Six-year prospective multicenter randomized comparison of autologous saphenous vein and expanded polytetrafluoroethylene grafts in infrainguinal arterial reconstructions

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Autologous saphenous vein (ASV) and polytetrafluoroethylene (PTFE) grafts were compared in 845 infrainguinal bypass operations, 485 to the popliteal artery and 360 to infrapopliteal arteries. Life-table primary patency rates for randomized PTFE grafts to the popliteal artery paralleled those for randomized ASV grafts to the same level for 2 years and then became significantly different (4-year patency rate of 68% ± 8% [SE] for ASV vs. 47% ± 9% for PTFE, $p < 0.025$). Four-year patency differences for randomized above-knee grafts were not statistically significant (61% ± 12% for ASV vs. 38% ± 13% for PTFE, $p > 0.25$) but were for randomized below-knee grafts (76% ± 9% for ASV vs. 54% ± 11% for PTFE, $p < 0.05$). Four-year limb salvage rates after bypasses to the popliteal artery to control critical ischemia did not differ for the two types of randomized grafts (75% ± 10% for ASV vs. 70% ± 10% for PTFE, $p > 0.25$). Although primary patency rates for randomized and obligatory PTFE grafts to the popliteal artery were significantly different ($p < 0.025$), 4-year limb salvage rates were not (70% ± 10% vs. 68% ± 20%, $p > 0.25$). Primary patency rates at 4 years for infrapopliteal bypasses with randomized ASV were significantly better than those with randomized PTFE (49% ± 10% vs. 12% ± 7%, $p < 0.001$). Limb salvage rates at 3½ years for infrapopliteal bypasses with both randomized grafts (57% ± 10% for ASV and 61% ± 10% for PTFE) were better than those for obligatory infrapopliteal PTFE grafts (38% ± 11%, $p < 0.01$). These results fail to support the routine preferential use of PTFE grafts for either femoropopliteal or more distal bypasses. However, this graft may be used preferentially in selected poor-risk patients for femoropopliteal bypasses, particularly those that do not cross the knee. Although every effort should be made to use ASV for infrapopliteal bypasses, a PTFE distal bypass is a better option than a primary major amputation.
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It is generally believed that autologous saphenous veins (ASVs) provide the best possible conduit for all arterial reconstructions below the inguinal ligament. However, these veins may be unavailable or inadequate to use as an arterial graft in many patients. This fact plus the disadvantages of the harvest of autologous vein have prompted surgeons to seek an alternative arterial prosthesis for bypasses to the popliteal and infrapopliteal arteries. Numerous graft materials have been used with early encouraging results only to later fall into disfavor because of poor mid- and long-term patency rates or late complications such as aneurysmal dilatation.

Polytetrafluoroethylene (PTFE) grafts were first used as arterial conduits in patients in 1976.[1] A femoropopliteal bypasses in patients with infrain-

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Table I. Patients, operations, and risk factors in the three centers

	Centers			*Total*	
	I	*II*	*III*	*No.*	*%*
No. of patients in study	520	175	64	759	—
No. of operations in study	622	206	64	892*	—
Exclusions after entrance into study†	36	1	10	47	—
Popliteal operations in study	375	82	28	485	—
Operative indications					
Gangrene (%)	42	6	18	—	35
Ulcer (%)	29	16	18	—	26
Rest pain (%)	25	20	56	—	26
Claudication (%)	3	51	4	—	11
Unknown (%)	1	7	4	—	2
Diabetes (%)	71	26	54	—	62
Age (yr)					
Mean ± SD	71 ± 11	61 ± 1	65 ± 8	69 ± 11	—
70-80 (%)	38	18	21	—	33
>80 (%)	18	6	4	—	15
Previous infrainguinal operation (%)	17	5	18	—	15
Infrapopliteal operations in study	211	123	26	360	—
Operative indications					
Gangrene (%)	61	12	31	—	42
Ulcer (%)	22	16	19	—	20
Rest pain (%)	16	47	50	—	29
Claudication (%)	0	24	0	—	8
Unknown (%)	1	1	0	—	1
Diabetes (%)	78	37	50	—	62
Age (yr)					
Mean ± SD	72 ± 10	65 ± 11	68 ± 11	70 ± 11	—
70-80 (%)	48	35	27	—	42
>80 (%)	23	7	15	—	17
Previous infrainguinal operation (%)	14	26	27	—	19

*During the study period, 29 other bypasses were performed to the popliteal or an infrapopliteal artery for causes other than arteriosclerosis.
†For reasons see text.

guinal arteriosclerosis, these grafts were reported to have early and mid-term patency results comparable to ASV grafts, although the PTFE grafts were generally employed in patients who were judged not to have acceptable ASV.[2,3] More recently, late patency results extending over 5 years have been documented.[4,5] On the basis of these reports, PTFE grafts have become the most commonly used synthetic conduit for arterial reconstructions below the inguinal ligament. Moreover, several surgeons, citing the advantages of decreased duration and complexity of operation and the ability to spare a healthy saphenous vein for future use as a limb salvage or coronary bypass, have advocated the preferential use of PTFE grafts for femoropopliteal bypass even in patients who had an adequate greater saphenous vein in the involved extremity.[6,7] Nevertheless, the exact indications for use of PTFE grafts in infrainguinal arterial reconstructions have remained unclear and controversial. This confusion and controversy were fueled by a number of reports showing that PTFE grafts to arteries at and below the knee performed poorly.[8-10]

In the final analysis the indications for the use of any bypass graft depend on the results that can be achieved with it compared with other available alternatives in a variety of situations. The problem with the evaluation of the relative effectiveness of PTFE compared with other grafts in infrainguinal bypass operations is that *many variables other than graft material* can influence patency results. Without rigorous standardization of these other patient-related and surgeon-related variables, comparative evaluations of various graft materials by the same surgeons are meaningless, and similar comparisons of data obtained from different surgeons are of even less value.

