Focus on Surgical Technique

The Superficial Femoral-Popliteal Vein Graft: A Reliable Conduit for Large-Caliber Arterial and Venous Reconstructions

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ABSTRACT **Vascular surgeons are increasingly called upon to perform arterial reconstructions in patients who have unusable or absent saphenous veins forcing consideration of alternative conduits. Although prosthetic grafts have excellent performance when used as bypasses involving the aorta and its branches, there are clearly circumstances in which autogenous conduits are preferable. The superficial femoral popliteal vein (SFPV) has proven to be an outstanding alternative in these situations. Although the SFPV was originally used at our institution for the treatment of aortic graft infections, the success of reconstructions for this indication has led us to utilize the SFPV conduit in many other situations. The SFPV has proven to be superior to prosthetic grafts for infrainguinal limb salvage procedures and for hemodialysis access in certain situations. In addition, the SFPV appears to be the conduit of choice for use in infected fields of all types and for large caliber venous reconstructions. The purpose of this article is to review the use of the SFPV conduit in creation of the neoaortoiliac system (NAIS), update our results, and survey alternative uses for this versatile conduit. We also address the technical details of its harvest and implantation technique.**

Keywords **Superficial femoral-popliteal vein graft, aortic graft infection, autogenous graft**

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ADVANTAGES AND PROPERTIES OF SFPV GRAFTS

Size

Although the greater saphenous vein (GSV) is the most frequently used autogenous vein graft, this conduit is often too small for large-caliber arterial reconstructions. The superficial femoral popliteal vein (SFPV) graft is usually 7 to 12 mm in diameter. In our initial experience with the neoaortiliac system (NAIS), GSV grafts had a high failure rate when used to bypass aortoiliac segments. Although 64% of GSV grafts eventually required additional intervention for thrombosis or stenosis, none of SFPV grafts did.[1] Our data show that the SFPV is the autogenous conduit of choice in the aortoiliac position, and size match seems to be a key component of its success. In other revascularizations, notably brachiocephalic reconstructions, the size match with the common carotid, innominate, and proximal subclavian arteries also favors the SFPV over GSV.

Reduced Thrombogenicity

In comparison with prosthetic grafts, autogenous grafts with an endothelial surface are less prone to thrombotic occlusion. This property of autogenous grafts contributes to better long-term patency, decreases the risk of downstream embolization, and avoids the need for long-term anticoagulation.

Infection Resistance

Although in-line reconstructions using prosthetic grafts have been suggested for the treatment of prosthetic graft infection, the reinfection rate is reported to be as high as 50%.[2] In contrast, the SFPV conduit is resistant to infection. We have not limited the use of the NAIS reconstruction to patients with low virulence prosthetic biofilm infections. In fact, we have successfully utilized the SFPV in patients harboring polymicrobial infections, fungal sepsis, and feculent abscess cavities.[3]

Resistance to Aneurysmal Degeneration

We have followed over 200 SFPV reconsructions with serial duplex ultrasound over the last 12 years. None of the NAIS reconstructions at our institution have required reoperation or intervention for aneurysmal degeneration of the SFPV graft. We have revised one SFPV graft in a patient with a focal aneurysmal dilation at a valve sinus that we detected 55 months following a brachiocephalic SFPV reconstruction.

Adaptation

On serial duplex ultrasound examinations, we noted a small but significant decrease in lumen dimensions of SFPV grafts months to years after implantation. The mean lumen diameter at 6 months was 10.8 ± 1.1 mm compared with 7.8 ± 1.1 at 60 months ($p < 0.01$).[4] We attribute this to wall thickening that appears to stabilize over time. We have characterized "arterialization" in these vein grafts in an ongoing study that examines the pathologic changes occurring in SFPV graft biopsies taken variable times after implantation. Pre- and postimplant SFPV grafts were analyzed and compared with GSV graft controls. There were no significant baseline differences between GSV and SFPV grafts in wall thickness or composition. The GSV and SFPV grafts showed a greater than threefold increase in the thickness involving all three layers of the vessel wall in response to arterial implantation. However, there was a significantly higher elastin/collagen ratio in the media of SFPV grafts than in GSV grafts, and the histologic appearance of GSV grafts was strikingly more fibrotic than SFPV grafts. The relatively higher content of medial elastin in SFPV grafts suggests a compliance advantage and, perhaps, more resistance to aneurysmal degeneration.

Conduit Length

Santilli et al. have published a rigorous anatomic evaluation of the SFPV in response to concerns about significant morbidity following SFPV harvest.[5] They determined the average lengths of the superficial femoral vein and the popliteal vein, and the number and location of valves and collateral veins. Forty-four SFPVs were harvested from 39 cadavers. The mean vein length was 24.4 cm for the superficial femoral vein and 18.8 cm for the popliteal vein segments. Male segments were approximately 3.5 cm longer than female segments for both segments. By defining the anatomic "safe length" as the longest SFPV graft that could be harvested while still preserving one popliteal vein valve and one collateral branch, they found that the average "safe length" was 50 cm in men and 40 cm in women. They concluded that harvesting SFPV conduits of these lengths would be expected to result in minimal morbidity due to collateral flow from the patent popliteal vein to the common femoral vein through collateral circulation involving the profunda femoris vein.[5] In our experience, these lengths are sufficient for use in almost all SFPV reconstructions.

Minimal Venous Morbidity

Although concerns about venous hypertension have previously been expressed,[6] significant venous morbidity has been rare. Wells et al. at our insti-

tution evaluated a large number of patients undergoing SFPV harvests using venous physiologic testing and postoperative duplex examination.[7] Limbs from which the SFPV were harvested were compared with normal limbs in which the SFPV was present. There were no significant differences between SFPV harvest and nonharvest limbs using the CEAP classification system (**C**linical signs, **E**tiologic classification, **A**natomic distribution, **P**athophysiologic dysfunction).[8] There were also no differences in limb circumference at multiple levels. In 34% of patients having SFPV harvest, duplex ultrasonography demonstrated large (4 to 6 mm) direct venous collaterals between the residual popliteal vein and the profunda femoris vein, whereas the remaining patients had smaller, less direct collaterals. Although venous outflow obstruction was identified using plethysmography in 93% of the harvest limbs, this was mild and stable on serial follow-up with no tendency to worsen over time. Direct measurement of ambulatory venous pressure documented mild to moderate venous hypertension in most patients. Perhaps the most significant finding was the absence of venous valvular reflux on quantitative testing. Wells et al. postulated that the most likely mechanisms contributing to the lack of venous morbidity were the presence of collateral channels, maintenance of valvular competence in the remaining deep system and its collaterals, and the lack of progression of venous obstructive physiology in the harvested limbs. Others have reported minimal morbidity on late clinical follow-up as well.[9] Initial concerns existed about harvesting an SFPV segment from a limb in which the GSV has already been harvested; however, this does not consistently lead to postoperative morbidity. In the study by Wells et al. the presence or absence of the ipsilateral GSV did not affect clinical outcome.[7]

HARVEST TECHNIQUE

Preoperative Evaluation

All patients undergo preoperative venous duplex scanning of their lower extremities including evaluation of the common femoral vein, superficial femoral vein, profunda femoris vein, popliteal vein, and GSV. Veins are examined for the presence of acute and chronic thrombotic changes. Sclerotic or recanalized veins are not usable as conduits.[10] Most important, the size of the SFPV is determined from the popliteal vein to the junction of with the profunda femoris vein. Most range from 7 to 12 mm in diameter, and we have found that SFPVs less than 5 mm in diameter are usually unsatisfactory. The presence of superficial femoral vein duplications is encountered approximately in about 15% of patients and does not preclude use of the vein because one portion of the duplication are usually larger than the other. Occasionally, we have taken advantage of a duplicated segment for construction of a natural "Y" graft to major arterial branches when the clinical situation dictates (Fig. 1). The other anomaly detected is the presence of a dominant profunda venous drainage system with the superficial femoral vein

