Outcomes of complex femorodistal sequential autologous vein and biologic prosthesis composite bypass grafts

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Objective: **Femorodistal autologous vein bypass proves to be the preferred surgical therapy for long arterial occlusions and provides excellent early and long-term results in critical lower limb ischemia. Whenever vein length was insufficient and two distal outflow arteries were present, a sequential composite bypass configuration was chosen with human umbilical vein (HUV) or ovine collagen prosthesis (Omniflow II; Bio Nova International Pty Ltd, North Melbourne, Australia) as the proximal prosthetic part of the bypass. Single-center experience with this technique regarding limb salvage, graft function, secondary reinterventions, and biodegeneration is presented.**

Methods: **Between January 1998 and January 2009, 122 consecutive sequential composite bypass operations were performed on 116 patients for short-distance claudication (2), chronic critical ischemia (117), or acute ischemia (3) in the absence of sufficient autologous vein length. HUV was used in 90 cases and Omniflow II in 32 cases. Grafts were followed by duplex scan supplemented by angiography in case of recurrent ischemia with prospective documentation of follow-up data in a computerized vascular database. Retrospective analysis of graft patency, limb salvage, and aneurysmal degeneration of the biologic prosthesis was performed.**

Results: **Mean follow-up was 59 ± 45.5 months (range, 1-161 months). The 30-day mortality was 4.1%. Early postoperative complete or partial bypass thrombosis developed in 16% (20 cases) and required successful revision in 16 cases. During follow-up, 30 complete and 12 partial bypass occlusions occurred, necessitating selective surgical or interventional revision. Primary, primary assisted, and secondary patency rates and the limb salvage rate were 48%, 62%, 71%, and 87%, respectively, after 5 years and 26%, 46%, 54%, and 77%, respectively, after 10 years for all bypasses. Late biodegeneration of HUV prostheses was detected in four instances.**

Conclusions: **Late graft patency and limb salvage were good. These factors, combined with a tolerable rate of late aneurysmal degeneration, justify the use of biologic vascular conduits and autologous vein for complex femorodistal reconstructions. (J Vasc Surg 2014;60:1543-53.)**

In critical chronic lower limb ischemia, crural or pedal bypass surgery with autologous vein provides excellent long-term graft patency and limb salvage. Synthetic or biologic vascular prostheses must be considered as graft material when autologous vein is limited. Prosthetic femorodistal bypass still provides unsatisfactory outcome in terms of patency and limb salvage, although vein patches or cuffs for specific anastomotic configurations yield improved results.[1-3] In historical series, some authors advocated the sequential anastomotic composite technique to improve graft outflow, combining good-quality vein segments with a synthetic prosthetic inflow graft.[4-9] Recent studies with polytetrafluoroethylene (PTFE) prostheses showed promising results with respect to limb salvage and bypass patency even in reoperations.[10,11] Promising early results with complex human umbilical vein (HUV)-vein sequential bypasses have already been reported by our group.[12] Because the manufacture of HUV was suspended in 2006, the only biologic vascular conduit currently commercially available is the modified glutaraldehyde denatured ovine collagen prosthesis (Omniflow II; Bio Nova International Pty Ltd, North Melbourne, Australia). The results of a single-center consecutive series of sequential composite bypass (SCB) combining autologous vein with HUV or the Omniflow II prosthesis are analyzed.

METHODS

From a total of 2569 infrainguinal bypass operations documented in a computerized vascular database, all SCBs performed between January 1998 and January 2009 were identified. A bypass was classified as SCB when its proximal prosthetic part consisted of a biologic conduit and its distal part of autologous vein anastomosed to two or more distal recipient arteries (n = 118) or when, in a reoperation, a biologic conduit was

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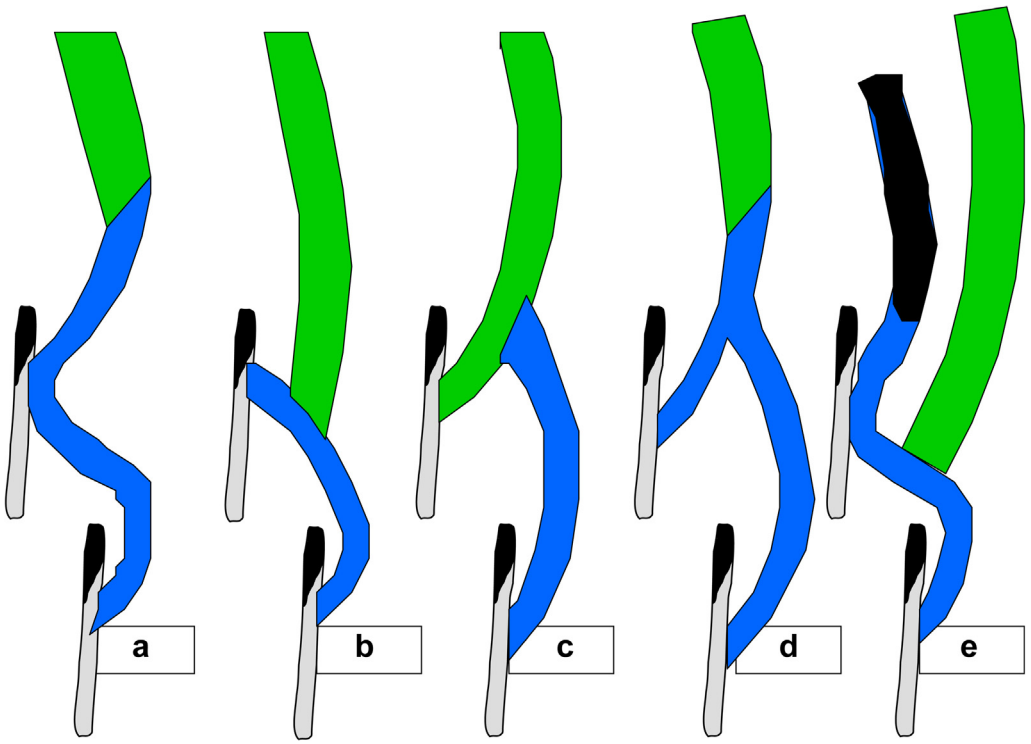


