite the increasing evidence results are still inconclusive.[2] Therefore, the choice of graft often is left to the surgeon's preference.[3]

Presently, four grafts are available for femoro-popliteal bypass: the autologous saphenous vein, polytetrafluoroethylene (PTFE), double velour polyester (Dacron) and Human Umbilical Vein (HUV).[4] Saphenous vein is considered the gold standard for bypass whether the distal anastomosis is either above (AK) or below the knee (BK).[5] Prosthetic grafts are used routinely in the absence of the saphenous vein and are feasible for AK distal anastomosis.[6] Some argue that patency rates for prosthetic grafts and saphenous vein are equivalent in AK bypass for patients treated by anticoagulant drugs. However, the general assumption is that saphenous vein bypass has a lower risk of graft failure.[7] No explicit consensus exists on superiority of any particular prosthetic graft. HUV is considered the most satisfactory and provides the best long-term patency rates.[8,9] However, previous reports provide evidence that a prosthetic graft covered with an antithrombotic farmacon, may be the preferred graft for AK bypass.[10,11]

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1078–5884/000061 + 07 $32.00/0

The aim of the present study was to compare long-term patency rates between Human Umbilical Vein and Heparin-bonded Dacron (HBD) prosthesis in femoro-popliteal bypass.

Patients and Methods

Study design

A randomized, prospective, multi-center clinical trial was performed comparing heparin-bonded collagen coated polyester (Dacron, Intergard, Intervascular, Inc., La Ciotat, France) and human umbilical vein (Dardik, Biograft, Bio-Vascular, Inc., Saint-Paul, MN) for femoro-popliteal bypass. Femoro-popliteal bypass was defined as the insertion of a bypass graft with the proximal anastomosis above the adductor canal to the common-, profunda- or superficial femoral artery and distal to the popliteal artery AK or BK. The standards for reporting lower extremity ischemia[12] were implemented in this study. Critical limb ischemia was defined as ischemic rest pain and/or tissue loss combined with an ankle pressure < 60 mmHg with flat or barely palpable pulsations at the ankle or metatarsals.

Sample size

This trial originally was designed to compare short-term patency between both grafts. The initial power analysis required a study population of 200 patients to determine a significant difference in patency of $>10\%$ at two years follow-up. Unfortunately, the inclusion period provided only 129 patients, which proved insufficient for short-term analysis. In order to determine whether a five years follow-up evaluation would be adequate, a second power analysis based on the observed 1-year event rates of 0.24 and 0.14 in both groups was performed. In order to demonstrate a 20% patency difference at 5 years with a power of 80% two groups each with 66 patients are required.

Patients

A femoro-popliteal bypass was performed in 129 patients between 1996 and 2001. Seventy patients were randomized to HUV while 59 patients received HBD prosthesis, even if the saphenous vein was adequate. Preoperative workup included detailed evaluation of patient history, cardiovascular risk factors, physical examinations, standard treadmill walking tests and calibrated angiography of the affected extremity.

Male and female patients, aged 31–89, with disabling intermittent claudication and an ankle/brachial index (ABI) below 0.8 at rest were included in the present study. All patients received elective femoro-popliteal reconstruction for either occlusive arterial disease or aneurysms of the superficial femoral- or popliteal artery.

Patients younger than 30 - or older than 90 years of age or patients with an ABI higher than 0.8 at rest were excluded. Other exclusion criteria were: emergency surgery for trauma, acute thrombosis or embolism of the popliteal artery, the diagnosis or treatment for malignancy within 12 months, hospital in-patient treatment for cardiac failure in the previous six months, the absence of the possibility for adequate follow-up or contraindications for anticoagulant drug therapy.

The trial patients also participated in the Dutch BOA-trial,[13] comparing the effect of coumarin derivatives and acetylsalysilic acid after infra-inguinal bypass surgery. Cooperation was established with the BOA-trial investigators to simplify randomization and data collection for the mutual benefit of both studies. The present study was approved by the local Institutional Review Board and fully informed consent, given in writing, was obtained from all patients.