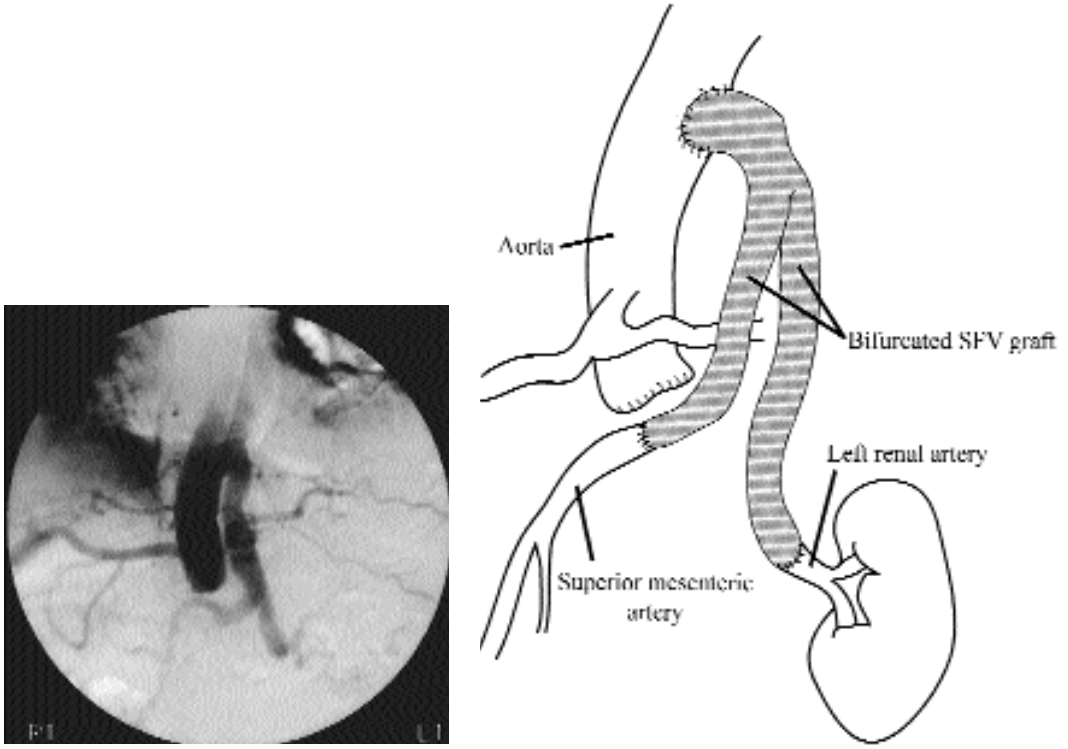


Fig. 1 **(A)** Descending thoracic to left renal artery and superior mesenteric artery using naturally occurring bifurcation in a superficial femoral-popliteal vein graft. **(B)** Diagram illustrating conformation and course of bypass graft. This patient had an infected thoracofemoral prosthetic bypass and underwent reconstruction using PTFE axillofemoral grafting and visceral-renal autogenous reconstruction with SFPV.

being diminutive, incomplete, or absent. Fortunately, this anomaly is present in only 7% of patients.[11] We have harvested the profunda femoris vein for NAIS operations in four patients, leaving a vestigial superficial femoral vein intact, and have not noted increased venous morbidity.

Exposure

Though this dissection may be accomplished expeditiously, a two-team approach is helpful for aortic reconstructions, utilizing one team on each side for dual vein harvests, or one team for SFPV harvests, while the second team completes the abdominal dissection. Every effort is made to maintain sterility of the harvest site by isolation of an infected groin wound from the thigh incision using iodine-impregnated plastic drapes. The circumferentially prepped lower extremity is flexed at the knee and externally rotated. Placement of a large soft roll under the proximal thigh facilitates the "frog-leg" positioning. A line is drawn from the anterior superior iliac spine to the ipsi-

lateral medial femoral condyle, approximating the course of the sartorius muscle. Dissection is carried along the lateral border of this muscle, preserving its predominately medial blood supply. This site is several centimeters lateral to the standard vertical femoral incision and aids in preventing cross-contamination when infected groin wounds are present. The sartorius is reflected medially to expose the adductor canal. The superficial femoral vein is usually found medial and deep to the superficial femoral artery in the proximal thigh. Care is taken to preserve major collateral branches of the superficial femoral and popliteal arteries. Branches of the SFPV are doubly ligated or suture ligated. The saphenous nerve, which may be intimately applied to the vascular structures within the canal, should be carefully preserved to prevent postoperative saphenous neuralgia. Proximally, the confluence of the superficial femoral and profunda femoris veins must be exposed.

The adductor hiatus is opened by dividing the tendinous insertion of the adductor magnus muscle, which causes no detectable postoperative abnormal lower extremity muscular function. The most tedious portion of the dissection is usually in the distal adductor canal region, where there are often multiple large branches that must be carefully ligated, and where the vein is usually in close apposition to the artery and aponeurosis of the adductor magnus. The distal extent of the dissection is determined by the length of conduit needed but can include the entire popliteal vein behind the knee.

Following completion of the dissection, antibiotic soaked gauze pads are placed within the wound and the wound is covered to minimize dessication of the vein as well as heat loss from the large open thigh wound. The vein is left in continuity while the remaining dissection is completed in the abdomen or elsewhere. Postoperatively, useful adjuncts in the prevention of deep venous thrombosis are the application of pneumatic compression hose along with low-dose heparin prophylaxis.

TECHNICAL DETAILS

Double Ligation of Branches

The importance of careful and secure ligation of the SFPV side branches cannot be overemphasized. The ligatures on these branches may be displaced when passing the large-caliber conduits down the restrictive retroperitoneal tunnels to the femoral sites if not securely ligated. We usually doubly ligate with silk ties all but the smallest of side branches. Suture ligatures are used for branches $\geq$ 3 mm in diameter.

Exclusion of Thin-Walled Areas

At major branch points along the SFPV, there may be a thinner area of the vein that usually includes the vein wall and the adjacent portion of the branch

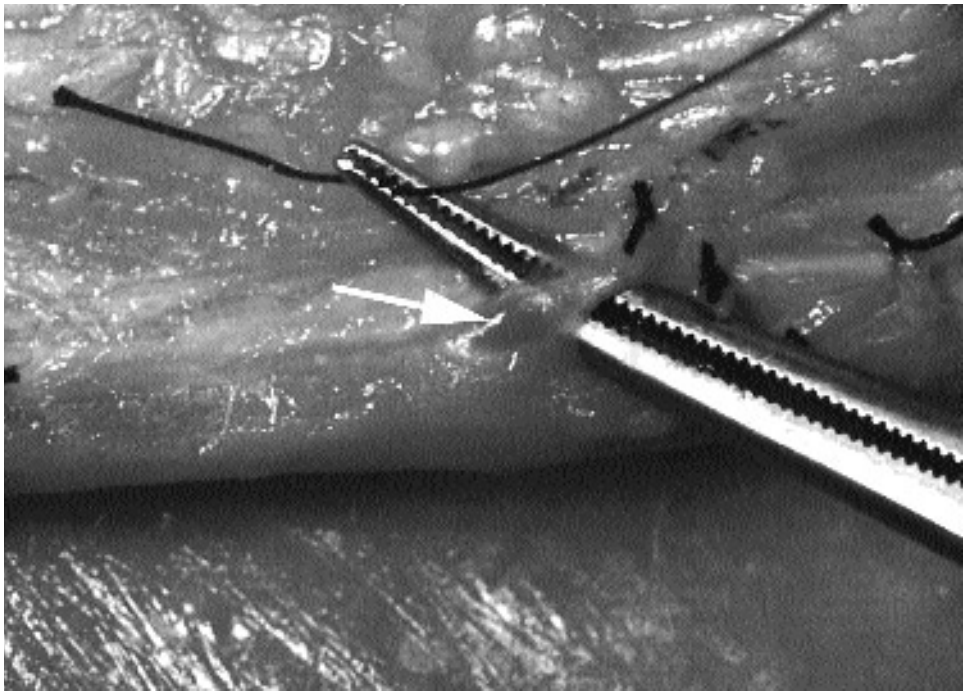


Fig. 2 Ligation of side branch. Note thin-walled area of the branch vein, which must be excluded during side-branch ligation (arrow).

(Fig. 2). It is important to incorporate this thin-walled area in the side branch tie to prevent annoying leakage during vein graft distension. This is counter to principles of GSV harvest, where ties close to the vein may constrict this narrower conduit.

Varicosities

Occasionally, varicosities are encountered along the SFPV (Fig. 3). These are thin-walled, weakened areas of the veins, and we exclude these sections from use in arterial reconstructions, even though this may require a separate veno-venous anastomosis.