Because of these considerations and the resulting uncertainty about the indications for use of PTFE grafts below the inguinal ligament, in November 1978, we began a randomized prospective multicenter comparison between PTFE and ASV grafts as infrainguinal arterial bypass conduits. Our primary purpose was to compare the relative efficacy of PTFE and ASV grafts in bypasses to the popliteal and infrapopliteal arteries in patients who could have either

Table II. Details and numbers of operations

	Centers			
	I	*II*	*III*	*Total*
Common femoral to popliteal artery				360
Above-knee	152	21	7	180
Below-knee	108	61	11	180
Superficial femoral or popliteal to popliteal artery				125
Above-knee	64	0	4	68
Below-knee	51	0	6	57
Common femoral to distal artery				225
Anterior tibial	45	48	3	96
Posterior tibial	18	34	6	58
Peroneal	27	39	5	71
Superficial femoral or popliteal to distal artery				135
Anterior tibial	70	1	5	76
Posterior tibial	18	0	5	23
Peroneal	33	1	2	36

graft. This study also provided answers to a number of secondary questions. (1) Were there, within the overall patient groups having bypasses to the popliteal and infrapopliteal arteries, subsets of patients with differing results? For example, were results different for above-knee and below-knee femoropopliteal bypasses, or for those with good and poor outflow from the popliteal artery as measured angiographically? (2) Were results in patients who had to have an *obligatory PTFE* graft because of inadequate or unavailable ASV or poor general condition different from results in patients who could have had an ASV graft but who actually received a *randomized PTFE* graft? (3) What was the relationship between graft patency and limb salvage in patients undergoing bypass operations for limb salvage?

This article reports data that fulfill the primary purpose and answer some of the secondary questions addressed by our study. It thereby clarifies the indications for the use of PTFE grafts below the inguinal ligament and highlights some of the advantages and disadvantages of this use.

METHODS

Our methods were detailed in a previous preliminary report[11] and will only be summarized briefly here. From November 1978 onward, the three cooperating centers in New York (center I), Chicago (center II), and Milwaukee (center III) with nine participating surgeons attempted to enter into the study all patients who required a bypass to the popliteal or an infrapopliteal artery to control ischemia caused by arteriosclerosis. In general the three surgical groups had a conservative attitude toward performing these operations in the treatment of intermittent claudication and an aggressive attitude toward performing them to control limb-threatening or critical ischemia.[12] Although there were some differences in surgical techniques and philosophies between the three groups, there were many similarities. All nine surgeons had a demonstrated interest in and considerable experience with the operations being studied. All operations were performed in the most meticulous fashion possible, often with optical magnification and intraoperative angiographic control. Some details relating to risk factors, operative indications, and the number and kinds of operations entered into the study by the three centers are presented in Tables I and II.

Exclusions and numbers of patients and operations. Patients with infrainguinal arteriosclerosis who could be treated solely by a deep femoral artery reconstruction or solely by percutaneous transluminal angioplasty of the superficial femoral, popliteal, or an infrapopliteal artery were not included in the study. Overall, these were patients with less severe, stenotic disease. Patients who required an infrainguinal bypass for reasons other than arteriosclerosis were excluded from the study. Such exclusions, which numbered 29 during the period of the study, included bypasses for trauma, embolic disease *without* arteriosclerosis, adventitial cysts, entrapment syndromes, and tumor surgery. After these exclusions, 892 operations in 759 patients were entered into the study data base and subjected to the randomization procedure described later. Those operations considered to be *sequential bypasses* (two or more distal sites of insertion) or requiring *composite grafts* (with ASV

Table III. Operative indications, risk factors, and mortality in patients receiving the three types of grafts

	Bypasses to popliteal artery			*Bypasses to tibial or peroneal artery*		
	Randomized ASV	*Randomized PTFE*	*Obligatory PTFE*	*Randomized ASV*	*Randomized PTFE*	*Obligatory PTFE*
No. of operations	147	171	167	106	98	156
Indications						
Gangrene (%)	29	33	25	41	43	41
Ulcer (%)	27	29	25	23	21	17
Rest pain (%)	22	26	28	21	24	37
Claudication (%)	18	11	4	11	11	4
Unknown (%)	4	1	18	4	1	1
Bypass insertion						
Below-knee (%)	33	31	36	—	—	—
Into isolated segment (%)	19	19	20	—	—	—
Previous infrainguinal operation (%)	12	12	34	12	27	56
Diabetes (%)	58	68	61	73	60	87
Age (yr)						
Mean ± SD	68 ± 10	69 ± 11	70 ± 12	70 ± 12	69 ± 11	70 ± 11
70-80 (%)	37	33	29	35	39	41
>80 (%)	9	16	20	17	12	15
Operative mortality (%) (within 30 days)	3	5	8	6	4	6

ASV = autologous saphenous vein; PTFE = polytetrafluoroethylene.

and PTFE segments) were excluded from the present analysis. During the study period, approximately 25 patients received vein grafts without randomization *(obligatory vein grafts)*. These were performed in patients who (1) refused randomization, (2) had a bypass with overt infection in or immediately adjacent to an anastomotic site, or (3) had a tibiotibial bypass. Some bypass operations to an isolated tibial artery segment also fell into this category as did some operations conducted after failure of a study bypass performed with a PTFE graft.