The grafts

The Dacron prosthesis consists of double velour polyester with a reversed locknit construction. The graft is coated with heparin on its inner surface and type I collagen on the outer surface. The Human Umbilical Vein is glutaraldehyde tanned and surrounded by a tightly knitted Dacron mesh.

Currently, both prostheses are used for femoro-popliteal bypass.[14] The HUV graft only may be used in accordance to renewed European Union guidelines. These demand a confirmed exclusion of HIV contamination of the original human umbilical blood (EC Treaty, article 250, Brussels, 2003).

Randomization and follow-up

Randomization was controlled by the BOA-trial agency using a dedicated computer program. The graft type for femoro-popliteal reconstruction was determined at least 24 hours prior to surgery. All patients were treated with heparin peri-operatively.

Post-operatively, patients were randomized to life-long treatment with either acetylsalysilic acid (Aspirin) 80 mg daily or coumarin derivates (Sintrom) [target INR ratio 3.0–4.5], in accordance to local

treatment protocols. Patient follow-up visits were at 3 monthly intervals during the first postoperative year and yearly thereafter.

Endpoints and patency evaluation

Graft patency was determined at follow-up visits, assessed at yearly intervals and stratified by graft material and type of anticoagulant medication. Palpable graft pulsations combined with definite distal pulses were considered evidence for an open lumen. Graft occlusions were detected by angiography, duplex scanning or operative exploration. Patency was categorized as follows:

- Primary patency; the time from implantation of the graft to primary occlusion without adjunctive measures, marking the primary endpoint.
- Primary assisted patency; the time from implantation to primary graft occlusion achieved by adjunctive measures to maintain graft patency.
- Secondary patency; the time after restoring patency by an intervention such as thrombectomy, thrombolysis or percutaneous transluminal angioplasty. The secondary endpoint was marked by final graft occlusion, graft removal or amputation of a limb.

Statistical analysis

The trial was conducted on an 'intention to treat' basis. Once entered a patient was not withdrawn or excluded from this analysis. Graft patency, limb salvage and mortality were assessed by the Kaplan-Meier survival model. The difference in patency between both grafts was analyzed statistically by the log rank test. The influence of various risk factors on patency was examined by the Cox regression analyses.

Results

Patient cohorts

Patient enrollment and allocation is outlined in Fig. 1. Eight patients received an autologous saphenous vein bypass and consequently were excluded from analysis. The risk factors in HUV and HBD groups were similar (Table 1). The common femoral artery was used for proximal anastomosis in 126 procedures (98%). The distal anastomosis was AK popliteal in 122 cases (95%), BK popliteal in 4 (3%) and to the tibioperoneal trunk in 3 (2%) patients. Postoperatively, median AB-indices increased from 0.56 (0.16−0.80) to 0.9 (0.22−1.1) for HUV and from 0.60 (0.19−0.80) to 1.0 (0.27−1.3) for HBD. Median postoperative Rutherford classifications were 0 (0−6) for HUV and 0 (0−5) for HBD. Postoperative anti-coagulant drug treatment was equally distributed between both groups. Coumarin derivates were prescribed to 68 patients (53%); HUV 36 and HBD 32. Sixty-one patients (47%) were treated with acetylsalysilic acid; HUV 34 and HBD 27. Median hospital stay was 10 days (4−109) for HUV and 11.5 (6−30) for HBD grafts. Twelve patients (9%) were lost to follow-up. Median follow-up was 60 months (range 3−96 months).

Morbidity and mortality

Thirteen patients (10%) died during follow-up, 9 (13%) in the HUV group and 4 (7%) in the HBD group. Grafts were patent to the time of death in 12 of these patients (HUV 8, HBD 4). Two patients died within 30 days after the operation, accounting for 2% operative mortality. Cumulative survival was 92%, 90% and 87% at 1, 3 and 5 years follow-up.