Fig 1. Configuration types of 122 sequential composite bypasses (SCBs) with a biologic prosthesis and autologous vein: **(a)** serial anastomoses, **(b)** bridge technique, **(c)** jump graft, **(d)** inverted Y graft with natural bifurcation, and **(e)** "secondary bridge."

anastomosed to a patent part of a failed previous sequential vein bypass with preservation of the original sequential outflow anastomoses (n = 4). Patient characteristics and perioperative and follow-up data were evaluated in a retrospective analysis.

Operative technique and graft configuration. Ipsilateral or contralateral great saphenous vein was considered the graft of first choice. Veins were assessed with preoperative vein mapping if needed. A vein diameter of 3 to 3.5 mm after vein distention was accepted. For as much suitable vein material as possible to be used, good-quality vein segments were spliced together if necessary. The composite configuration was chosen if the length of the harvested suitable vein was insufficient to reach the best outflow vessel. Patent popliteal or crural artery segments were integrated in the form of sequential anastomoses. The configuration of the SCB was chosen according to the length and configuration of the harvested vein and the site of the recipient vessels (Fig 1). When the bridge technique proposed by Deutsch was employed, the two distal recipient arteries were connected with the vein segment in an end-to-side technique and the prosthesis to the proximal part of this bridge in an end-to-side configuration[10] (Fig 1, *b*). In the case of reoperation for a failing previous sequential vein graft, the prosthesis was anastomosed to the intact distal interarterial part of the vein graft in the form of a "secondary bridge" (Fig 1, *e*). Vein valves were routinely destroyed with a modified Leather retrograde valvulotome (V. Mueller Care Fusion, San Diego, Calif).

Prostheses were rinsed, followed by instillation of undiluted heparin solution (25,000 IU or 50,000 IU) for 15 minutes. Distal anastomoses were constructed with polypropylene suture (7-0) after routine intravenous administration of 5000 IU heparin. The common femoral artery was preferred for the proximal anastomosis. The bioprosthesis was placed as gently as possible in a subfascial layer. A subcutaneous position was chosen only in the case of heavy scarification after previous bypass operations. Protamine was not used routinely.

Graft patency was confirmed intraoperatively with transit time flow measurement (CardioMed Medi-Stim, Oslo, Norway; Transonic Systems, Ithaca, NY). Postoperative duplex scan and angiography (magnetic resonance angiography, digital subtraction angiography, or computed tomography angiography) before discharge were employed to document patency and graft configuration. Intravenous administration of heparin was started postoperatively in combination with additional temporary dual antiplatelet medication (aspirin plus ticlopidine or aspirin plus clopidogrel). Oral anticoagulation with phenprocoumon (Marcumar) was the preferred long-term antithrombotic therapy and was started within a few days postoperatively and continued indefinitely at an international normalized

Table I. Patient demographics, risk factors, comorbidities, and previous procedures

	No.	*%*
Patients	116	
Mean age ± SD (range), years	74.1 ± 8.5 (53.9-92.7)	
Female	49	42.3
Male	67	57.7
Risk factors and comorbidities		
Hypertension	107	92.2
Hyperlipidemia	79	68.1
Diabetes mellitus	79	68.1
Nicotine abuse	44	37.9
Coronary artery disease	79	68.1
Cerebrovascular accident	14	12.0
End-stage renal disease	13	11.2
Previous ipsilateral vascular procedures		
Surgical revascularization[a]	37	30.3
Endovascular procedure	30	24.6
Inflow procedure	9	7.3

[a]One to four (mean, 1.35) failed surgical revascularization procedures.

Table II. Indications for sequential composite bypass (SCB) surgery

Indication	*No.*	*%*
Severe disabling claudication[a]	2	1.6
Critical limb ischemia	117	96.0
Rest pain	25	20.5
Necrosis or ulceration	92	75.5
Acute ischemia[b]	3	2.4
Total	122	100

[a]Very short distance claudication without critical ischemia.
[b]Acute thrombotic occlusion of popliteal aneurysm with impaired outflow in one case.