Lysis of Valves

Valves are fractured by retrograde passage of a valvulotome so that the large proximal end may be comfortably anastomosed to the aortic stump in a nonreversed configuration. There are usually only three or four major valves within the long SFPV graft. Valves within 10 to 15 cm of the ends are easily visualized by everting the vein and transecting the valve leaflets under direct

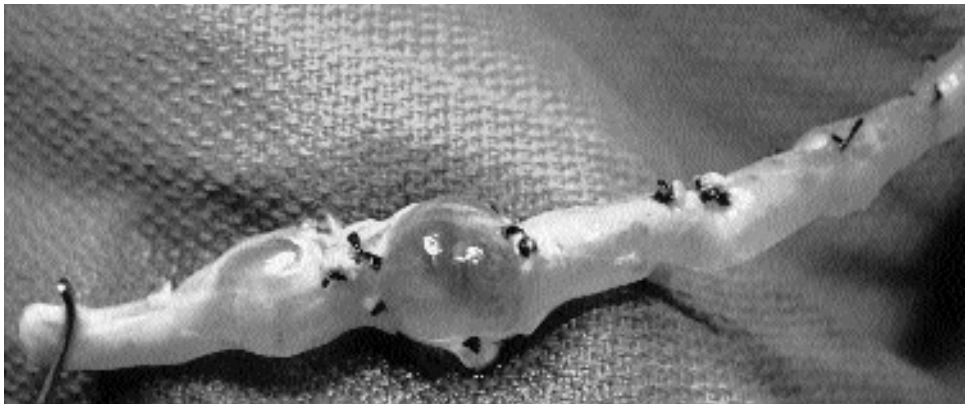


Fig. 3 Varicosities of superficial femoral vein. Fortunately rare, these are excluded by transection or separate veno-venostomy if necessary.

visualization. We have also used these conduits in a reversed fashion for brachiocephalic and visceral reconstructions.

Ligation Flush with Profunda Femoris Vein Junction

A critical point in preventing excessive venous hypertension is the preservation of the profunda femoris vein junction with the common femoral vein (Fig. 4). The superficial femoral vein is controlled with an atraumatic vascular clamp, transected, and then oversewn flush with fine prolene suture to effect a closure that results in a smooth, nonrestricting transition of the profunda into the common femoral vein. This maneuver also prevents the formation of a stump of superficial femoral vein that can serve as a nidus for thromboembolism.

Preservation in Cold Vein Solution

Immediately upon removal from the dissection bed, vein grafts are flushed and gently dilated with a 4°C solution consisting of Ringer's lactate (1 L), heparin (5000 U), albumin (25 g), and papaverine (60 mg). The grafts are stored in the same solution until ready for use.

Aortic Reconstruction Anastomosis

Although direct end-to-end anastomosis between SFPV grafts and aorta is almost always feasible, dilated aortic segments may require special technical considerations. Variations of proximal aortic anastomotic configurations are presented in Figure 5. If end-to-end anastomosis is not initially feasible due to a size discrepancy, we have utilized several techniques that ensure that the

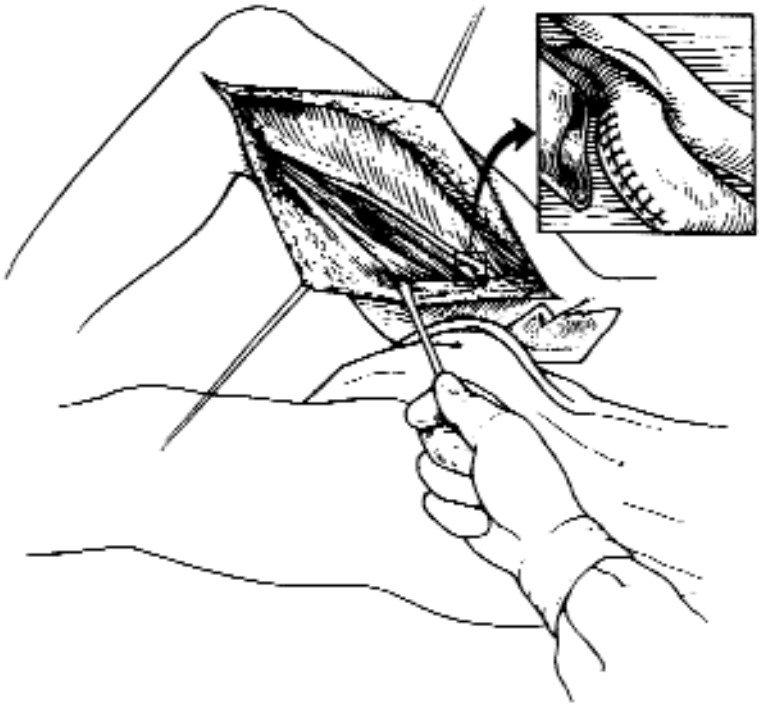


Fig. 4 Oversewing of superficial femoral vein-profunda femoris vein confluence creating smooth transition between profunda and common femoral vein. This avoids a blind-ending vein stump that may serve as a nidus for thrombus formation. (Reprinted with permission from the authors.)

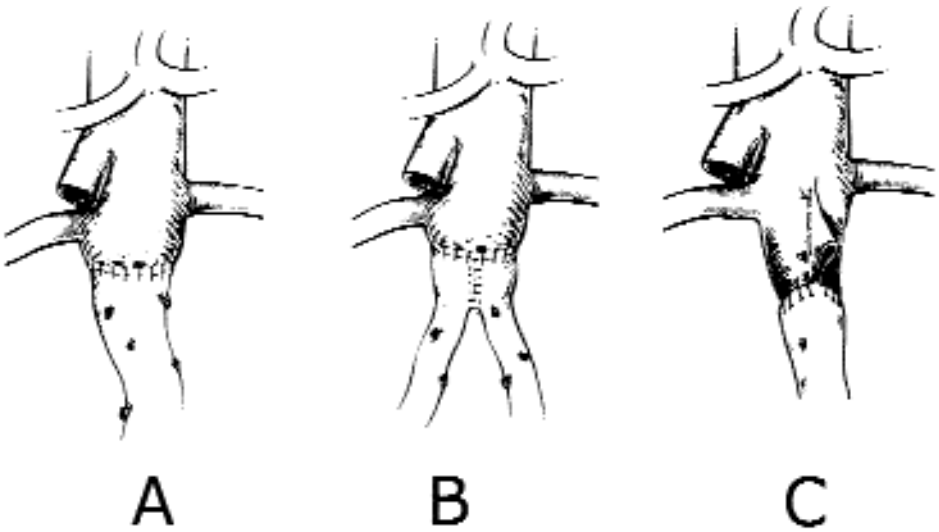


Fig. 5 Proximal aortic anastomotic configurations. **(A)** End-to-end anastomosis. **(B)** "Pantaloon SFPV" graft. **(C)** Plicated aorta for end-to-end anastomosis.

vein-aorta configuration is optimal. This involves either plicating a dilated distal aorta with mattress sutures to allow end-to-end anastomosis, partitioning a dilated aortic segment into two sections using mattress sutures, or creating a "pantaloon" graft by sewing two SFPVs together and then joining the common orifice to the aorta. Variations of distal anastomoses used in various NAIS reconstructions are demonstrated in Figure 6.

SFPV GRAFT SCENARIOS

Prosthetic Graft Infections

By far our most extensive experience with the SFPV conduit has been the NAIS reconstruction for the treatment of infected aortic grafts. We reported in situ replacement of the aortoiliac system with autogenous SFPVs for the treatment of prosthetic infection and other complex aortic problems in 1993.[1] The disadvantages of extraanatomic bypass include poor patency, the propensity for sudden thrombotic occlusion, the need for multiple revisions, the requirement for long-term anticoagulation therapy in many patients, and the high rate of amputation on long-term follow-up. In our experience, diffuse occlusive disease with poor distal runoff is frequently encountered in this population of patients. Approximately one-third of such patients will require major amputation within three years after extraanatomic bypass for infected aortic prostheses.[12] In addition to poor patency, the potential for infection of the prosthetic extraanatomic bypass and aortic stump blowout are limitations.[13,14]

Vein autograft replacements should theoretically result in superior patency. The unfavorable experience with GSV stimulated us to try SFPVs to replace infected aortoiliac/femoral prostheses, and our initial experience was favorable.[1] Shortly thereafter, success in this approach was also reported by a European group.[15] In both reports, a small number of patients were followed for limited periods of time. Long-term patency, as well as durability, remained uncertain. In addition, concerns about the potential for aneurysmal degeneration, acute disruption, limb swelling, and other venous morbidity could not be assessed.