A total of 43 complications was reported in 40 patients (31%) with 18 (26%) in the HUV group and 25 (42%) for HBD. Complications were postoperative bleeding (3%), graft infection (3%), cardiac events (4%) and wound morbidity (18%). The incidence of graft infection did not differ between groups, with 2 cases in each. Re-operation was required in 7 patients (10%) in the HUV- and 5 patients (8%) in the HBD group.

Graft performance

Overall primary patency rates were 79%, 66% and 58% at 1, 3 and 5 years postoperatively. Primary patency rates for HUV were 74%, 64% and 58% at 1, 3 and 5 years and 84%, 68% and 58% for HBD, respectively (log-rank test, $p = 0.745$) (Fig. 2 and Table 2). Primary patency rates at 5 years in the HUV group were 55% for patients on acetylsalysilic acid and 48% for patients on coumarin medication (log-rank test $p = 0.406$). In the HBD group these rates were 47% and 62%, respectively (log-rank test $p = 0.362$). An overall analysis of all four subgroups showed no differences (log-rank test $p = 0.428$).

PTA was performed in 3 patients to prevent primary graft occlusion. Therefore, primary assisted patency rates were almost identical to the primary patency rates.

We were able to restore patency in 32 of the 50 primary graft occlusions (64%), 18 for HUV and 14 for HBD. Long-term (5 yr) patency was achieved in only 9 patients. Surgical thrombectomy was required in 21 patients (16%) and resulted in long-term patency