Table III. Bypass graft material and graft configurations

Prosthetic part of bypass	*No.*	*%*
HUV	90	73.7
Diameter 5 mm	45	
Diameter 6 mm	45	
Omniflow II	32	26.3
Diameter 5 mm	1	
Diameter 6 mm	31	
Venous part of bypass[a]		
Ipsilateral great saphenous vein	97	62.2
Contralateral great saphenous vein	12	7.7
Arm vein	35	22.3
Lesser saphenous vein	9	5.8
Superficial femoral vein	3	2.0
	156	100
Bypass configuration		
Serial sequential bypass technique	54	44.2
Bridge graft technique	50	41.0
Jump graft technique	9	7.4
Natural venous bifurcation	5	4.1
Secondary bridge graft technique[b]	4	3.3
	122	100

HUV, Human umbilical vein.
[a]A total number of 156 vein segments was used in 122 composite bypasses. Spliced vein grafts consisting of two or three segments were used in 30 bypasses for the distal autologous part of the composite bypass.
[b]Anastomosis of the prosthesis to a pre-existing patent distal part of a failing or failed sequential bypass.

ratio level of 2.5. Sole long-term antiplatelet medication was started only in the presence of contraindications to oral anticoagulation.

Patients were enrolled into an indefinite follow-up scheme with angiologic visits after 3, 6, 12, 18, and 24 months with annual repetitions thereafter. The complete graft length was scanned with duplex ultrasound at each visit with a linear probe by use of a corrected Doppler angle for stenoses or dilation. Significant high-grade stenosis was defined as a maximum peak systolic velocity of >3 m/s. Recommended standards for reports dealing with lower extremity ischemia were applied.[13] A bypass was regarded as failed in the case of complete occlusion of both the prosthetic and venous parts; in the case of complete occlusion of the prosthetic part despite preserved patency of the distal venous part with a patent interarterial connection; and with complete graft replacement or major amputation despite a patent prosthesis. A bypass was regarded as patent in the case of patency of the prosthetic part and unimpaired inflow into one of the two distal anastomoses with occlusion of one distal anastomosis. Follow-up data were prospectively entered into a computerized database (ACCESS 2000 for Windows) and retrospectively analyzed (SPSS 21.0 for Windows) with Kaplan-Meier survival test and log-rank test. The protocol and the informed consent were approved by the Institutional Review Board according to the regulations for clinical studies of the ethics committee of the state of Rhineland-Palatinate, Germany.

RESULTS

Patients, risk factors, and indication for operation. During an 11-year period, 122 femorodistal SCBs were constructed in 116 patients in 120 lower limbs (four patients with bilateral operation and two repeated procedures with the same technique). Patient characteristics, risk factors, previous ipsilateral operations, interventions, and inflow procedures as well as indications for surgery are listed in Tables I and II.

HUV was used until September 2006, when its commercial distribution was discontinued. As of October 2006, the Omniflow II prosthesis was implanted instead. The serial sequential technique and the bridge graft technique were the preferentially used configurations. In 65.6% of the cases, the most distal anastomosis was located at the level of the distal calf or foot. Mean operative time was 260 ± 53 (range, 110-390) minutes. A subcutaneous position for the prosthesis was chosen in eight instances (6.5%). The major part of the vein was tunneled subcutaneously in 36 instances (30%). Graft material, bypass configurations, and locations of arterial and composite anastomoses are listed in Tables III and IV.

Perioperative (30-day) outcomes. The 30-day mortality was 4.1% (five patients). Early postoperative partial or

Table IV. Location of bypass anastomoses

	No.	*%*
Proximal anastomosis		
Common femoral	100	82.0
Inflow bypass	2	1.6
Profunda femoris	1	0.8
Superficial femoral	18	14.8
Popliteal	1	0.8
Composite anastomosis		
Middle thigh	4	3.3
Distal thigh	24	19.7
Proximal calf	69	56.5
Distal calf	25	20.5
First sequential anastomosis	118	
Popliteal artery (below knee in 42 cases)	51	43.2
Proximal portion of tibial artery	24	20.3
Middle and distal portion of tibial artery	43	36.5
Second sequential anastomosis[a]	119	
Proximal and middle portion of tibial artery	39	32.8
Distal portion of tibial artery	28	23.5
Pedal artery	52	43.7
Previous sequential vein graft[b]	4	3.3

[a]Three distal anastomoses in one patient.
[b]Secondary bridge with intercrural connection.

Table V. Early complications and patient outcome

Postoperative (30-day) complications in 122 operations	*No.*	*%*
Death (ischemic heart failure, stroke, sepsis)	5	4.1
Myocardial infarction, cardiac failure, arrhythmia	14	11.5
Stroke, transient ischemic attack	4	3.2
Respiratory failure, pneumonia	5	4.1
Renal failure (reversible)	2	1.6
Sepsis, systemic inflammatory signs	7	5.7
Delirium	11	9.0
Others	3	2.5
Combined mortality and morbidity[a]	30	24.6
Hematoma (surgical revision)	9 (4)	7.3
Wound infection or delayed wound healing	24	19.6
Prosthetic graft infection	3	2.5
Major amputation	3	2.5
Minor amputation	28	23.0
Late patient outcome: mean follow-up, 59 ± 45.4 months (1-161 months)		
Death (cardiovascular, tumor)	83	71.5
5-year survival (Kaplan-Meier)		48
Major amputation during follow-up	13	

[a]Forty-six severe systemic vascular and nonvascular complications in 30 patients.

complete bypass thrombosis occurred in 20 bypasses (16.4%). Despite occlusion of the most distal anastomosis in one case, conservative treatment was chosen because of sufficient foot perfusion. Surgical revision was initiated in 17 cases and restored patency in all but one instance that necessitated early major amputation. Ten of the successfully revised reconstructions failed during follow-up after a median of 19.5 months. Early postoperative infection of the prosthesis occurred in two HUV grafts and one Omniflow II prosthesis. Two limbs underwent early major amputation without graft revision (Table V).