Randomization. All patients in the study who were believed to have a usable ipsilateral ASV were randomly selected to have as their bypass conduit either a *randomized ASV* or a *randomized PTFE* graft. Randomization techniques were as previously reported.[11] All patients believed, on the basis of history of prior removal or saphenous venography, not to have an ipsilateral ASV segment long enough to serve as the required bypass received an *obligatory PTFE* graft. This group was augmented by patients originally randomized to receive an ASV graft but who at operation were found to have a diseased, absent, or small ASV. Size criteria for vein unacceptability were a minimum distended diameter of <4.0 mm for grafts to the popliteal artery and <3.0 mm for grafts to infrapopliteal arteries. Occasional critically ill patients were placed in the obligatory PTFE group to shorten the duration of the operative procedure. All PTFE grafts to the popliteal artery were 6 mm in diameter; all those to infrapopliteal arteries were tapered from 6.5 mm proximally to 4.5 mm distally. The distribution of operative indications, risk factors, and mortality data in the operations with the three types of grafts is shown in Table III.

Before randomization all patients were told about the nature of the study and informed consent was obtained in accord with each center's institutional review board policy. Results in the randomized groups of patients were continually monitored in each center so that randomization of bypasses to the infrapopliteal or popliteal level could be discontinued if and when statistically significant differences became apparent. The last patient was entered into the infrapopliteal portion of the study in April 1983, whereas randomization of bypasses to the popliteal artery was continued until March 1985.

Pharmacologic management. Systemically administered heparin was given during periods of arterial occlusion and was neutralized thereafter with protamine. Antiplatelet agents (aspirin, 0.3 gm and dipyridamole, 125 mg) were administered postoperatively three times daily to all patients in all three centers. Compliance with the reduced dosage of these drugs that the patients were asked to take after hospital discharge (0.3 gm and 100 mg each day, respectively) was difficult to determine and certainly not uniform. One center (I) attempted to begin these agents 48 hours before operation. However, spot checks revealed that this preoperative drug admin-

istration was not uniform, and some patients received no preoperative antiplatelet medication.

Follow-up information and definitions. All study patients were seen after operation on a regular basis by one of the nine operating surgeons. The frequency of these visits was, if possible, every 2 months for the first postoperative year, every 3 to 4 months for the second postoperative year and every 4 to 6 months thereafter.

Graft patency intervals were established on the basis of unequivocal pulse examination evidence of patency as determined by one of the participating surgeons and, if there was any doubt, confirmation by segmental limb pressure measurements, pulse volume recordings, or angiography.[11] Any change in pulse examination or noninvasive parameters was an indication for angiography, which was used liberally in these study patients.[13,14] No patency interval was included unless the patient was examined by one of the authors or had objective evidence of graft patency by angiography or noninvasive laboratory criteria. No presumption of patency was made on the basis of mail or telephone contact.

One definition of graft failure was the first graft occlusion with thrombosis at any time after operation. If graft patency could be restored by some form of reintervention such as thrombectomy, this secondary patency interval was recorded but not considered further for purposes of the present analysis. Grafts that developed anatomic, functionally important defects in their lumen or at, proximal to, or distal to one of their anastomoses were also considered to have failed if some form of reintervention (angioplasty or operation) was required to correct the defect. Detection of these failing grafts[14] or hemodynamic failures[13] was one of the benefits of the frequent follow-up required by the present study; relatively simple reinterventions were made possible; and graft thrombosis was prevented with considerable benefit to the patients.

Limb salvage intervals were also determined at the time of all follow-up visits. In every instance in which a limb was saved, it proved to be of functional value either in enabling bipedal gait in patients whose other lower extremity was intact or had a functional prosthesis, or in permitting transfer if the patient had a contralateral major amputation.

Data management and reduction. All raw data relating to the patients, their operative details, and their follow-up examinations were collected and submitted to one center. These raw data were entered into an IBM AT computer with a data base management program (Dataease, Software Solutions Inc.). Patency and limb salvage intervals were ended, and the graft and limb withdrawn from the study, when patients died or were irretrievably lost to follow-up. Patency intervals were also ended and the graft and limb withdrawn from the study at the time of a major amputation of a limb with a patent graft. Primary patency intervals were ended and the graft considered failed at the time of first graft thrombosis or reintervention for a failing graft. From this data base and the associated graft patency intervals and limb salvage intervals cumulative graft patency and limb salvage rates were calculated by the life-table method for different groups and subgroups of operations according to standard methods.[15-17] When two or more life-table rates were compared, the statistical significance of observed differences was evaluated by the log rank test.[16,17]

Although the primary focus of our study was the influence of the graft employed, the size and depth of the collaborative data base that was collected also permitted analysis of the effect of a large number of other variables. Only a few of these can possibly be included in the present report. Others will be the subject of subsequent communications. In addition each of the three centers was free to collect additional data on other variables as part of the cooperative study. These data may also be suitable for separate analysis and reporting.