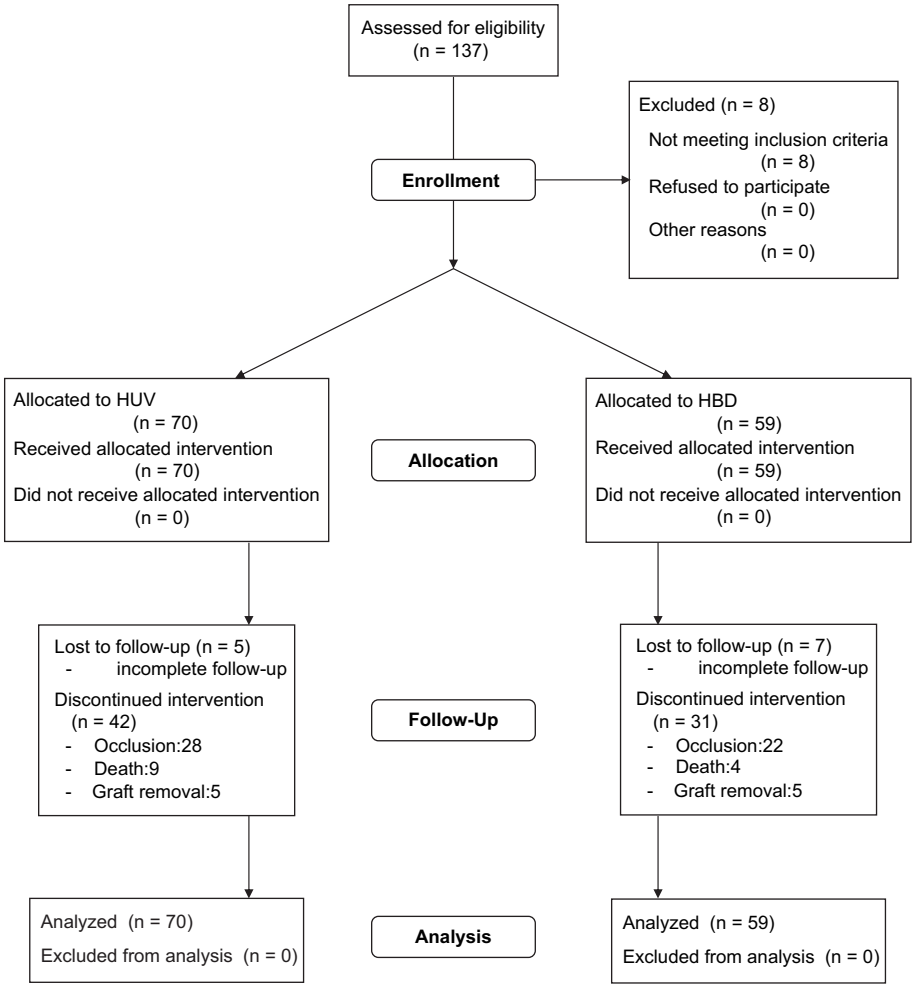

Fig. 1. Study flow chart.

for 6 patients. Eleven patients (9%) underwent thrombolysis, successfully maintaining graft patency in 3 cases. The graft was replaced in 10 patients (8%), who were excluded from further analyses. Eight patients (6%) received conservative treatment. Overall secondary patency rates were 82%, 72% and 61% at 1, 3 and 5 years postoperatively. Secondary patency rates were 78%, 71% and 60% for HUV grafts and 85% and 73% and 61% for HBD grafts at 1, 3 and 5 years respectively (log-rank test, $p = 0.602$).

Limb salvage

Major amputation was required in 11 patients (9%). Six amputations were performed after HUV bypass (9%) and 5 after HBD implantation (8%). Pre-operative median Rutherford classification for limb loss patients was 4 (range 3–5), indicating critical ischemia. No amputations were performed in patients with intermittent claudication. Six amputations (5%) were performed as a secondary intervention after primary graft occlusion. Overall cumulative limb salvage at 5 years follow-up was 89%. Limb salvage for HUV was 87% and 90% for HBD.

Risk factors

Cardiovascular risk factors were assessed during patient work-up and included: diabetes mellitus, smoking history, hyperlipidemia, angina pectoris, myocardial infarction, cerebro-vascular events, hypertension and hyperhomocysteinemia. The influence on graft occlusion of critical limb ischemia, choice of anticoagulant drug treatment, graft material, gender, age and the number of patent crural arteries also were assessed. The mean number of patent crural arteries was 1.6 for patients who suffered graft occlusion and 2.3 for patients with a patent graft at 5 years

Table 1. Patient characteristics

Parameter	HUV	HBD
n	70	59
Age (y), median (range)	65 (41–88)	65 (36–84)
Gender (%)		
- Male	52 (74%)	35 (59%)
Co-morbidity (%)		
- DM	23 (33%)	21 (36%)
- Smoking	47 (67%)	43 (73%)
- Hyperlipedemia	21 (30%)	26 (44%)
- Angina/MI	20 (29%)	16 (27%)
- Cerebrovascular events	12 (17%)	4 (7%)
- Hypertension	34 (49%)	29 (49%)
- Homocysteinemia	2 (3%)	2 (3%)
Rutherford classification, median (range)	3 (1–6)	3 (2–5)
Critical limb ischemia (%)	27 (39%)	18 (30%)
Tissue loss (%)	12 (17%)	9 (15%)
ABI preoperative, median (range)	0.56 (0.16–0.80)	0.60 (0.19–0.80)
Number of patent crural arteries, mean	2	2
Supragenicular bypass (%)	65 (93%)	57 (97%)
Days hospital stay, median (range)	10 (4–109)	11.5 (6–30)

DM: Diabetes Mellitus, MI: Myocardial Infarction, CVA: Cerebro Vascular Accident.
No statistical differences were detected between groups ($p = \text{ns}$).

follow-up. Cox regression modeling of these potentially important co-variables determined smoking ($p = 0.019$), the number of patent crural arteries ($p = 0.030$) and previous cerebro-vascular events ($p = 0.030$) as significant predictors of graft occlusion. Graft material was a non-significant predictor ($p = 0.293$).