Late outcome. One patient was lost to follow-up and 48 patients (41%) could be followed up for more than 60 months. The 5- and 10-year survival was 45.1% and 16.6% for men and 51.0% and 33.3% for women, with a better survival for women ($P = .045$) (Fig 2). During later follow-up, 13 patients were not able to attend further scheduled duplex surveillance because of deterioration of their general state of health. However, information about the status of the limb that was operated on was obtained from the attending general practitioner.

One additional bypass infection of an HUV was detected 3 months after surgery and treated by successful partial graft replacement.

Failure of the prosthetic part with preserved patency of both distal anastomoses was found in five cases. Late occlusion of one of the distal anastomoses with preserved patency of the biologic prosthesis was noted in 18 cases (15%), in three cases the first distal anastomosis and in 15 the most distal anastomosis. Subsequent complete bypass failure developed in 33% an average of 34 (3-84) months after detection of the partial anastomotic occlusion.

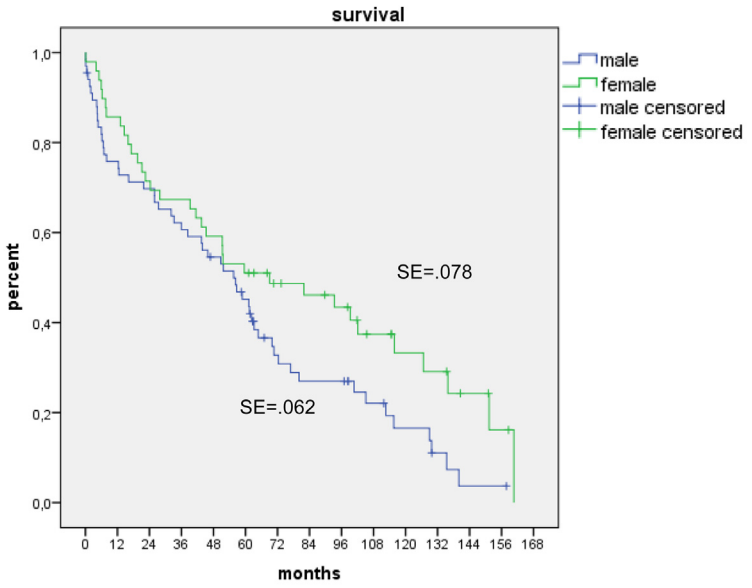
All in all, 35 bypasses (28.0%) failed. Asymptomatic occlusion without any further need for intervention or amputation was diagnosed at the time of routine duplex scan in eight grafts (6.5%). All other patients presented with recurrent ischemia. Fourteen grafts underwent single or multiple revisions to restore patency, but durable patency could be achieved only in five grafts. Seven patients underwent a repeated bypass operation.

Repetitive duplex imaging according to the protocol was available for 114 grafts (93%). It unmasked significant stenotic lesions in 21 (17.2%) patent grafts, in most instances at the anastomoses or in the venous part of the bypass after a mean of 45 months (3-158 months). These lesions required 28 additional interventions or operations to maintain graft patency, leading to durable bypass function in 19 cases even in very old grafts (Table VI and Fig 3).

Duplex examinations detected aneurysmal dilation of the prosthetic bypass component in four HUV grafts (4.4%) after 114, 113, 101, and 95 months, respectively, in one case combined with a graft stenosis. After a limited follow-up, no aneurysmal changes have been detected in Omniflow II prostheses up to now.

During follow-up, another 14 major amputations (12 above knee) were necessary, in one instance despite graft patency (Table VI).

Primary, primary assisted, and secondary patency rates and the limb salvage rate for HUV sequential bypasses were 49%, 66%, 74%, and 87%, respectively, after 5 years and 26%, 49%, 56%, and 77%, respectively, after 10 years. Primary, primary assisted, and secondary patency rates and the limb salvage rate for Omniflow II sequential bypasses were 45%, 50%, 62%, and 85% after 4 years (Figs 4 to 6). There was a trend suggesting a better secondary patency for the HUV grafts within the first 48 postoperative months ($P = .09$). Bypass patency and limb salvage were not influenced by the location of either the composite



Months	0	12	24	36	48	60	72	84	96	108	120	132	144	156
At risk male	67	50	46	40	35	28	17	14	14	9	6	3	1	1
SE male		.053	.057	.060	.061	.062	.060	.058	.058	.057	.054	.048	.034	.034
At risk female	49	42	35	33	29	25	20	18	16	11	8	7	4	2
SE female		.050	.065	.067	.070	.071	.072	.072	.073	.074	.077	.078	.078	.084

Fig 2. Survival of 67 men and 49 women operated on with human umbilical vein (HUV)—vein and Omniflow II—vein sequential composite bypasses (SCBs). *SE,* Standard error.

anastomosis (thigh, proximal or distal calf) or the most distal bypass anastomosis (proximal and middle calf or distal calf and foot; $P = .46$ and $P = .74$). Limb salvage was not associated with the type of prosthesis used ($P = .56$). No significant difference for secondary patency and limb salvage was found for serial sequential anastomoses or the bridge technique ($P = .22$ and $P = .95$). However, the bridge technique showed significantly better results for primary patency ($P = .03$).