In 1997, we reported an expanded series of 41 patients with longer follow-up. Aortoiliac/femoral reconstructions most often utilized bilateral SFPVs and were performed at the same time as excision of infected prostheses. There were no immediate operative deaths, and graft-related mortality was 7.3%, with these patients dying from multisystem organ failure in-hospital after 1 month. At least one-half of patients had significant perioperative morbidity, including amputation (5%), compartment syndrome (12%), lower extremity paralysis/paresis (7%), or major gastrointestinal complications. The most preventable complication was compartment syndrome, and this appeared to be associated with prolonged ischemia time (usually in patients

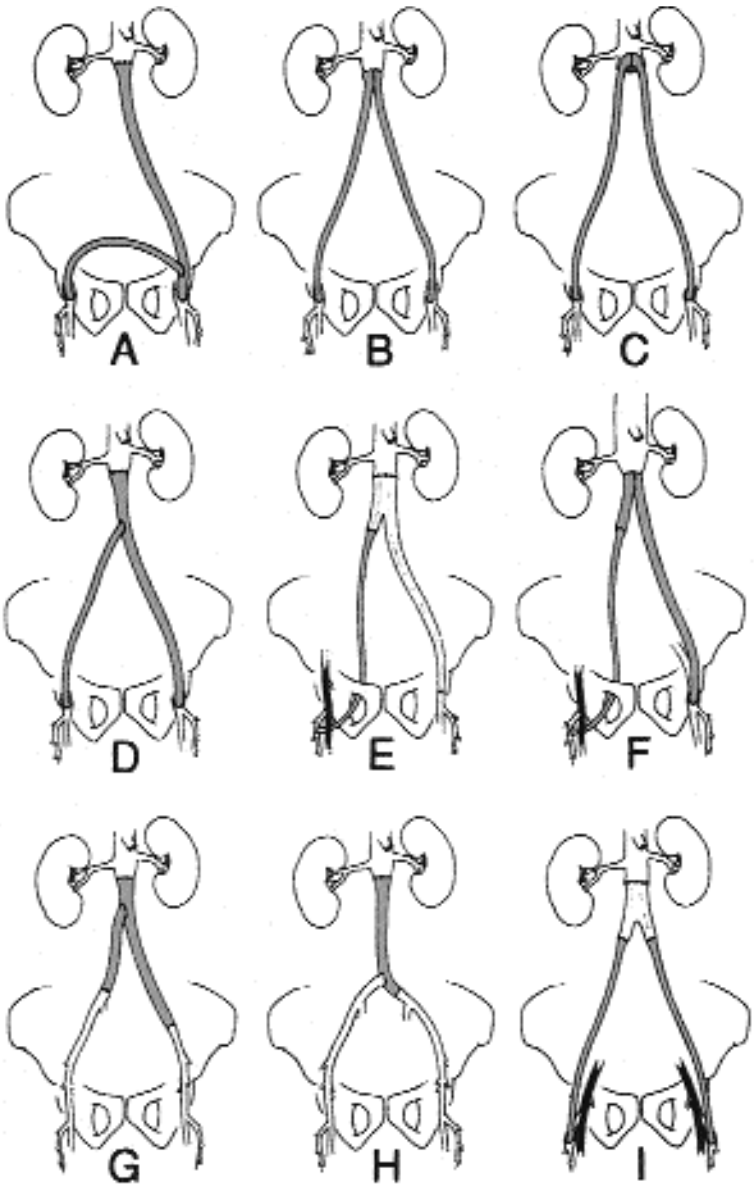


Fig. 6 Variations of NeoAortoIliac System grafts. **(A)** Aortofemoral bypass with femoral-femoral cross-over SFPV graft. **(B)** Bilateral aortofemoral bypass with proximal "pantaloon" anastomosis. **(C)** Bilateral aortofemoral bypass with dual end-to-side proximal anatomoses. **(D)** Unilateral aortofemoral with SFPV-femoral end-to-side graft. **(E)** Obturator bypass for unilateral prosthetic aortobifemoral limb infection. **(F)** Obturator bypass with contralateral aortofemoral bypass. **(G)** Aortobiiliac bypass. **(H)** Single SFPV aortoiliac anastomosis with implantation of contralateral iliac artery end-to-side. **(I)** Bilateral limb replacement in prosthetic aortobifemoral graft infection limited to the groins. (Reprinted with permission from the authors.)

with preoperative critical ischemia), need for adjunctive infrainguinal bypass, and simultaneous, ipsilateral harvest of both the SFPV and GSV. Currently we strongly consider prophylactic fasciotomies in patients with these risk factors. On long-term follow-up, primary patency was 86%, assisted/secondary patency 100%, and limb salvage 86%.

As our experience has increased, our center has become a source for referral of increasingly complex patients with aortic prosthetic infection. We recently reported a small series of patients with advanced infections in whom conventional extraanatomic bypass would be impossible because of infection and thrombosis of previously placed extraanatomic bypass, massive groin and/or thigh sepsis, or both.[3] These patients had prior attempts at either extraanatomic bypass or in situ prosthetic replacement after excision of infected aortic prostheses. NAIS reconstruction was a tertiary procedure in these patients and was the third or fourth major operation dealing with an aortic prosthetic infection in every case. Predictably, our results have been worse in this subgroup of patients with an in-hospital mortality and acute amputation rate three times that of our earlier reports. Despite the high mortality and morbidity rates among this disadvantaged group of patients, long-term outcomes have been good, with sustained patency, limb salvage, freedom from reinfection, and minimal lower extremity venous morbidity. There were two main conclusions from this experience: (1) NAIS reconstruction is an excellent option for patients with advanced, complex aortic infections in whom extraanatomic bypass is impossible and limb loss and/or death would be inevitable without revascularization; and (2) the results of NAIS for aortic prosthetic infection are much better when performed as a secondary rather than a tertiary procedure.[3]

The threefold variation in mortality in our own experience (with the highest mortality coming, unexpectedly, in our later experience) raises an important issue relative to reporting vascular prosthetic infections. A wide range of mortality incidence and other outcomes have been reported with multiple operative approaches. The advantages and disadvantages of each, along with mortality, major amputation, reinfection rate, and primary patency, are presented in Table 1. Because of the heterogeneity of patients and their varying severity of illness, differences in acute outcomes are more likely due to differences in patients rather than differences in operations. Severity of illness is dependent on extent and virulence of infection, severity of underlying occlusive disease, presence and types of medical comorbidities, types of initial aortic reconstruction, presence of additional prosthetic infrainguinal bypasses involved with infection, presence of an enteric erosion or fistulae, and performance of previous secondary or tertiary operations to treat primary aortic prosthetic infection. Unfortunately, these details are frequently lacking in many reports, making it difficult to determine the relative effectiveness of various approaches.

Table 1 Reconstruction Options Following Removal of Infected Aortic Grafts: Pooled Data from Contemporary Series Since 1985

	Reference	Patients (n)	% Mortality (Range)	% Major Amputation (Range)	% Aortic Disruption	% Re-infection	% Five-Year Patency	Primary Advantages	Disadvantages
Extra-anatomic Bypass	12,13,35 36,37,38, 39,40,41, 42,43,44, 45,46	551	20.5 (5.0–40.6)	13.4 (0–15.6)	8.5	11.4	61.8	Procedure can be staged. Less physiologic stress.	Poor patency, potential for reinfection and aortic stump blow-out. Thrombectomy, revision often required. Long-term anticoagulation.
In situ Superficial-Femoral-Popliteal-Vein Replacement	4,15,47	63	8.9 (6.7–9.8)	5.3 (4.9–6.7)	0	0	84	Autogenous reconstruction, resists infection. Low rate of secondary procedures to maintain patency.	Complex procedure. Long ischemia time.
In situ Allograft Replacement	48,49,50, 51	224	18.8 (8.3–24.0)	1.3 (0–3.0)	4.0	4.0	?	Expenditious procedure. No aortic stump.	Reinfection. Allograft deterioration. Availability issues.
In Situ Prosthetic Replacement	52,53,54, 55,56	77	14.3 (8.0–21.7)	0	0	15.3	?	Expeditious procedure. No aortic stump.	Reinfection rate high and unpredictable.