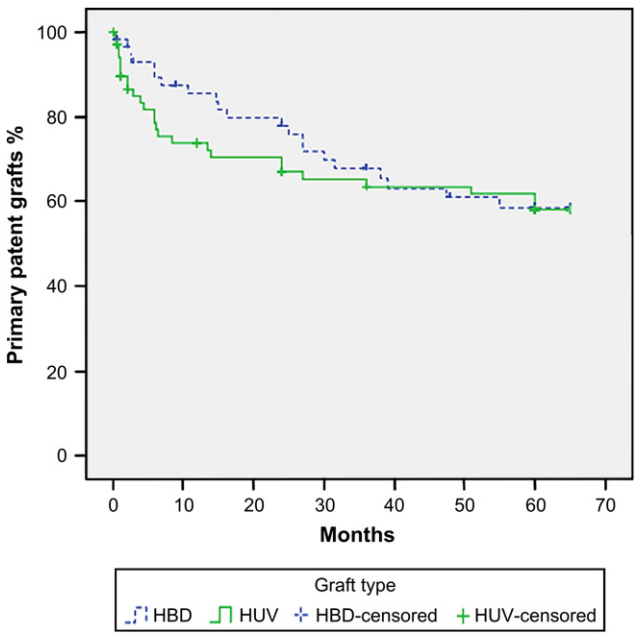

Fig. 2. Kaplan-Meier analysis of primary patency rates for HUV and HBD groups.

Table 2. Numbers of patients ($n = 129$) at risk in Kaplan-Meier analysis of Fig. 2

Time (months)	HUV ($n = 70$)	HBD ($n = 59$)
0	67	56
12	46	45
24	41	41
36	36	35
48	34	25
60	22	16

Discussion

In the early 1970s, the use of polyester fibre (Dacron) as prosthetic bypass graft material for infrainguinal arterial reconstructions was abandoned since autologous vein bypass grafting achieved better results.[7] Superior saphenous vein patency rates were attributed to the fact that any prosthetic graft surface has a higher grade of thrombogenicity than graft material with a genuine endothelial lining. Prosthetic grafts other than polyester mainly consisted of polytetrafluoroethylene (PTFE) or human umbilical vein graft material (HUV). Other factors that have been identified to influence the outcome of bypass grafting are distal anastomotic level, diabetic disease, the continuation of tobacco use and the dimension of distal run-off.[15,16] Carefully randomized controlled trials showing the benefit of the use of antithrombotic medication later redirected interest towards the use of polyester bypass grafts. In the mean time, modifications of the prosthetic fabric and thus, the graft surface, were made in order to reduce thrombogenicity.[12,17,18]

An obvious approach to the development of a vascular prosthesis is a graft that closely resembles a natural blood vessel in both composition and mechanical characteristics.[19] In the absence of a suitable autologous vein graft, the concept of human umbilical vein (HUV) grafts serves as an alternative to a conduit with a genuine intimal layer. It consisted of glutaraldehyde stabilized human umbilical vein in its original form. Presumably because of mechanical fatigue through the lack of stability of collagen cross-links, it was prone to long-term degradation, dilation, and frank aneurysm formation. To counter this possible disadvantage, a polyester mesh cover was introduced, which unfortunately decreased handling quality. The concerns regarding biodegradation and aneurysm formation were never truly scientifically founded.[20]

When implanted, the luminal surface of a prosthetic graft, on exposure to a high blood flow, immediately is coated with a layer of coagulation proteins, mainly consisting of fibrin. Heparin coverage of the graft surface may aid in disrupting the coagulation cascade and therefore reduce the intrinsic thrombogenicity of the graft.[13]