RESULTS

Randomized ASV and PTFE grafts to the popliteal artery

Graft patency. Fig. 1 shows the cumulative life-table primary patency rates for all these grafts, most of which were used as a femoropopliteal bypass.* Important differences in patency only became apparent after 2½ years. After 4 years of observation in meaningful numbers of patients, these differences were statistically significant ($p < 0.025$).

Fig. 2 shows the patency rates of the two types of grafts inserted into the above-knee popliteal artery (Fig. 2, *A*) and the below-knee popliteal artery (Fig. 2, *B*). There is a trend toward superior patency for ASV grafts in the above-knee position ($p > 0.25$), but only in the below-knee position is there a statistically significant difference between ASV and PTFE grafts ($p < 0.05$). The patency rates for randomized

*Three popliteal-to-popliteal bypasses were also included in this group.

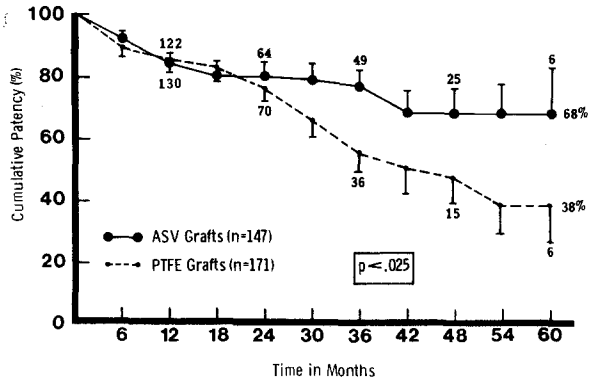

Fig. 1. Cumulative life-table primary patency rates for all randomized bypasses performed to popliteal artery with autologous saphenous vein *(ASV)* and polytetrafluoroethylene *(PTFE)* grafts. Number with each point indicates number of patent grafts observed for that length of time. Standard error of each point is shown.

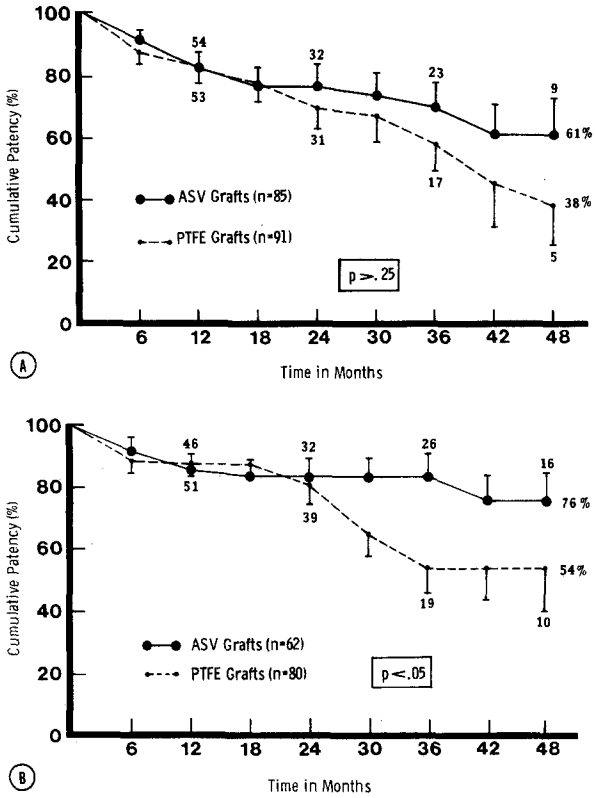

Fig. 2. Cumulative life-table primary patency rates for all randomized autologous saphenous vein *(ASV)* and polytetrafluoroethylene *(PTFE)* bypasses performed to popliteal artery **(A),** above-knee; **(B),** below-knee. Number with each point indicates number of patent grafts observed for that length of time. Standard error of each point is shown.

below-knee grafts of both types appear to be superior to those for above-knee grafts, although the reasons for this remain unclear. Differences in uncontrolled patient-related factors other than those prompting the selection of the above-knee or below-knee popliteal artery for graft insertion may contribute to these patency differences. Thus, this study should not be considered to provide firm evidence that preferential use of the below-knee popliteal artery would improve femoropopliteal graft patency.

When randomized bypasses to isolated popliteal artery segments were considered separately, no significant difference in patency rates between the ASV and PTFE grafts could be observed up to 2 years after operation (70% ± 18% [SE] vs. 75% ± 11% 2-year patency, respectively, $p > 0.75$). Insufficient numbers of these grafts were observed beyond 2 years to permit meaningful comparison for longer periods. The larger number of randomized operations performed to popliteal arteries with angiographically better runoff had significantly better patency rates with ASV grafts than with PTFE grafts (81% ± 5% vs. 77% ± 5% 2-year patency and 73% ± 7% vs. 54% ± 9% 4-year patency, respectively, $p < 0.025$). This better runoff subgroup of operations had uninterrupted flow from the popliteal artery down to at least one infrapopliteal artery for a distance of 5 cm or more.