Anticoagulation. Long-term oral anticoagulation with phenprocoumon (Marcumar) was regarded as the optimal anticoagulation and initiated in 104 instances (85%). It was not started in 18 cases because of perioperative death (five), poor compliance and poor general status, end-stage renal insufficiency, compliance concerns with age older than 90 years, or early bypass occlusion with amputation. Four of the remaining 13 bypasses under early antiplatelet therapy failed, with the consequence of amputation. Bleeding complications after oral anticoagulation during follow-up were noted in 12%, predominantly minor bleedings or gastrointestinal bleeding, and led to a change in the medication to antiplatelets. Oral anticoagulation was subsequently discontinued in a further 16% of cases, generally because of poor compliance or new diagnosis of a malignant tumor. In three of these instances, the discontinuation of oral anticoagulation without sufficient alternative antithrombotic medication caused occlusion of the complete bypass and major amputation without evidence of previous bypass stenosis.

DISCUSSION

Autologous vein should be used for all infrainguinal bypass reconstructions whenever possible.[14,15] However, there is a substantial need for small-diameter vascular prostheses in case of insufficient vein. One concept for improvement of long-term bypass graft patency is based on reduction of distal outflow resistance. The concept of sequential anastomoses was promoted 30 years ago.[4-6] It was based on Jarrett's experimental work, which showed a significant increase of the flow rate by integration of a second arterial outflow.[16] Preserved partial patency in case of later occlusion of the distal portion of the reconstruction was reported to possibly reduce the rate of severe recurrent ischemia.[7] The most frequently described sequential bypass technique is the jump graft technique with the prosthetic anastomosis at the popliteal artery and a distal extension with autologous vein originating from the synthetic graft. Promising early primary patency rates between 35% and 64% with a limb salvage rate of 64% to 84% were reported for this technique.[11,17-20] Oppat found a poor patency for PTFE jump grafts of only 20% after 5 years associated with a high amputation rate in case of graft failure.[19] This poor limb prognosis is confirmed by our results, which indicate a high risk of major amputation on failure of the

Table VI. Early and late graft function and limb salvage in 122 complex sequential bypass grafts: modes of treatment and success

Early graft failure (<30 days)	*No.*	*Grafts affected, %*	*Patency restored*	*Patency not restored*	*Late failure despite initial success*
Complete graft occlusion or intraluminal thrombus with occlusion of only prosthetic part or one distal anastomosis	20	16.4	16	4	8
Occlusion of most distal anastomosis →conservative treatment	1				1
Operative revision performed	17		16	1	9
Thrombectomy alone	7		6	1	4
Thrombectomy, additional AV fistula distal anastomosis	2		2	0	1
Thrombectomy, patch angioplasty distal anastomosis	1		1	0	1
Thrombectomy, graft extension to tibial artery	2		2	0	2
Thrombectomy with partial graft replacement	4		4	0	1
Partial graft replacement only (new short vein segment)	1		1	0	0
Failed revision → major amputation	1				
Major amputation without revision	2				
Early prosthetic graft infection (2 HUV, 1 Omniflow II)	3	2.4			

Graft failures and interventions during follow-up (>30 days)	*No.*	*Grafts affected, %*	*Patency maintained or restored*	*Patency not restored*	*Late failure despite initial success*
Bypass occlusion	35	28.7	9	26	4
Conservative treatment with sufficient perfusion	8		0	8	0
Surgical or interventional treatment	14		10	4	5
New bypass	7		0	0	0
Major amputation	14				
Amputation after failed revision	4				
Amputation without graft revision	9				
Amputation with patent bypass	1				
Treatment to prevent failure of patent graft (duplex diagnosis of severe disease)	21	17.2	21	0	2
Patchplasty proximal anastomosis[a]	5		5	0	1
Patchplasty distal anastomosis	1		1	0	0
Patchplasty composite anastomosis	1		1	0	0
Patchplasty bypass	1		1	0	0
Partial replacement of venous part[b]	5		5	0	1
Partial replacement for localized infection	1		1	0	0
Bypass graft extension	2		2	0	0
PTA bypass (stent)	3 (1)		3	0	0
PTA distal anastomosis	1		1	0	0
Multiple graft revisions (PTA; partial replacement)	1		1	0	0

AV, Arteriovenous; *HUV,* human umbilical vein; *PTA,* percutaneous transluminal angioplasty.
[a]One late bypass thrombosis with revision and amputation.
[b]One later complete bypass thrombosis with new bypass.

complete bypass. One of the reasons for this high late failure rate might be explained by the fact that patency of the distal venous part in jump grafts is completely dependent on a patent prosthetic inflow. Therefore, Roddy suggested a patent artery distal to the prosthetic anastomosis as the origin for the venous bypass part to preserve the vein graft patency in case of a proximal prosthetic failure.[20] Bastounis reported favorable results with a 5-year patency of 59% and a limb salvage rate of 80% for the serial PTFE composite bypass, which are similar to the findings in our series.[21] The most recent results for sequential PTFE bypass were provided

