Changing Arteriosclerotic Disease Patterns and Management Strategies in Lower-limb–Threatening Ischemia

FRANK J. VEITH, M.D., SUSHIL K. GUPTA, M.D., KURT R. WENGERTER, M.D., JAMIE GOLDSMITH, R.N., STEVEN P. RIVERS, M.D., CURTIS W. BAKAL, M.D., ALAN M. DIETZEK, M.D., JACOB CYNAMON, M.D., SEYMOUR SPRAYREGEN, M.D., and MARVIN L. GLIEDMAN, M.D.

From January 1, 1974 to December 31, 1989, we treated 2829 patients with critical lower-extremity ischemia. In the last 5 years, 13% of patients had therapeutically significant stenoses or occlusions above *and* below the groin, while 35% had them at two or three levels below the inguinal ligament. Unobstructed arterial flow to the distal half of the thigh was present in 26% of patients, and 16% had unobstructed flow to the upper third of the leg with occlusions of all three leg arteries distal to this point and reconstitution of some patent named artery in the lower leg or foot. In the last 2 years, 99% of all patients with a threatened limb and without severe organic mental syndrome or midfoot gangrene were amenable to revascularization by percutaneous transluminal angioplasty (PTA), arterial bypass, or a combination of the two, although some distal arteries used for bypass insertion were heavily diseased or isolated segments without an intact plantar arch. Limb salvage was achieved and maintained in more than 90% of recent patient cohorts, with a mean procedural mortality rate of 3.3%. Recent strategies that contributed to these results include (1) distal origin short vein grafts from the below-knee popliteal or tibial arteries to an ankle or foot artery (291 cases); (2) combined PTA and bypass (245 cases); (3) more distal PTA of popliteal and tibial artery stenoses (233 cases); (4) use of *in situ* or ectopic reversed autogenous vein for infrapopliteal bypasses, even when vein diameter was 3 to 4 mm; (5) composite-sequential femoropopliteal-distal (PTFE/vein) bypasses; (6) reintervention when a procedure thrombosed (637 cases) or was threatened by a hemodynamically significant inflow, outflow, or graft lesion (failing graft, 252 cases); (7) frequent follow-up to detect threatening lesions before graft thrombosis occurred and to permit correction of lesions by PTA (58%) or simple reoperation; and (8) unusual approaches to all infrainguinal arteries to facilitate secondary operations, despite scarring and infection. Primary major amputation rates decreased from 41% to 5% and total amputation rates decreased from 49% to 14%. Aggressive policies to save threatened limbs thus are supported.

From the Departments of Surgery and Radiology, Montefiore Medical Center–Albert Einstein College of Medicine, New York, New York

ENORMOUS STRIDES WERE made in the treatment of arteriosclerotic lower extremity ischemia in the last 35 years. Operative techniques for bypassing or otherwise overcoming stenotic or occlusive lesions above and below the inguinal ligament have been developed and proved effective. However, when the arteriosclerotic disease process was advanced enough to produce ischemia that threatened limb viability, major amputation at the above- or below-knee level often has been deemed necessary. During the last two decades, we and a few others[1–5] aggressively have attempted revascularization in most patients whose lower extremities were threatened because of ischemic gangrene, ulceration, or rest pain and have shown that these efforts were valuable. Although this aggressive approach to limb salvage was first received with skepticism, such surgery now is accepted widely and practiced in many centers.

Although atherosclerosis is a segmental disease and although ideal candidates for operative and other endovascular treatments have hemodynamically significant lesions of large proximal arteries interspersed in an otherwise normal arterial tree, it has become apparent that many patients with limb-threatening ischemia have a different pattern of arterial disease characterized by diffuse and multilevel arterial involvement. Furthermore occlusive or stenotic lesions may be present entirely or predominantly below the lower half of the thigh or entirely below the knee. Many surgeons still think these patients have arteries that are inoperable because their disease is 'too distal' and

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Address reprint requests to Frank J. Veith, M.D., 111 East 210 Street, New York, NY 10467.

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involves arteries that are 'too small.' The frequency of such disease patterns is unknown.

In the present study we reviewed our last 16 years' experience with patients with lower-limb–threatening ischemia to accomplish several objectives. The first was to examine the therapeutically important patterns of arteriosclerotic lesions in these patients and to determine how frequently lesions at multiple levels above and below the inguinal ligament required treatment. The second was to determine how these patterns of disease have appeared to change over the years. These changes were apparent because it was the perception or recognition of disease patterns that changed rather than the pattern of the disease itself. These apparent patterns were reflected in the level of operative or other interventional therapy that was performed. A third objective was to determine the frequency and extent of arterial involvement that occurred only distal to the midthigh or distal to the knee. A fourth objective was to evaluate the impact of percutaneous transluminal angioplasty (PTA) on the management of this entire patient group. A fifth goal was to determine the importance of reintervention for failed (thrombosed) or failing (threatened but not thrombosed) primary arterial procedures. The sixth goal was to describe new therapeutic strategies that facilitate management of the patterns of disease and the need for reintervention that were encountered in many patients. A final purpose of this review was to evaluate the overall efficacy of treatment of these patients.