After formation, the fibrin layer becomes organized by ingrowth of myofibroblasts arising from the bloodstream and most importantly, from ingrowth through the interstices of the graft wall. This 'pseudointimal' layer is of utmost importance, because its thickness influences luminal diameter and thus, the passage of blood. This is a particular issue for small diameter conduits on distal and therefore smaller vessels.[21,22] It was thought, that the process of formation and amount of a 'neointima' could be influenced by changing the internal surface of the graft material through the use of graft flow-surface modifications and treatment with antithrombotic or anti-proliferative agents. The choice of heparin as a supplement to the graft is based on the rationale that it both prevents thrombosis via inhibition of thrombin and activated clotting factors IX, X, XI and XII, and it reduces intimal hyperplasia through antiproliferative effects on smooth muscle cells.[23] Its ability to reduce intimal hyperplasia has been investigated both in animal studies and in clinical practice.[24,25] Therefore, heparin has been incorporated into a wide range of medical devices from haemodialysis filters to vascular stents and grafts. As heparin has a strong anionic character, ionic bonding is achieved on surfaces pre-treated with cationic substances. A general disadvantage of this method, however, is the rapid release of heparin upon exposure to blood or plasma. This may be overcome by the co-polymerization of surfaces with substances carrying a positive charge. Quaternary ammonium salts with hydrophobic tails, such as tridodecylmethylammonium chloride (TDMAC), have found wide application in this role. In the manufacture of the heparin-bonded graft used in this study the heparin is bound to the luminal surface of the graft as a complex with TDMAC.[8]

Johnson and co-workers[3] performed a large, prospective randomized trial reporting 73%, 53% and 39% patency rates for saphenous vein, HUV and PTFE at five years follow-up, respectively. Possibly, a higher rate of early bypass graft thromboses and major amputations within the first 30 days in the HUV group (12.3% for HUV vs. 6.1% for PTFE) combined with the higher technical requirements and costs explain the selection of PTFE by many surgeons at the time. Multiple studies have confirmed the superior long-term patency rate for saphenous vein over HUV and for HUV over PTFE.[8,9,26,27] Additionally, Post and co-workers suggested that PTFE and Dacron were equally suitable for femoro-popliteal bypass,[28] whereas Jensen and co-workers stated that Dacron might even be superior to PTFE.[29] Devine and co-workers[10] found significantly better patency rates for HBD (59%) compared to PTFE (49%) at three years follow-up. This trial also suggests a higher incidence of limb amputation in the PTFE group at five years follow-up.

Primary and secondary patency rates of femoropopliteal bypasses did not differ between HUV and HBD in our study. The observed patency rates compared favourably with other studies. Systematic reviews of category A and B randomized trials report no evidence for the preferred use of Dacron, PTFE, or HUV grafts in the femoropoliteal area.[4] In some studies, different patency rates exist between HUV and PTFE in relation to the time after surgery: Johnson and Lee[8] state that there is a small advantage for PTFE in the short-term compared to HUV grafts. Our study did not indicate a difference in secondary patency rates at 1, 3 or 5 years follow-up.

Most of the patients in this study also participated in the Dutch BOA trial investigating the effect of postoperative anticoagulant medical treatment on bypass graft patency, which might be a possible source of bias. Tangelder and co-workers[12] concluded that acetylsalysilic acid significantly reduced non-venous graft occlusion, although the absolute difference was small. Participation in the BOA-trial did not interfere with the present study because patients were randomized to either coumarin derivates or acetylsalysilic acid. Thus, the possible benefit of acetylsalysilic acid medication was equal in both groups. Moreover, our analyses did not reveal an influence of anticoagulant medication on primary graft patency.

Our results suggest that HBD is an acceptable alternative for HUV in femoro-popliteal bypass surgery. There is no reason to assume that a significant difference in primary or secondary patency exists between grafts. HUV grafts did not suffer from higher early failure rates than HBD grafts.

Femoro-popliteal bypass surgery cannot be performed with one single, suitable graft for every situation. The choice of an arterial substitute depends upon many factors.[30] Superficial femoral artery disease thus presents a complex challenge for therapy while at the same time, the surgical armamentarium is rapidly expanding.[31] Sophisticated treatment options, including endovascular techniques, are still being refined but until endovascular techniques have been subjected to rigorous comparison with conventional bypass surgery, bypass surgery will continue to have an important role in vascular surgery.