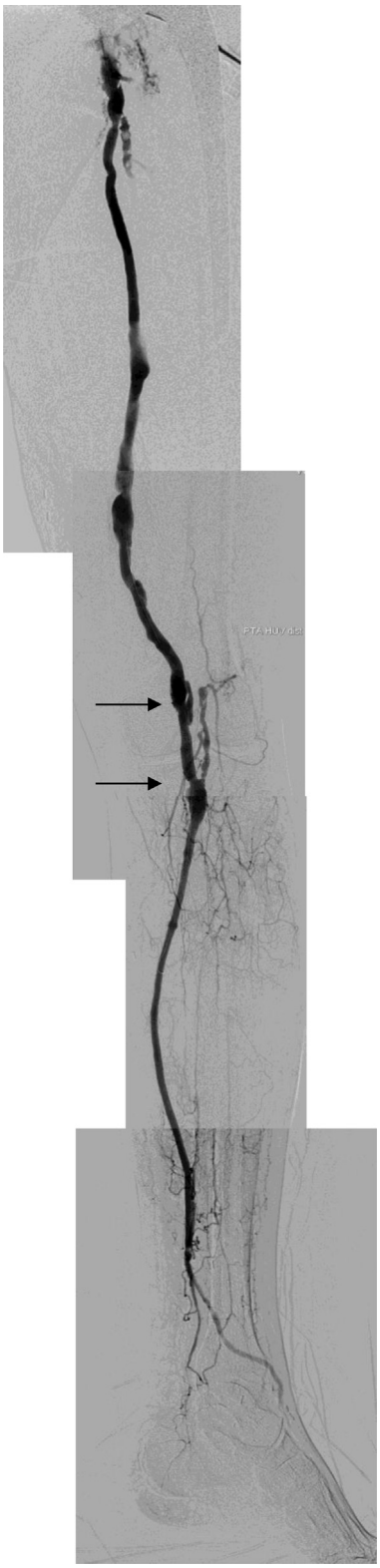


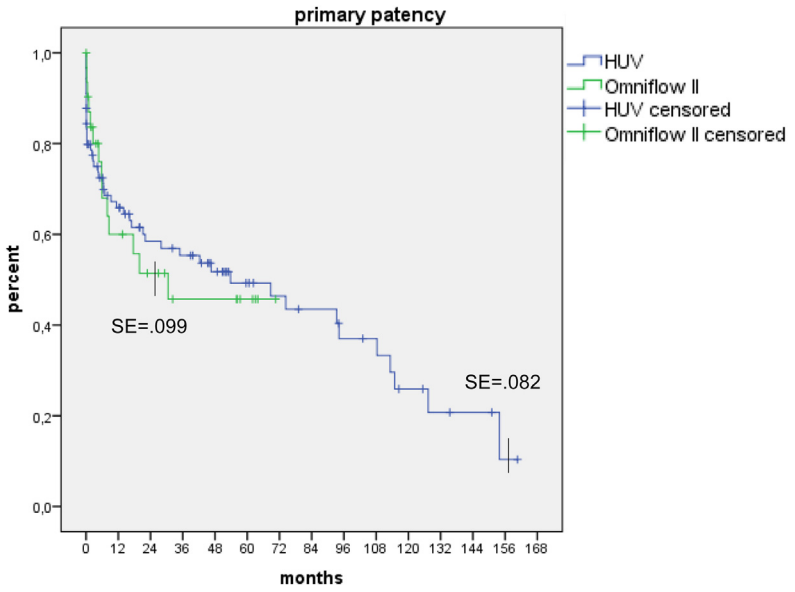
Fig 3. Sequential composite bypass (SCB) with human umbilical vein (HUV) and greater saphenous vein (bridge technique with three distal anastomoses: popliteal artery, posterior tibial artery, and dorsalis pedis artery) 158 months postoperatively. Note the aneurysmal degeneration of the distal part of the HUV with implanted self-expandable stent in a stenotic HUV segment (*arrows*). Patency of all distal anastomoses is unimpaired. (Reproduced with permission of Peter von Flotow, MD, Department of Angiology, Westpfalz Klinikum Kusel, Germany.)

by Gargiulo, who presented a favorable 5-year primary patency rate of 65% and a 4-year limb salvage rate of 85% with the Deutsch technique.[10,22] He also emphasized the option of a reoperation with use of the preserved venous outflow for a new prosthetic graft anastomosis.[22] The bridge technique seems to have the advantage that a complex revascularization is possible even if only short residual saphenous vein or an unusual vein like the superficial femoral vein is available. The technique is easy as all anastomoses are end to side, and the course of the prosthesis can be controlled easily. Except for the jump graft technique and the natural bifurcation, a preserved patency of the distal intercrural venous part is possible and may be regarded as a distinct advantage of sequential bypass configurations. This preserved patent vein segment can be used for a repeated procedure.[8] We found this phenomenon in five cases. In two patients, this patent vein segment could be chosen for a proximal prosthetic extension. In three patients, the leg remained viable without further intervention. This might be explained by a slightly improved foot perfusion through the preserved distal interarterial connection. For this reason, the jump graft and natural bifurcation technique should not be used preferentially; in the case of failure, the complete reconstruction will be occluded.