Our current experience includes more than 100 patients with aortic prosthetic infections. Continued excellent patency, limb salvage, and freedom from reintervention have been hallmarks of this experience. Microorganisms encountered are listed in Table 2. Polymicrobial infections have been present in one-quarter of the patients. SFPV grafts have resisted these infections, and there have been no acute vein ruptures. One severely immunosuppressed patient on steroids and Imuran was successfully treated for an aortic false aneurysm 8 months after operation. Two others developed fatal anastomotic false aneurysm rupture (iliac and femoral) more than 6 weeks after operation.

Although NAIS reconstruction is a successful option in these patients, extraanatomic bypass is still considered by some to be the procedure of choice.[13,14] Although we agree that extraanatomic bypass is a viable option in certain extremely high-risk patients unable to tolerate the NAIS reconstruction, autogenous vein reconstruction remains our primary choice in the treatment of prosthetic graft infections. We feel that reconstruction using SFPV grafts accomplishes all of the management goals of these challenging patients, namely eradication of infection, rapid healing of all wounds, minimal risk of reinfection, excellent long-term patency, low amputation rate, and minimal venous morbidity.

Mycotic Aneurysms

Three patients with mycotic aortic aneurysms were included in the original series of NAIS reconstructions.[1] We have treated an additional three

Table 2 Organisms Cultured from Patients Undergoing SFPV Reconstruction for Infected Grafts

Staphylococcus aureus
Staphylococcus aureus (methicillin-resistant)
Staphylococcus epidermidis
Pseudomonas aeruginosa
Bacteroides species
Klebsiella species
Escherichia coli
Candida albicans
Candida glabrata
Enterobacter cloacae
Propionibacterium acnes
Enterococcus faecalis
Enterobacter aerogenes
Streptococcus pyogenes
Acinetobacter species
Salmonella species
Mycobacterium tuberculosis

patients within the last 5 years with mycotic abdominal aortic aneurysms using SFPV (Fig. 7) with excellent results, including a patient with concomitant infected pancreatic necrosis.[16] Using autogenous tissue avoids complications inherent in extraanatomic bypass grafting and graft removal,[13] and

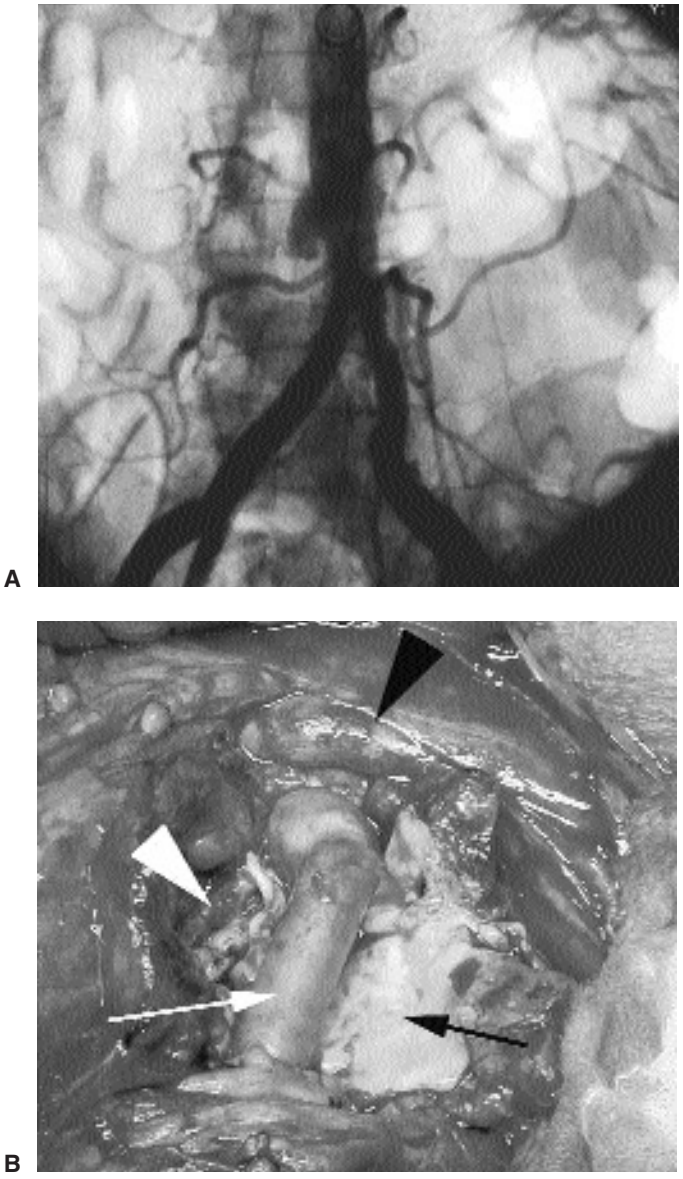


Fig. 7 **(A)** Arteriogram of 56-year-old male with a mycotic abdominal aortic aneurysm. **(B)** Repair using in-line SFV graft. Black arrowhead: renal vein; white arrowhead: debrided mycotic aneurysm sac; white arrow: SFV graft; black arrow: intact aortic wall.

prosthetic in situ reconstruction where reoperation rates of up to 63% for gram negative infections and 20% for gram positive infections have been reported.[17] Benjamin et al. recently reported their experience using SFPV reconstructions for mycotic aneurysms.[18] In a 2-year period, they resected eight mycotic aneurysms and performed a variety of SFPV reconstructions depending on the site of arterial infection. Six of these resulted from drug abuse and self-injection into the area of the artery. There were no deaths, and all grafts were open at a mean of 7.4 months of follow-up. There was no postoperative leg swelling and there were no septic complications. Based on this experience, the authors concluded that the "ideal bypass graft should be tunneled remotely, through uninfected tissue planes, and be of adequate caliber for direct reconstruction of the native artery involved. A bypass graft constructed of deep leg vein can accomplish all these goals with excellent limb salvage, low rates of re-infection, and low patient morbidity."[18]

Aortic Reconstruction for Occlusive Disease

Aortobifemoral bypass (AFB) with prosthetic is the gold standard for the surgical treatment of aortoiliac occlusive disease. Mortality for this operation at experienced centers is approximately 1 to 2%, and primary patency rates of 85 to 90% at 5 years are typically reported.[19] These favorable results, however, are not realized in some disadvantaged subgroups. Valentine et al. identified a cohort of 73 consecutive young patients less than 49 years old who were evaluated after aortoiliac reconstructions performed for occlusive disease.[20] At 24 months of follow-up, the rate of AFB femoral limb occlusion was 50% in patients with small aortic diameters ($\leq$ 1.8 cm) and only 10% in normal and large (> 1.8 cm) aortas ($p < 0.001$). The The risk factors of young age (premature atherosclerosis) and small aorta were powerful predictors of AFB failure. This unfavorable experience in these patients led us to consider alternative methods using SFPV grafts. A randomized, prospective clinical trial approved by the Institutional Review Board of the University of Texas Southwestern Medical Center is now ongoing at our institution that seeks to evaluate the outcome of primary NAIS versus prosthetic reconstructions for aortoiliac occlusive disease in young men and women (age $\leq$ 55 years) with small-diameter infrarenal aorta (for men: $\leq$ 19 mm, for women: $\leq$ 16 mm).

Femoral Popliteal Occlusive Disease

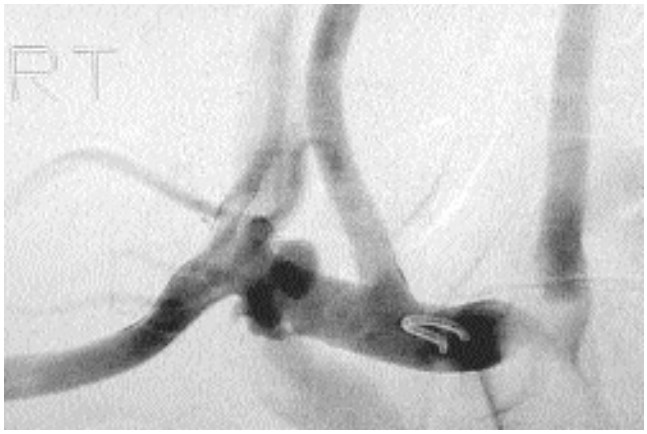
Schulman first reported using SFPV grafts for femoral-popliteal bypass procedures in 1981.[21] Schulman's group published further data in 1987 with 5-year primary and secondary patency rates of 82% and 90% in 97 limbs.[22] Wozniak et al. have recently reported an experience with composite polytetrafluoroethylene (PTFE) and superficial femoral vein grafts in 32 patients (20 men and 12 women) undergoing limb-salvage procedures.[23] The mean

length of superficial femoral vein removed was 13.2 cm. Postoperatively, patients underwent serial follow-up with ankle-brachial index measurements, color duplex ultrasound, and arteriography when necessary. During follow-up period of 48 months, the cumulative patency rate was 56.3 %, with 6 patients (18.7%) developing early bypass occlusion resulting in major amputations in 5 patients (15.6%). There were no perioperative deaths. In addition, there were no complications due to venous stasis from vein harvest. These results, though inferior to saphenous vein bypasses, are better than the reported cumulative patency rates of 12 to 37% with distal bypasses utilizing PTFE.[24,25] These bypasses may offer an alternative when more traditional vein conduits are unavailable.