Acknowledgements

Trial Participants:

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5. Den Bosch, Jeroen Bosch Hospital: J. Wever, MD

References

1 Berglund J, Bjorck M, Elfstrom J. Long-term results of above knee femoro-popliteal bypass depend on indication for surgery and graft-material. *Eur J Vasc Endovasc Surg* 2005;**29**:412–418.
2 Gisbertz SS, Hissink RJ, de Vries JP, Moll FL. Future perspectives in the treatment of femoro-popliteal arterial occlusions. *J Cardiovasc Surg (Torino)* 2005;**46**:371–384.
3 Johnson WC, Lee KK. A comparative evaluation of polytetrafluoroethylene, umbilical vein, and saphenous vein bypass grafts for femoral-popliteal above-knee revascularization: a prospective randomized Department of Veterans Affairs cooperative study. *J Vasc Surg* 2000;**32**:268–277.
4 Mamode N, Scott RN. Graft type for femoro-popliteal bypass surgery. *Cochrane Database Syst Rev* 1999, Issue 2. Art. No.: CD001487. doi:10.1002/14651858.CD001487.
5 Klinkert P, Post PN, Breslau PJ, van Bockel JH. Saphenous vein versus PTFE for above-knee femoropopliteal bypass. A review of the literature. *Eur J Vasc Endovasc Surg* 2004;**27**:357–362.
6 Dormandy JA, Rutherford RB. Management of peripheral arterial disease (PAD). TASC Working Group. TransAtlantic Inter-Society Consensus (TASC). *J Vasc Surg* 2000;**31**:S1–S296.
7 Devine C, Hons B, McCollum C. Heparin-bonded Dacron or polytetrafluoroethylene for femoropolpiteal bypass grafting: a multicenter trial. *J Vasc Surg* 2001;**33**:533–539.
8 Aalders GJ, van Vroonhoven TJ. Polytetrafluoroethylene versus human umbilical vein in above-knee femoropopliteal bypass: six-year results of a randomized clinical trial. *J Vasc Surg* 1992; **16**:816–823.
9 Parker HJ, Fell G, Devine TJ, King RB. Femoropopliteal bypass using autogenous vein and modified human umbilical vein. A comparative study. *J Cardiovasc Surg (Torino)* 1988;**29**:727–732.
10 Devine C, McCollum C. Heparin-bonded Dacron or polytetrafluorethylene for femoropopliteal bypass: five-year results of a prospective randomized multicenter clinical trial. *J Vasc Surg* 2004;**40**(5):924–931.
11 Abbott WM, Green RM, Matsumoto T, Wheeler JR, Miller N, Veith FJ *et al*. Prosthetic above-knee femoropopliteal bypass grafting: results of a multicenter randomized prospective trial. Above-Knee Femoropopliteal Study Group. *J Vasc Surg* 1997;**25**:19–28.
12 Rutherford RB, Baker JD, Ernst C, Johnston KW, Porter JM, Ahn S *et al*. Recommended standards for reports dealing with lower extremity ischemia: revised version. *J Vasc Surg* 1997;**26**:517–538.
13 Dutch bypass oral anticoagulants or asprin (BOA) study group. Efficacy of oral anticoagulants compared with aspirin after infrainguinal bypass surgery (The Dutch Bypass Oral Anticoagulants or Aspirin Study): a randomised trial. *Lancet* 2000;**29**(355): 346–351.
14 Scharn DM, Oyen WJ, Klemm PL, Verhofstad AA, van der Vliet JA. Thrombogenicity and related biological properties of heparin bonded collagen coated polyester and human umbilical vein prosthetic vascular grafts. *J Surg Res* 2006 Aug;**134**:182–189.
15 Budd JS, Brennan J, Beard JD, Warren H, Burton PR, Bell PR. Infraninguinal bypass surgery: factors determining late graft patency. *Br J Surg* 1990;**77**:1382–1387.