An overview of clinical series with the respective results is provided in Table VII.[9-12,17-24]

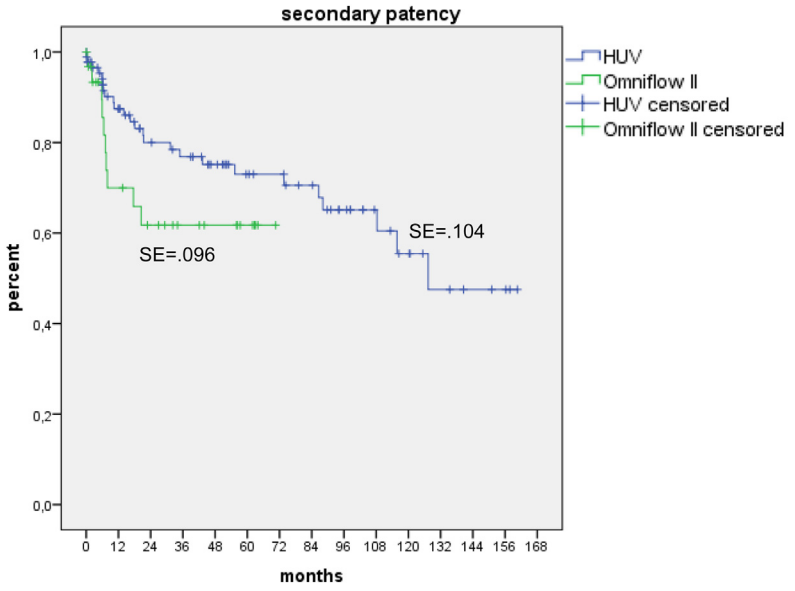
Our policy to use a biologic prosthesis in complex femorodistal bypass surgery was founded on confirmed superior patency for HUV compared with PTFE in above-knee femoropopliteal bypass in historical randomized trials.[25] In addition, excellent late results for above- and below-knee bypasses were reported by Dardik as well as by our group with a tolerable rate of late aneurysmal degeneration.[26,27] Our early results for sequential HUV composite bypass with a 4-year secondary patency of 67% and a limb salvage rate of 88% were promising.[12]

Having had such positive experience with the HUV, we decided to use the ovine collagen Omniflow II prosthesis as a substitute for the HUV when it became unavailable because it exhibits similar handling and preparation features. Although the Omniflow II prosthesis has been in clinical use for three decades, only sparse information about clinical results is available. Excellent early 3-year patency of 92% for above-knee bypass was reported in patients with intermittent claudication, but these results may reflect a selection bias of patients with excellent distal outflow.[28] An Austrian group reported on more than 270 ovine collagen grafts implanted mostly for limb salvage



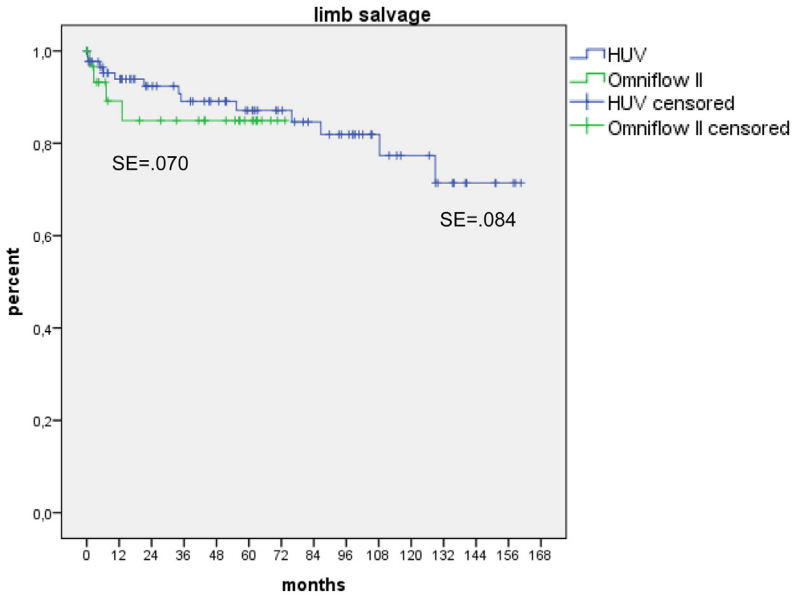
Months	0	12	24	36	48	60	72	84	96	108	120	132	144	156
At risk HUV	90	49	38	35	27	18	16	14	11	10	6	4	3	1
SE HUV		.052	.056	.057	.059	.061	.064	.066	.070	.072	.073	.074	.082	.082
At risk Omni	32	15	11	7	7	4	0							
SE Omni		.095	.099	.103	.103	.103								

Fig 4. Primary patency in 90 human umbilical vein (*HUV*)–vein and 32 Omniflow II–vein sequential composite bypasses (SCBs). *SE*, Standard error.



Months	0	12	24	36	48	60	72	84	96	108	120	132	144	156
At risk HUV	90	64	52	48	41	33	31	27	20	14	10	6	4	2
SE HUV		.037	.047	.050	.052	.054	.054	.058	.065	.075	.084	.103	.104	.104
At risk Omni	32	18	14	11	8	5	0							
SE Omni		.089	.096	.096	.096	.096								

Fig 5. Secondary patency in 90 human umbilical vein (*HUV*)–vein and 32 Omniflow II–vein sequential composite bypasses (SCBs). *SE*, Standard error.



Months	0	12	24	36	48	60	72	84	96	108	120	132	144	156
At risk HUV	89	71	59	54	49	42	36	31	27	18	14	10	5	3
SE HUV		.026	.030	.037	.037	.041	.041	.047	.053	.067	.067	.084	.084	.084
At risk Omni	31	21	19	17	14	9	0							
SE Omni		.059	.070	.070	.070	.070								

Fig 6. Limb salvage in 120 limbs operated on with human umbilical vein (*HUV*)—vein and Omniflow II—vein sequential composite bypasses (SCBs). *SE*, Standard error.

with patency rates of 46% to 69% for below-knee popliteal bypasses and rather disappointing results for crural reconstructions with direct anastomosis. However, the authors classified the results as superior to those obtained with their PTFE prosthetic bypasses.[29,30] They found no graft infections and a very low rate of aneurysmal degeneration.