We perform femoral below-knee bypass grafting in limb salvage situations utilizing full-length SFPV conduits when there are no other sources of usable vein. This comprises approximately 5 to 10% of patients undergoing femoral-popliteal bypass at out institution. We have limited experience in only two patients in using SPFV grafts for tibial bypass. Both of these were "desperation cases" when there were no other sources of vein and PTFE bypasses had failed. Despite the large size discrepancy, we have been surprised and gratified to note short-term (6- and 18-month) success.

Brachiocephalic Reconstruction

Revascularization of brachiocephalic arteries with prosthetic grafts offers excellent patency for the majority of reconstructions.[26,27] Synthetic grafts have been shown to be superior to vein grafts for carotid-subclavian bypass.[28] For complex brachiocephalic reconstructions, reoperative procedures, reconstructions for infection, and long bypasses, autogenous conduits may be preferable.[29,30] We have recently reviewed our experience with brachiocephalic arterial reconstructions utilizing SFPV as alternative conduits. The SFPV graft provides excellent size match for these reconstructions. Over a 6-year period, 71 patients underwent carotid, subclavian, or axillary artery bypass. In 18 of these reconstructions (25%), SFPV was used as the conduit. Indications for use of SFPV bypass grafts included inadequate or absent GSV in 13 patients, infection in 3, and 2 patients with thrombosis of previous prosthetic bypass. Ten were reoperative procedures (55%), 3 (17%) were performed after failed prosthetic grafts, and 3 were performed adjacent to infected fields. Bypasses were to the common carotid artery (7 patients), axillary artery and internal carotid artery in 4 patients each, external carotid artery in 2 patients, and subclavian artery in the last patients (Fig. 8). There were no in-hospital deaths. One patient has since died of a probable myocardial infarction within 30 after discharge days, for a mortality of 5.5%. Early complications included one transient ischemic attack perioperatively. During a mean follow-up of 20.0 months, there were no graft thromboses or infections. These results document that SFPV is a safe and durable conduit for



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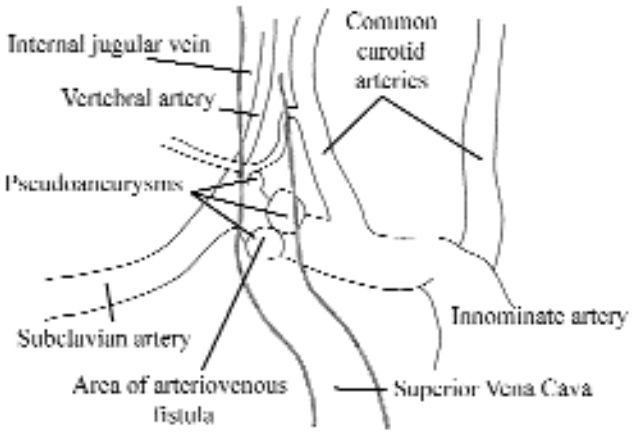

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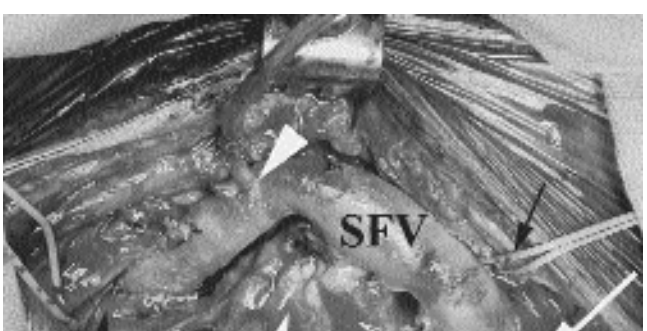

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Fig. 8 **(A)** Arteriogram of a patient with a right subclavian artery to right internal jugular arteriovenous fistula that occurred following attempt at central venous access. In addition, the patient developed a localized infection and osteomyelitis of the right clavicular head requiring claviculectomy prior to fistula repair. **(B)** Diagrammatic representation of anatomic relationships. **(C)** Intraoperative photo of an innominate to subclavian artery bypass with superficial femoral vein. Large black arrow: right subclavian artery; small white arrow: ligated internal jugular vein and arteriovenous fistula; white arrowhead: reimplanted vertebral artery; SFV: superficial femoral vein graft; small black arrow: vessel loop around common carotid artery (posterior to graft); large white arrow: innominate artery.

complex brachiocephalic reconstructions involving reoperative procedures or infected fields.

Renal, Hepatic, Visceral Arterial Reconstruction

Although GSV continues to be the conduit of choice for most visceral and renal arterial reconstructions, we use SFPV when GSV is small or unavailable, especially when infection is present. In addition to primary aortorenal and aortoceliac/superior mesenteric bypass, the SFPV graft has been especially useful in reoperative visceral procedures. Figure 9 illustrates a sequential thoracic aorta to splenic and superior mesenteric artery bypass in a patient with an occluded aortoceliac and superior mesenteric artery GSV bypass.

Hemodialysis Access

An autogenous fistula is the procedure of choice for hemodialysis access.[31] When primary autogenous fistulas have failed or forearm vascular anatomy precludes their construction, our next choice is upper arm fistula when feasi-

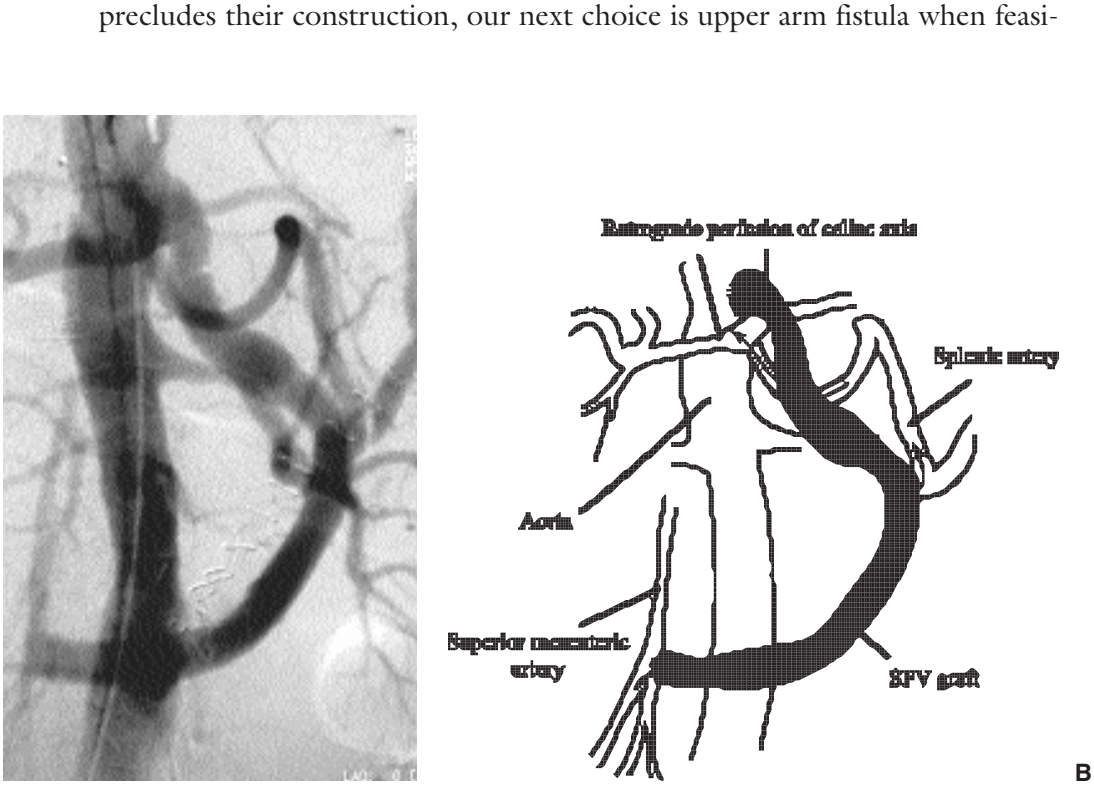

Fig. 9 **(A)** Eighteen-month follow-up arteriogram of a sequential thoracic aorta to splenic and superior mesenteric artery bypass using SFPV in a patient with an occluded GSV graft to the superior mesenteric artery and proximally occluded celiac axis. **(B)** Diagrammatic representation of graft conformation. Note retrograde perfusion of celic axis through splenic artery.