Methods

During the past 16 years (January 1, 1974 to December 31, 1989), 2829 patients on whom we had not performed a previous ipsilateral revascularization were admitted to Montefiore Medical Center with one or both lower extremities threatened by ischemia due to arteriosclerosis (Table 1). In this analysis we have included only diabetic and nondiabetic patients who had progressive or nonhealing toe, heel, foot, or leg gangrene or ulceration or severe rest pain uncontrolled by conservative treatment.[6] Excluded from this study were patients with only intermittent claudication (who comprised 2% to 5% of our patients undergoing operation or PTA) and those whose limbs were threatened because of infection and/or gangrene in association with intact major arterial circulation as indicated by palpable foot pulses and normal forefoot pulse volume recordings. Also excluded were patients with popliteal or femoral aneurysms without occlusive disease and patients whose limbs were threatened but who were treated by thromboembolectomy alone.

Patients with severe organic mental syndrome or gangrene and/or infection involving the deeper tissues of the midtarsal region of the foot were subjected to primary major amputation above or below the knee. Except for such patients, who comprised 4% of all those admitted to our institution,[1] all patients underwent arteriographic examination by the transfemoral or translumbar route. Visualization of all patent arteries from the renal arteries to the forefoot was possible in almost all patients. With this visualization more than 94% of earlier patient cohorts[1] and virtually all of more recent patients cohorts had some patent visualized arterial segment, albeit sometimes relatively isolated, which could be used in an attempted revascularization. The only exceptions were patients who had undergone previous operations or who had suffered an acute arterial occlusion. Extensive forefoot and heel gangrene, recent congestive heart failure or myocardial infarction, an incomplete plantar arch, and heavy circumferential calcification were not considered contraindications to attempting limb salvage, and successful revascularization often has been achieved in each of these circumstances.[1,7,8]

Our medical and surgical policies for treating these patients until 1981 have been detailed previously.[1] Important recent modifications include the following.

Graft Material

Until 1976 woven Dacron grafts were used for all bypass procedures above the groin or extending to the groin, and autologous vein grafts were used for all infrainguinal bypass operations. If no vein was available for the latter procedures, knitted Dacron grafts were used. From 1976 to 1987, woven Dacron was used for some aortofemoral grafts; expanded polytetrafluoroethylene (PTFE) grafts were used for some aortofemoral bypasses, all iliofemoral, axillofemoral, and femorofemoral procedures, and (until 1982) infrainguinal bypass operations if autologous vein was unavailable in the ipsilateral lower extremity. Some sick elderly patients requiring femoropopliteal bypass and those with veins that did not dilate to a diameter of more than 3.5 mm had the procedure performed with PTFE grafts, even if they had a usable ipsilateral vein. From 1978 to 1982, all patients undergoing infrainguinal bypass procedures who had usable ipsilateral autologous vein were randomized to receive either a vein or a PTFE graft.[9] Since 1982 any bypass to an infrapopliteal artery was performed with autologous vein if this was present in any of the four extremities as a single or composite graft of undiseased vein. Patency of long (more than 40 cm) reversed vein grafts less than 3.5 mm and all vein grafts less than 3.0 mm in minimal distended diameter was inferior to that of larger-diameter vein grafts.[10] From 1982 to 1985, randomization of femoropopliteal bypass grafts to PTFE or ipsilateral vein continued. Thereafter these grafts were performed preferentially with ipsilateral vein if it was present and had a minimal distended diameter 3.5 mm or greater, except in patients whose life expectancy was

TABLE 1. *Procedures Performed in 2829 Patients with First-time-Threatened Limbs During 16 Years**