Limb salvage. When all patients who had randomized bypasses to the popliteal artery to treat critical ischemia were considered together, there were no statistically significant differences in limb salvage rates between those whose operations were performed with an ASV graft and those with a PTFE graft (Fig. 3).

In no randomized popliteal bypass subgroup, on the basis of location of the distal anastomosis or angiographic runoff, was there a statistically significant difference in limb salvage rates in patients with ASV and those with PTFE grafts. In contrast to patency rates (Fig. 2), limb salvage rates for randomized above-knee popliteal bypasses with both ASV and PTFE tended to be slightly better (78% ± 13% and 77% ± 13% 4-year limb salvage, respectively) than those for below-knee popliteal bypasses with ASV and PTFE (75% ± 14% and 62% ± 14% 4-year limb salvage, respectively). Limb salvage rates for ASV and PTFE limb salvage bypasses to isolated popliteal artery segments (83% ± 15% and 77% ± 11% at 2 years, respectively) were somewhat worse than comparable rates for ASV and PTFE limb salvage bypasses to popliteal arteries with angiographically better runoff (91% ± 4% and 83% ± 5% at

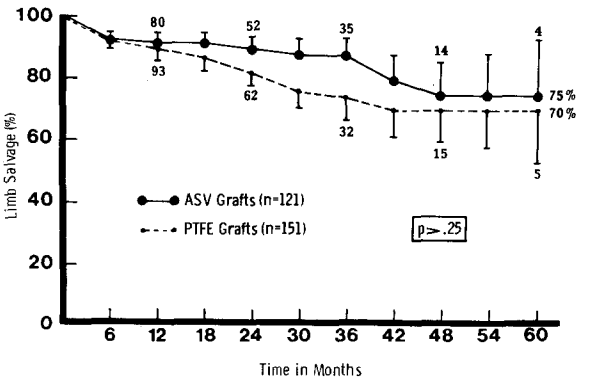

Fig. 3. Cumulative life-table limb salvage rates for all patients with randomized autologous saphenous vein *(ASV)* and polytetrafluoroethylene *(PTFE)* grafts to popliteal artery. All operations represented here were performed to control critical ischemia. Number with each point indicates number of operated limbs observed to be intact for that length of time. Standard error of each point is shown.

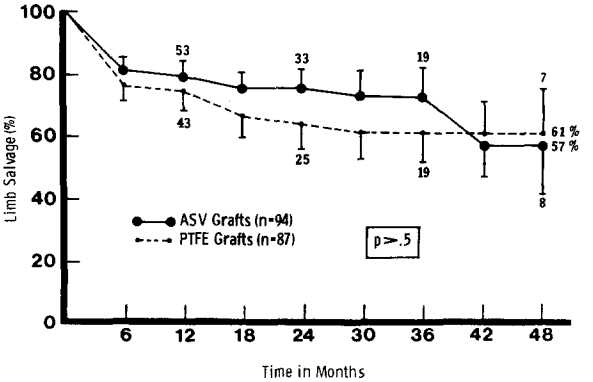

Fig. 5. Cumulative life-table limb salvage rates for patients with randomized autologous saphenous vein *(ASV)* and polytetrafluoroethylene *(PTFE)* grafts to infrapopliteal arteries. All operations represented here were performed to control critical ischemia. Number with each point indicates number of operated limbs observed to be intact for that length of time. Standard error of each point is shown.

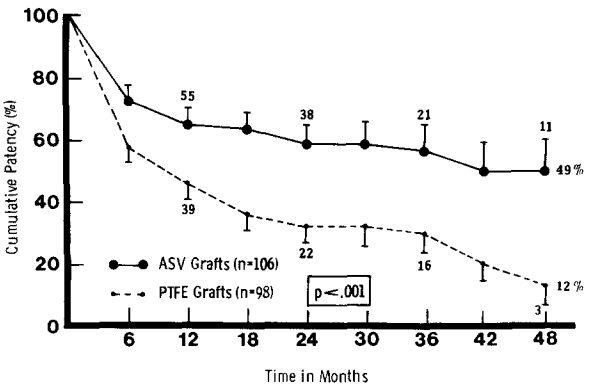

Fig. 4. Cumulative life-table primary patency rates for all randomized bypasses to infrapopliteal arteries with autologous saphenous vein *(ASV)* and polytetrafluoroethylene *(PTFE)* grafts. Number with each point indicates number of grafts observed to be patent for that length of time. Standard error of each point is shown.

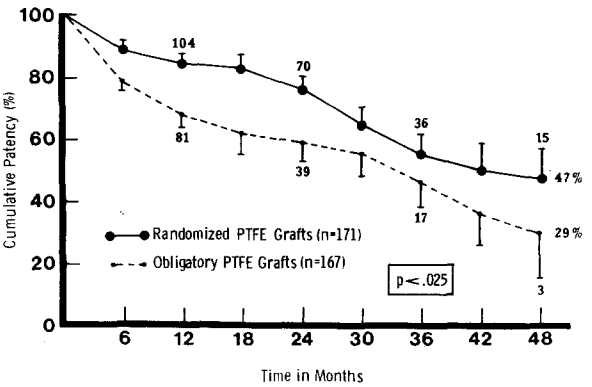

Fig. 6. Cumulative life-table primary patency rates for all randomized and obligatory polytetrafluoroethylene *(PTFE)* bypasses to popliteal artery. Number with each point represents number of patent grafts observed for that length of time. Standard error of each point is shown.