ble. Recently we have utilized SFPV as a conduit for upper arm fistula formation when there are no other options. One of us (M.R.J.) has also described transposition of the SFPV (Fig. 10) for hemodialysis access in two patients who had multiple failed upper extremity access attempts and central venous occlusion.[32] Although flow rates through the fistulae were high (700 mL/min to 1600 mL/min), neither patient developed congestive heart failure or symptoms of lower extremity ischemia. Given these flow rates, however, patients should undergo careful screening for congestive heart failure and lower extremity vascular disease. We have since utilized this technique in six additional patients with central venous occlusion and multiple failed upper extremity grafts with good results.

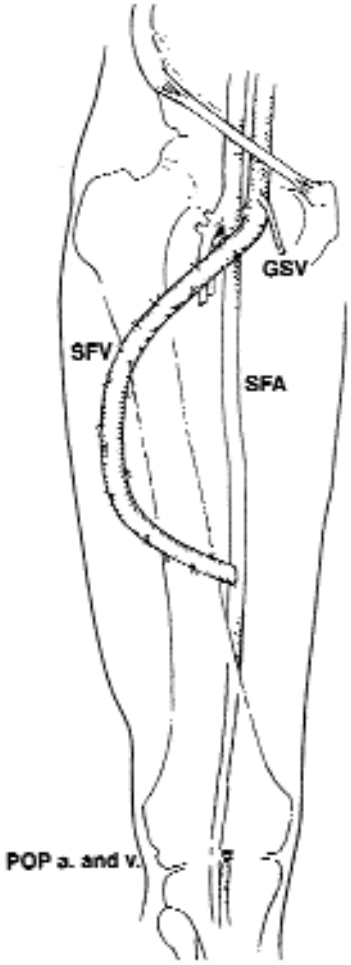

Fig. 10 Superficial femoral vein (SFV) transposition for hemodialysis access. GSV: greater saphenous vein; SFA: superficial femoral artery; POP a. and v.: popliteal artery and vein. (Reprinted with permission from the author.)

Venous Replacement

Successful reconstruction of major venous structures is limited by the lack of large-caliber, nonthrombogenic venous conduits that will remain patent. The first reported use of SFPV grafts in superior vena cava reconstruction was by Klassen et al. in 1951.[33] We reported our experience with large-caliber venous reconstructions using SFPV in 1997.[34] Seven patients underwent venous reconstruction (three central and four peripheral.) There were no early graft failures, and patency was documented in all patients at a mean of 20 months follow-up. Venous thromboembolism did not occur during follow-up. In addition, postoperative anticoagulation was not used. The use of SFPV grafts provides excellent results without requiring proximal arteriovenous fistulae, chronic anticoagulation, or antiplatelet therapy.

CONCLUSION

The SFPV has many of the features of an ideal conduit. It is readily available, is nonthrombogenic, resists infection and aneurysmal degeneration, causes minimal harvest morbidity, and is well matched in size for use in large artery and vein reconstructions. It is our conduit of choice in aortic reconstruction when infection is present, in many brachiocephalic bypasses, and in venous reconstructions. It may also be used for femoral-popliteal and, possibly, distal bypasses when GSV is absent or when the alternative conduit would have poorer long-term patency. Future use may include primary aortoiliac reconstruction in young patients with small aortas who are at high risk for early graft failure.

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Expert Commentary

John H. N. Wolfe, M.S., F.R.C.S.[1]

The authors are to be congratulated for highlighting the value of the superficial femoral vein for major arterial and venous reconstruction. Their sensible views are clearly based upon extensive experience, and, before stating my opinions I must explain that I have no experience using this conduit, except under very exceptional circumstances.

The majority of their discussion deals with the treatment of an infected prosthetic aortic graft, and this is an area where we need improved techniques and results. The difficulty of assessing the rather depressing literature on this topic relates to the different cohorts of patients that can be included in such studies.

Irrigation of the retroperitoneal space without the removal of the graft is the most conservative approach that has been suggested. Good initial results have been claimed by Quick et al.[1] in England in a small group of patients, and it is conceivable, although to me unlikely, that a graft surrounded by a contaminated seroma could be treated in this way. In these patients there is no systemic or local evidence of infection other than the bacteriological report from the serous fluid. In the vast majority of patients (or perhaps all) it is essential to remove the inert prosthetic material in order to achieve long-term success. In our own series, patients who had partial removal of the graft (presumably because the surgeon thought that the residual graft was uninfected) ultimately became infected in every case. If we are to remove all the graft material we then face the dilemma of how to restore blood supply to the legs.

In the past aortic stump blow-out was a significant problem if the prosthetic graft was removed. This continues to be quoted as a major complication of extra-anatomic reconstruction, but recently surgeons appear to have overcome this problem by more proximal exposure of the aorta and ensuring that the aortic repair is through clean tissue. In our own series (reported in 1996[2] there was a high complication rate, but we did not have a single aortic stump blow-out. Furthermore, we have not had one in the past 5 years. Nevertheless, there are those who have moved to an in-situ technique in order to avoid this potential complication. Hayes et al.[3] Intuitively it seems that insertion of a second prosthetic graft is highly likely to become infected. This is

Perspectives in Vascular Surgery and Endovascular Therapy, Volume 14, Number 1, 2001. Address for correspondence and reprint requests: John H.N. Wolfe, M.S., F.R.C.S., St. Mary's Hospital Regional Vascular Unit, Praed Street, London UK, W21NY. [1]Department of Surgery Regional Vascular Unit, St. Mary's Hospital, London, UK. 1531-0035,p;2001,14,01,081,084,ftx,en;pvs00119x.

where the type of graft infection is important. For many of us the majority of grafts are either grossly infected (green-stained and associated with pus) or they involve an aorto-enteric fistula. I would submit that insertion of a prosthetic graft under these circumstances would not succeed in the long-term. Rifampicin coating may help a little, but in a randomized study of primary extra-anatomic reconstructions it failed to improve infection rates.

Another in-situ technique is the allograft, an approach that has been particularly supported by some French surgeons. Allografts avoid some of the problems of re-infection related to Dacron, but other problems may arise unless these grafts are used very carefully. The graft may split if it is unfrozen inappropriately and aneurysmal dilatation can be a late complication. Although allografts may be a possible solution under these difficult circumstances, we still need to look for alternative solutions, since they are less than ideal.

For some of the above reasons we continue to use extra-anatomic bypass with bilateral axillo-unifemoral prosthetic grafts, followed by removal of the infected abdominal graft. However, this approach has two significant complications. The first is the possibility of re-infection of the prosthetic material. There is no reason for this to occur (except possibly due to bacteremia), unless the groins are involved with the infective process. Under these circumstances novel routes have to be used to avoid the prosthetic graft being contaminated by the groin infection. The second problem relates to revascularization in patients with occlusive arterial disease. In these patients there is an unfortunately high amputation rate and an axillo-unifemoral graft is not an ideal conduit, when there is high resistance run off.