Risk of subsequent amputation. Previous series have stressed the fact that once such a complex reconstruction fails, the risk of subsequent limb loss is high.[19] We believe that long-term duplex scan surveillance may detect a significant number of stenotic lesions that threaten graft patency. In our series, an individualized approach with endovascular or surgical procedures helped avoid graft failure in the majority of these cases (19 of 21). Severe stenosis was detected even in relatively old grafts beyond a 120-month follow-up. For this reason, it is our policy that duplex scan surveillance for complex reconstructions should be lifelong, or at least as long as the patient is able to ambulate.

Problem of biodegradation. Historically, the rate of biodegeneration for the HUV was as high as 57% after 2 years.[31,32] The incidence of graft aneurysms decreased significantly for the more recent implants.[33] Our series of second-generation HUVs in the popliteal position identified a late aneurysm rate of 7% for grafts with a low intervention rate of 3.5%. Most of these degenerations were detected more than 5 years after implantation and did not cause recurrent limb ischemia.[27] More recent rates of biodegeneration for the ovine collagen prosthesis are not available, but it must be speculated that this may become an issue for grafts with a long-term patency. In our current series, four cases of biodegeneration in HUVs were found during late follow-up after a mean of 105 months, all of them having maintained bypass function. These findings reconfirm our position that a tendency to late graft degeneration may be tolerable in biologic grafts in favor of an excellent long-term function and preserved limb perfusion. Lifelong duplex scan surveillance seems necessary to correct patency-threatening changes in the bypass configuration.

Role of anticoagulation. As mentioned, we regarded indefinite oral anticoagulation as the optimum medical treatment for the complex bypass reconstructions. This strategy is supported by older data that found a better patency for vein bypasses, especially those regarded as at risk for failure.[34,35] Even more recent reports with PTFE in the distal crural position favor the use of oral anticoagulation to enhance patency.[36] On the other hand, oral anticoagulation can be difficult to maintain at the intended level, especially when compliance problems occur or the general physical status of the old patients deteriorates. This problem may be reflected by the fear of bleeding complications that may have influenced the decision of some attending general practitioners to discontinue oral anticoagulation and explains the rate of 16% for discontinuation of oral anticoagulation during later follow-up. In such

Table VII. Historical and actual data for sequential femorodistal bypass with small-caliber prostheses

Author	*Year*	*No. of bypasses*	*Prosthesis*	*Graft configuration*	*Popliteal artery included*	*At ankle or pedal level*	*Repeated procedure*	*Primary patency, %*	*Secondary patency, %*	*Limb salvage, %*
Verta	1982	54	PTFE	Jump graft	Yes	Yes	Unclear	Not given	72.4 (4 years)	78 (4 years)
Flinn	1984	30	PTFE	Jump graft	Yes	Unclear	Unclear	Not given	80 (2 years)	?
McCarthy	1992	67	PTFE	Jump graft	Yes	Yes	>50%	40 (4 years)	Not given	70 (4 years)
Chang	1995	55	PTFE	Serial anastomoses	Yes		75%	35 (8 years)	52 (8 years)	65 (8 years)
Alexander	1996	35	PTFE	Unclear	Yes	Unclear	Unclear	35 (2 years)		60 (2 years)
Bastounis	1999	21	PTFE	Serial anastomoses	No	Unclear	No	59 (5 years)	Unclear	80 (5 years)
Oppat	1999	102	PTFE	Jump graft	Yes	Unclear	Unclear	20 (7 years)	Unclear	Similar to patency
Deutsch	2001	45	PTFE	Venous bridge	No	Yes	62%	26 (4 years)	39 (4 years)	45 (4 years)
Roddy	2002	27	PTFE	Arterial origin of distal vein graft	Yes	Yes	>90%	64 (3 years)	64 (3 years)	88 (3 years)
Mahmood	2002	68	PTFE	Side-by-side anastomosis	Yes	Yes	49%	68 (2 years)	73 (2 years)	75 (2 years)
Neufang	2005	54	HUV	Serial anastomoses, 66% Venous bridge, 34%	44%	Yes	23%	53 (4 years)	67 (4 years)	88 (4 years)
Gargiulo	2010	25	PTFE	Venous bridge	88%	Unclear	64%	54 (5 years)		85 (4 years)
Neufang	2014	122	HUV Ovine collagen	Various configurations	43%	67%	30%	48 (5 years)	71 (5 years)	87 (5 years)

HUV, Human umbilical vein; *PTFE,* polytetrafluoroethylene.

situations, communication with the operating vascular department seems important for advice on how to best maintain a sufficient antithrombotic therapy and may possibly help avoid graft failure and amputation.

CONCLUSIONS

The reported patency and limb salvage rates for complex infrainguinal composite bypasses support the further use of this technique in appropriate cases. Lifelong duplex scan surveillance combined with patency-maintaining interventions is effective and leads to a favorable secondary patency and limb salvage. The use of biologic vascular prostheses as the inflow part of such constructions is associated with a durable bypass patency and an acceptable rate of biodegeneration and therefore seems to be justified. Further studies with this technique in patients with unsuitable veins are necessary. The risk of biodegeneration for the Omniflow II graft must be an object of ongoing investigation.

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