2 years, respectively, and 77% ± 10% and 73% ± 10% at 4 years, respectively).

Randomized ASV and PTFE grafts to infrapopliteal arteries

Graft patency. Cumulative patency rates for bypasses with these two types of grafts are shown in Fig. 4. Patency differences became apparent within 1 month of operation and increased progressively thereafter. At 4 years these differences were highly statistically significant ($p < 0.001$).

Limb salvage. There was no significant difference in limb salvage rates between patients with randomized ASV distal grafts and those with randomized PTFE distal bypasses (Fig. 5).

Obligatory vs. randomized PTFE grafts

Graft patency. Patency rates for randomized PTFE grafts to the popliteal artery were significantly better ($p < 0.025$) than those for obligatory PTFE grafts to the same artery (Fig. 6). However, there was no significant difference between patency rates of randomized and obligatory PTFE grafts to infrapopliteal arteries (29% ± 6% and 18% ± 5% 3-year patency and 12% ± 7% and 7% ± 7% 4-year patency, respectively, $p > 0.5$).

Limb salvage. No significant differences in limb salvage rates were present in patients with randomized and obligatory PTFE limb salvage bypasses to the popliteal artery (69% ± 10% and 68% ± 19% 4-year limb salvage, respectively, $p > 0.25$). How-

ever, patients with obligatory PTFE bypasses to infrapopliteal arteries had significantly worse limb salvage rates than did patients with randomized PTFE grafts to the same arteries (61% ± 9% vs. 38% ± 9% 3-year limb salvage and 61% ± 14% vs. 19% ± 12% 4-year limb salvage, respectively, $p < 0.01$).

DISCUSSION

These results show clearly that femoropopliteal bypasses performed with randomized PTFE grafts have patency rates inferior to those performed with randomized ASV grafts (Fig. 1). This fact does not support the routine preferential use of PTFE grafts for femoropopliteal arterial reconstructions. However, because patency rates with the two grafts in the femoropopliteal position remain similar for 2 years after operation and only diverge thereafter, a case can be made for the preferential use of PTFE grafts as femoropopliteal bypasses in poor-risk patients with a life expectancy of 2 to 3 years or less. This case is strengthened by the similar limb salvage rates in patients with femoropopliteal bypasses performed to control critical ischemia with both types of grafts (Fig. 3) and by the previously stated advantages of simplifying the operation, eliminating complications of vein harvest, and preserving the ipsilateral ASV for future use.[6,7] On the other hand, life expectancy is difficult to predict accurately, and the limb salvage rates after our PTFE bypasses were only achieved at a cost of more frequent reoperation for graft failure. This plus the significantly superior primary patency of ASV grafts below the knee and the trend toward lower limb salvage rates after a below-knee PTFE femoropopliteal bypass mandate that this graft not be used in this position in preference to a good ipsilateral ASV except in the worst-risk patients.

Equivalent patency and limb salvage rates were observed for ASV and PTFE bypasses to *isolated popliteal artery segments* with angiographically poor outflow or runoff. These data support the impression that such bypasses are worthwhile for limb salvage and cast doubt on the use of angiographic evaluation of runoff from the popliteal artery to exclude patients from limb salvage attempts. However, the number of cases and the period of observation in our study were insufficient to provide reliable information beyond the second postoperative year. Therefore, preferential use of PTFE grafts in this circumstance should be restricted only to patients with poor expectations of surviving beyond 2 years.

The patency and limb salvage results from this study also support the continued use of PTFE grafts for femoropopliteal bypass when a patient's ipsilateral ASV is absent, diseased, or inadequate. Since such obligatory PTFE femoropopliteal grafts were performed in higher risk circumstances than comparable randomized PTFE grafts (Table III), it is not surprising that the latter had significantly better patency rates (Fig. 6). However, there is no good explanation for the observation that limb salvage rates after these obligatory PTFE popliteal bypasses were no worse than those after randomized PTFE popliteal bypasses.

The present study confirms the clear superiority of randomized ASV grafts over randomized PTFE grafts for arterial reconstructions to infrapopliteal arteries.[11] This superiority was obvious from the first postoperative month and increased progressively thereafter (Fig. 4). However, this patency difference was not reflected in differing limb salvage rates because failure of a randomized PTFE distal bypass was not always associated with a renewed threat to the limb; and, when it was, a secondary vein bypass often resulted in continuing limb salvage. Obligatory PTFE distal bypasses had slightly lower patency rates but significantly lower limb salvage rates than randomized PTFE distal bypasses. These data mandate that every effort be made to perform all infrapopliteal bypasses with autologous vein. Techniques that facilitate vein availability, such as use of the superficial femoral or popliteal arteries for bypass origins[18] and utilization of arm veins,[19] certainly are appropriate in this regard. The poor patency and limb salvage results that were observed in the group of patients that had to have an obligatory PTFE distal bypass raise the question of whether a primary amputation should be performed in preference to a PTFE distal bypass if autologous vein is truly not available, and some have suggested this approach.[20] The 3-year limb salvage rate of 38% ± 9% obtained in such cases in the present study would argue against such a conclusion, particularly since the life expectancy of patients who require this kind of operation is so limited.[21] Obviously, however, there is a need for better small artery prostheses for use when autologous vein is not available.