I would therefore suggest that for grafts inserted for intra-abdominal aneurysmal disease the above approach is successful; the groins are not contaminated by the infected graft and most patients with aneurysmal disease have good distal vessels with low resistance. An infected aortobifemoral graft, inserted for occlusive disease, is a more daunting prospect, both in terms of re-infection of the new axillofemoral grafts and revascularization of the legs. Perhaps this is the most important role for in-situ vein. The use of the long saphenous vein has been espoused by Nevelsteen in Belgium[4], among others. In some patients this is a conduit of sufficient caliber and it certainly provides sufficient length. In others, however, one imagines that the saphenous vein is entirely inadequate for the task, and the current article addresses this issue. In their experience 64% of greater saphenous vein grafts required additional intervention for thrombosis or stenosis. One also assumes that there are some occasions when the surgeon does not even attempt to use an inadequate vein and seeks another conduit. The authors cite the advantages of using the superficial femoral vein regarding size, reduced thrombogenicity and infection rates, resistance to aneurysmal degeneration, and its better adaptation than greater saphenous vein.

I am therefore attracted to the idea that the superficial femoral vein may fulfil this role. My first question relates to the length of this vein, and the authors state a mean of 24.4 cm in a study performed by Santilli[4] (it is interesting that a superficial femoral vein of less than 5 mm in diameter is considered unsatisfactory since most long saphenous veins are smaller than this). In addition, they are prepared to remove the popliteal vein. This raises the eyebrows since we have all been taught that while it is possible to maintain adequate venous drainage without a superficial femoral vein, the addition of popliteal occlusion usually has deleterious effects leading to postphlebitic syndrome. The authors state clearly that this has not been their experience.

The second question relates to the extensive and deep dissection required for removing this vein in a patient who is often debilitated. In our practice the majority of patients referred have already undergone intervention and have been hospitalized for considerable lengths of time. As a result of this they have lost weight, their albumin is sometimes low, and their immune response suppressed. The necessary protracted and extensive operation is therefore a worry, and we do all we can to reduce both the time and extent of the procedure. We do not stage the revascularization; by employing 2 or 3 surgeons it is possible to insert the axillo-unifemoral grafts expeditiously. Once these have been inserted the common femoral arteries are clamped and the wounds sealed. The abdomen is opened and the infected graft removed. An operation performed in this way takes between 3 and 5 hours, and we do not believe that staging the procedure is in the patient's interests. The even greater length of time required to perform superficial femoral vein reconstruction might be a further burden to the patient.

My third question relates to the technical considerations of mismatch between aorta and vein graft. The authors have clearly managed this successfully since it has not been a problem in their series, but one imagines that this technique must be carefully learned. They imply that there is considerable mismatch on many occasions.

They then go on to other indications for using the superficial femoral vein; it is entirely logical to use it for venous replacement, but on most occasions this will not be possible due to the deep venous damage. In the days of caval plication and ligation local iatrogenic caval thrombosis could be treated by replacement with the superficial femoral vein. However, when there is primary venous disease it is likely that these veins will be too damaged to be useful. For brachiocephalic reconstruction the greater saphenous vein is usually sufficient for longer arm bypasses. Prosthetic grafts have stood the test of time for brachiocephalic reconstruction from the arch. Renal, hepatic, and visceral artery reconstructions usually require short segments of vein that can be harvested from more straightforward sites.

The use of the superficial femoral vein and the femoralpopliteal segment were pioneered by Schulman in the early 1980s[6] and the vascular fraternity

was slow to follow. He reported good results and his initiative inspired a few surgeons, such as the authors, to consider the value of the superficial femoral vein in many contexts.

We should congratulate the authors on bringing an underused conduit to our attention and for their clear exposition of the advantages and problems related to harvesting the superficial femoral vein.

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The Last Word G. Patrick Clagett, M.D., and Scott Seidel, M.D.

We appreciate Mr. Wolfe's insightful comments and agree with many of his points. Despite our preference for autogenous reconstruction with superficial femoral-popliteal veins (SFPVs) for aortic graft infection, extra-anatomic bypass is a perfectly acceptable choice for infected aortoiliac reconstructions in which femoral sites are free of sepsis and runoff is good. Extra-anatomic bypass may also be appropriate in desperately ill, unstable patients with aortoenteric fistulae. In exceptional circumstances, removal of the infected prosthesis, correction of the aortoenteric fistula, and in situ prosthetic replacement may be expeditious and lifesaving. This may be considered a bridge procedure to be followed later by more definitive treatment consisting of removal of aortic prosthesis and extra-anatomic bypass or SFPV reconstruction, depending on the patient's general condition and overall risk. It is a mistake to think that a single surgical approach is applicable to all patients with infected aortic prostheses. These complicated and multifaceted patients with varying levels of illness severity require individualized attention.

The vast majority of patients presenting with infected aortic grafts have multilevel occlusive disease, poor runoff, and septic femoral sites. Extra-anatomic bypass in these patients usually consists of bilateral axillo-unifemoral procedures with distal anastomoses to diseased and small profunda femoral or popliteal arteries. These are disadvantaged reconstructions with dismal long-term patency despite treatment with antithrombotic agents. The NAIS reconstruction from SFPVs provides vastly superior patency and limb salvage in comparison to extra-anatomic bypass.

In addition to poor patency, extra-anatomic bypasses are vulnerable to secondary infection. We are seeing increasing numbers of these patients in whom further extra-anatomic bypass is impossible and the NAIS reconstruction is the only remaining option. These patients have usually undergone multiple operations for their aortic graft infection and are among the most complex and ill patients that we encounter.

In response to Dr. Wolfe's first question, we remove a length of SFPV that is necessary to perform the reconstruction. For most NAIS procedures (aortofemoral reconstruction) and infrainguinal bypass procedures, the popliteal vein is harvested down to the level of the knee or just below. For shorter reconstructions (brachiocephalic, mesenteric, renal, and most major venous replacements), harvest of the superficial femoral vein is adequate. Of interest, we have noted no correlation between the length of vein harvested and the degree of long-term venous morbidity that has been minimal.

Approximately one quarter of patients will develop some degree of swelling after SFPV harvest that is usually transient, lasting weeks to a few months. In our previous studies, we have documented that venous hypertension is clearly present with elevations in the ambulatory venous pressure. However, the maintenance of venous valvular competence in the remaining deep system and its collaterals protect against long-term venous morbidity. In addition, we have documented the presence of collateral channels that develop from the remaining popliteal vein and the profunda femoris vein. Maintenance of unimpeded flow from the profunda femoris vein to the common femoral vein is critical in preventing excessive venous hypertension and morbidity. The importance of the profunda femoris vein is analogous to that of the profunda femoris artery in maintaining distal arterial perfusion in the presence of superficial femoral artery occlusion.

Mr. Wolfe's second question relates to the length and complexity of the NAIS operation. The operation usually takes 6–8 hours and approximates the total time required for extra-anatomic bypass and removal of an infected aortic prosthesis. We also use a two-team approach and sequence the operation to minimize aortic cross-clamp time. The operation begins with bilateral, simultaneous dissection of both SFPVs by two teams consisting of a surgeon and an assistant. The SFPVs are left in situ and the femoral regions are next dissected. After femoral dissections are complete, the abdomen is entered, the aorta cross-clamped, and the infected prosthesis removed. The SFPVs are then removed and the length tailored for comfortable aortic reconstruction.

These operations must be performed methodically in an unhurried manner with patience and attention to small details. A sense of urgency is fine; however, this must not deteriorate into a sense of frustration engendered by hunger, fatigue, and a full bladder! Surgeons should pace themselves, allowing frequent breaks for themselves and other members of the team during noncritical portions of the operation. With modern anesthetic care and meticulous, patient surgical technique, we have successfully applied this operation to a large number of critically ill, septic, and nutritionally depleted patients with multiple medical comorbidities. The overall procedure-related mortality remains constant at 10%.

Dr. Wolfe's final question is directed at the mismatch between the aorta and the SFPV graft. This is not as problematic as one might initially think. The normal aorta (approximately 2 cm in diameter) can be anastomosed quite comfortably to the proximal end of an SFPV graft that is usually 1.2–1.5 cm in diameter. One simply needs to make more advancement on the aortic side than on the vein graft side. With larger aortas and aneurysmal aortas, we have successfully used plication to reduce the aortic diameter and circumference. Joining two vein grafts together ("pantaloon" configuration) effectively doubles the circumference of the vein side of the anastomosis, and this technical maneuver will facilitate anastomosis to the largest aortas.

In summary, we would like to point out that the SFPV graft is an excellent choice when a large caliber, nonthrombogenic, infection-resistant conduit is desirable. The technical aspects of harvesting and using this conduit are well within the capabilities of a well-trained vascular surgeon and should not present extraordinary difficulties. Long-term venous morbidity has been minimal and aneurysmal degeneration of these grafts extremely rare.