16 Rutherford RB, Jones DN, Bergentz S, Bergqvist D, Comerota AJ, Dardik H *et al*. Factors affecting the patency of infrainguinal bypass. *J Vasc Surg* 1988;**8**:236–246.
17 Dorffler-Melly J, Buller HR, Koopman MM, Prins MH. Antithrombotic agents for preventing thrombosis after infrainguinal arterial bypass surgery. *Cochrane Database Syst Rev* 2003;**4**: CD000536.
18 Lambert AW, Fox AD, Williams DJ, Horrocks M, Budd JS. Experience with heparin-bonded collagen-coated grafts for infrainguinal bypass. *Cardiovasc Surg* 1999;**7**:491–494.
19 Laflamme K, Roberge CJ, Labonté J, Pouliot S, D'Orleans-Juste P, Auger FA *et al*. Tissue-engineered human vascular media with a functional endothelin system. *Circulation* 2005;**111**: 459–464.
20 Dardik H, Wengerter K, Qin F, Pangilinan A, Silvestri F, Wolodiger F *et al*. Comparative decades of experience with glutaraldehyde-tanned human umbilical cord vein graft for lower limb revascularization: an analysis of 1275 cases. *J Vasc Surg* 2002;**35**:64–71.
21 Nakamura M, Sawada T. Numerical study on the flow of a non-Newtonian fluid through an axisymmetric stenosis. *J Biomech Eng* 1988;**110**:137–143.
22 Sumner DS. The hemodynamics and pathofysiology of arterial disease. In: Rutherford RB, ed. Vascular surgery. W.B. Saunders Company: Philadelphia.
23 Guyton JR, Rosenberg RD, Clowes AW, Karnovsky MJ. Inhibition of rat arterial smooth muscle cell proliferation by heparin. In vivo studies with anticoagulant and nonanticoagulant heparin. *Circ Res* 1980;**46**:625.
24 Lin PH, Chronos NA, Marijianowski MM, Chen C, Bush RL, Conklin B *et al*. Heparin-coated balloon-expandable stent reduces intimal hyperplasia in the iliac artery in baboons. *J Vasc Interv Radiol* 2003;**14**:603.
25 Serruys PW, Emanuelsson H, van der Giessen W, Lunn AC, Kiemeney F, Macaya C *et al*. Heparin-coated Palmaz–Schatz stents in human coronary arteries. Early outcome of the Benestent-II Pilot Study. *Circulation* 1996;**93**:412.
26 McCollum C, Kenchington G, Alexander C, Franks PJ, Greenhalgh RM. PTFE or HUV for femoro-popliteal bypass: a multi-centre trial. *Eur J Vasc Surg* 1991;**5**:435–443.
27 Klinkert P, Schepers A, Burger DH, van Bockel JH, Breslau PJ. Vein versus polytetrafluoroethylene in above-knee femoropopliteal bypass grafting: five-year results of a randomized controlled trial. *J Vasc Surg* 2003;**37**:149–155.
28 Post S, Kraus T, Muller-Reinartz U, Weiss C, Kortmann H, Quentmeier A *et al*. Dacron vs. polytetrafluoroethylene grafts for femoropopliteal bypass: a prospective randomised multicentre trial. *Eur J Vasc Endovasc Surg* 2001;**22**:226–231.
29 Jensen LP, Lepantalo M, Fossdal JE, Roder OC, Jensen BS, Madsen MS *et al*. Dacron or PTFE for Above-knee Femoropopliteal Bypass. A Multicenter Randomised Study. *Eur J Vasc Endovasc Surg* 2007;**34**:44–49.
30 Online Surgical Dictionary – Vascular protheses. Available at: http://onlinesurgicaldictionary.com/ 2007.
31 Das T. Optimal therapeutic approaches to femoropopliteal artery intervention. *Catheter Cardiovasc Interv* 2004;**63**:21–30.

Accepted 7 August 2007
Available online 1 November 2007