Questions can also be raised concerning the relative merits of (1) PTFE grafts compared with other nonvein grafts and (2) reversed ASV grafts as used in this study compared with other kinds of autologous vein grafts, such as those fashioned from upper extremity veins or by the in situ technique. Unfortunately no valid statements can be made about these relative values on the basis of the present study. An abundance of patient-related and surgeon-related variables preclude valid comparisons between the present data and those from other published reports.

This underscores the importance of the present study, for only when these other variables are controlled can the true merits of proposed "improved techniques" or "better grafts" be adequately evaluated.

Even in our study, in which an effort was made to eliminate the influence on results of patient-related factors by randomization, it is still possible that a chance maldistribution of such risk factors could lessen the validity of some of our findings. The distribution and impact of these patient-related risk factors will be examined further in subsequent reports.

The present study, in addition to providing a valid comparison of two grafts and answering some secondary questions, raises other issues. One of these is the reason why limb salvage rates in patients whose operation was performed to control critical ischemia were so much higher than graft primary patency rates. One reason is that during the period of graft function, gangrenous and infectious foot lesions had been permanently healed so that critical ischemia did not recur when the graft failed. A second reason was the effectiveness of reoperation, which was employed regularly by all nine surgeons when primary arterial reconstructions failed and the involved limb was again threatened.

The present results may also contribute to an improved understanding of similarities and differences between ASV and PTFE grafts in regard to the mechanisms whereby femoropopliteal reconstructions with them fail. Such failures in the first 2 postoperative months are thought to be caused by technical factors or an improper choice of operation; those that occur from 2 to 18 months after operation are mostly a result of neointimal hyperplasia; and failures that occur more than 18 months after operation are largely due to progression of atherosclerosis.[22-25] ASV and PTFE grafts to the popliteal artery failed with roughly equal frequency up to 18 months; thereafter the PTFE grafts failed more frequently. This suggests that PTFE grafts, at least in the femoropopliteal position, may be disadvantaged because they promote progression of distal atherosclerosis in some as yet unclarified way.

In the last 15 years numerous claims have been made regarding the superiority of various grafts and technical modifications as means for improving the results of infrainguinal arterial reconstructive surgery. Usually these claims are made on the basis of a relatively short-term follow-up of a limited number of cases. Historical controls, frequently those from other centers, are offered to sustain the claim of superiority, and the new graft or technical modification becomes widely adopted. Although the present study required a large number of patients and many years to complete, the effort seems to have been justified by the value of the information gained. A large data base relating to infrainguinal bypass operations has been generated, which will permit a number of secondary questions not addressed in the present report to be answered in future communications. Most important, however, a valid comparison of the efficacy of ASV and PTFE grafts employed to treat infrainguinal arteriosclerosis now exists, and usage of PTFE grafts need no longer be based on whim, hope, or unjustified claims. It would seem appropriate to subject many other aspects of infrainguinal arterial surgery to the same kind of scrutiny by other similar studies.

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DISCUSSION

Dr. Robert W. Hobson (Newark, N.J.). This multi-institutional data collection serves as the model for cooperative study efforts confirming the excellence of autogenous saphenous vein as well as the increasingly convincing evidence on the limitations of polytetrafluoroethylene (PTFE) for bypass procedures in limb salvage cases. These data offer advantages in larger sample sizes over individual institutional reports such as our 5-year clinical follow-up of 246 femoropopliteal and tibial bypasses with autogenous saphenous vein used preferentially and obligatory PTFE in the absence of a vein, which we were privileged to present before this society last year (1984) in Atlanta. However, the close correlation between these data presented today and our past series stimulated my discussion. In our series, below-knee femoropopliteal bypass with autogenous saphenous vein at 5 years resulted in limb salvage and patency rates of 83% and 74%, respectively, whereas comparable data for PTFE were 35% and 22% respectively. For tibial bypasses at 5 years after operation, limb salvage and patency rates were 53% and 47% for saphenous vein, respectively, and 20% and 15% for PTFE, respectively (J VASC SURG 1985; 2:174-85).

On the basis of our series and its comparability to your multi-institutional assessment, I would like to present several questions.

You have reported on the status of above-knee and below-knee popliteal bypass with PTFE. I would appreciate your comments on the number of patients in whom such a bypass has been accompanied by a sequential or jump graft, cephalic or saphenous vein to the tibial level, discarding use of PTFE to a tibial artery entirely as we recommended.

Can you outline for us the management of the occluded PTFE vascular prosthesis? As we reported in 1984, our data did not support thrombectomy and distal revision of the tibial bypass, as we were unable to achieve any increase in either limb salvage or patency. Occlusion of our PTFE bypasses also resulted in substantial distal ischemia; however, your data demonstrate limb salvage in excess of patency, suggesting that prosthetic occlusion is well tolerated in a large number of patients. Could you please explain this apparent difference in our series?

Finally, can you give us any insight into institutional differences within the overall data that might account for this close correlation between our individual series and this cooperative effort?

We regard this as the definitive work on the role of PTFE in peripheral vascular occlusive disease.

Dr. Roger C. Rosen (Boston, Mass.). This study has demonstrated that a polytetrafluoroethylene (PTFE) graft to the popliteal artery can achieve primary patency rates similar to autologous saphenous vein for up to 2 ½ years. Since the goal of infrainguinal revascularization is to maintain a viable extremity for the longest period of time, then perhaps the subsequent period of limb salvage can be max-

imized by an initial prosthetic bypass to the popliteal artery, when feasible, followed by a more distal vein bypass when the prosthetic graft fails.

At the Boston Veterans Administration Medical Center we have examined this concept of *staged reconstructions*. The limb salvage rates following infrainguinal arterial reconstruction of 134 patients who were at risk for limb loss were examined. There were 59 above-knee popliteal prosthetic grafts (PTFE or umbilical vein), 75 below-knee popliteal or tibial in situ saphenous vein grafts; eight patients had a staged reconstruction, that is, a prosthetic graft followed by an in situ saphenous vein (ISV) reconstruction.

An above-knee prosthetic and a below-knee popliteal or tibial ISV graft achieve similar 3-year limb salvage rates of 75% and 71%, respectively. The staged group, albeit small, achieved 87% limb salvage at 3 years. Therefore, we believe that, if feasible, an initial prosthetic above-knee popliteal bypass should be considered. If failure occurs because of distal disease, a distal vein bypass can be performed. This staged reconstruction may prolong limb salvage for a greater length of time than an initial ISV graft alone.

I would like to ask the authors to give their thoughts with regard to this concept of staged reconstruction.

Dr. Martin L. Schulman (Great Neck, N.Y.). Let me congratulate the authors on presenting a classic study that will stand as a model of integrity and application of the scientific method.

My remarks concern the preliminary results of a randomized comparative study, started 4 years ago, of superficial femoral and popliteal veins vs. reversed saphenous veins as primary femoropopliteal bypass grafts. Results at 2 years, showing 87% patency of deep leg veins and 67% patency of the saphenous veins are statistically significant. More importantly, they are clinically significant, because we know the causes of failure of deep leg vein grafts, as a result of an intensive angiographic follow-up, with 214 postoperative arteriograms performed in the 62 deep leg vein cases.

Our results with a third autogenous graft source, arm veins, as reported at this society's meeting in 1982, were disappointing.

Three of the four occlusions occurring in deep leg veins between 1 month and 2 years were associated with advanced distal disease and were not graft-related. The hyperplastic changes frequently seen in the body of saphenous vein grafts were only seen once.

Deep leg vein occlusions in the third year were all intrinsic, because of recurrent distal anastomotic hyperplasia, usually treated by percutaneous angioplasty, and the embolization of graft mural thrombi in patients in whom, by present criteria, unacceptably large grafts were used.

Lessons learned during the course of this study, leading to modifications in technique, strategy, and graft selection, support a realistic expectation of significantly improved late results in the future.

At present, after an 11-year experience with these grafts, we use superficial femoral and popliteal veins preferentially as femoropopliteal bypass grafts.

Dr. Veith (closing). We had hoped that this study would settle things once and for all. Obviously, it has not. The reason is that there are two aspects to our study. One is the data or the facts, and the other is the interpretation of these facts. We are still in the process of interpretation as we sift through some of the details, but I think the facts are there for everybody to interpret once they have read the article. Clearly, some physicians are going to come up with different opinions on the basis of these facts, and I think these differences of opinion are responsible for some of the points raised in the discussion.

Dr. Hobson, I think that may account for some of our disagreement. One of the many variables that we have not yet analyzed, but will, is the interinstitutional variation. I do not think it will make much difference, but we are going to look at it all the same.

When do we use sequential grafts? In general, we favor the simplest procedure possible. In patients with a patent popliteal segment, the simplest operation is usually an above-knee femoropopliteal bypass. We generally restrict the use of sequential bypasses to patients who have extensive gangrene or infection in the foot and who need more blood supply to heal the foot. We believe our patency data justify this approach.

We have recently changed some of our thinking concerning reoperations for failed grafts. For failed above-knee PTFE femoropopliteal grafts, the follow-up patency rates for reoperations that include a thrombectomy are excellent. It is not as good with PTFE bypasses below the knee and certainly not good with tibial bypasses. Thus in both those circumstances we have changed our recommendation and prefer to do a totally new bypass, preferably with vein, when a PTFE graft fails.

Dr. Rosen, your approach is reasonable. However, we presently oppose the use of prosthetic grafts preferentially above the knee and certainly below the knee in a young patient who has a life expectancy of maybe 10 or 15 years. Of course it is difficult to judge life expectancy accurately. Moreover, there is as yet no conclusive proof that in situ vein grafts are superior to reversed vein grafts when both operations are performed with equal care and commitment.

Dr. Schulman, we agree that the saphenous vein is not always perfect. The arterial systems into which we put these grafts are not perfect either, and most of the failures resulted from deterioration in the patient's arteries, not from a problem in the graft. It is of interest, of course, that as surgeons become involved in this field, their results get better in general and in the specific procedure in which they have a particular interest.