Period	1						2					3					
Year	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Total
Total patients with threatened limbs	126	115	101	137	129	151	217	203	205	208	222	190	206	226	211	182	2829
Aorta or iliac to femoral bypass	5	3	5	4	4	4	12	10	14	13	19	20	27	35	18	16	209
Axillofemoral bypass	6	6	3	25	20	17	19	14	10	13	19	12	9	12	11	12	208
Femorofemoral crossover bypass	8	10	5	24	15	16	22	20	28	23	18	25	23	32	19	19	307
Iliac PTA	0	0	0	0	2	20	31	26	45	40	53	51	55	67	47	48	485
CFA/DFA/PSFA to PA bypass	22	24	44	65	63	62	77	73	91	76	92	93	92	91	78	79	1122
SFA PTA	0	0	0	0	0	5	21	14	10	21	23	28	42	31	17	29	241
PA PTA	0	0	0	0	0	4	16	26	4	16	16	10	20	21	11	12	156
CFA/DFA/PSFA to DA bypass	10	7	8	38	19	41	43	34	49	51	42	36	34	39	41	41	533
DSFA/AK PA to DA bypass	0	1	3	6	4	8	9	9	11	20	10	13	15	18	21	23	171
BK PA to DA bypass	0	0	1	2	2	1	15	9	12	24	28	29	34	32	18	30	237
DA to DA bypass	0	0	0	0	0	0	1	2	4	2	5	7	12	8	6	7	54
DA PTA	0	0	0	0	0	3	9	8	1	0	6	8	13	10	8	11	77
Vein graft PTA	0	0	0	0	0	0	2	4	3	3	2	5	12	4	5	10	50
Sympathectomy alone	31	29	7	0	2	1	0	1	1	1	1	0	0	1	0	0	75
Primary BK/AK amputation	52	48	34	26	29	23	45	42	36	32	41	18	36	32	10	11	515
Total procedures	134	128	110	190	160	205	322	292	319	335	375	355	424	433	310	348	4440
Secondary BK/AK amputation	7	11	23	28	44	33	38	44	43	41	34	22	34	31	17	18	468

* PTA, percutaneous transluminal angioplasty; CFA, common femoral artery; DFA, deep femoral artery; PSFA, proximal half of superficial femoral artery; DSFA, distal half of superficial femoral artery; PA, popliteal artery; DA, distal (infrapopliteal) artery; AK, above knee; BK, below knee.

judged to be less than 2 to 3 years. In most patients requiring a femoropopliteal-to-infrapopliteal sequential bypass, the proximal graft was PTFE and the distal autologous vein. Since 1983 axillofemoral bypasses were performed with ringed PTFE grafts, and PTFE femoropopliteal bypasses were randomized to ringed or nonringed grafts.[11] Since 1987 bypasses originating from the aorta were performed with albumin-coated knitted Dacron or PTFE grafts. Since July 1985 all patients who had a usable ipsilateral greater saphenous vein and who required a bypass from the proximal half of the thigh to an infrapopliteal artery were randomized to receive a reversed or *in situ* vein graft.[12]

Graft Origin and Length

Increasingly during the 16 years of this study we have tried to minimize the length of infrainguinal vein bypasses by using more distal sites of origin in patients with unobstructed proximal arteries.[1,7,13] Short vein bypasses originating from the superficial femoral, deep femoral, popliteal, and infrapopliteal arteries and extending to distal arteries have become increasingly common (Table 1). If vein length was limited, we have even placed grafts below stenoses of 20% to 40% of luminal diameter provided no postbypass pressure gradient was present. If such a gradient was present, a prosthetic extension was performed to a site proximal to the stenosis. The practice of using these distal origin short vein grafts has maximized vein use, avoided dissection in scarred or infected groins, and simplified operative procedures. Although it is not a topic of this review, problems arising from progression of disease proximal to a distal origin graft have occurred in less than 5% of cases. They have almost always not caused graft thrombosis and have been managed successfully by proximal prosthetic graft extension.

Improved Arteriographic Technique

In addition to the adjuncts previously outlined,[1] arteriographic visualization of patent foot arteries has been improved in the last 8 years by using digital augmentation techniques when necessary (3% of cases). Another advance has been the routine performance of aortic arch vessel arteriography *via* a translumbar approach in patients who are possible candidates for axillofemoral bypass. Twenty-five per cent of such patients had important and unsuspected axillary or subclavian disease that could have hampered bypass inflow.[14] When this was found, alternate adequate inflow sites were used.

Ankle and Foot Arteries as Bypass Insertion Sites

With adequate arteriographic visualization, it has been possible to find inframalleolar arteries that could provide bypass outflow in patients who previously would have been deemed unreconstructible.[1,7,15,16] The dorsalis pedis and the posterior tibial artery in the foot as well as their main branches, the lateral tarsal artery, deep metatarsal arch, and the medial and lateral plantar arteries, have been used to provide successful bypass outflow, even when there was no patent plantar arch and other major pedal arteries were occluded (Fig. 1).

FIG. 1. Arteriogram performed 7.5 years after a below-knee popliteal-to-posterior tibial bypass. The outflow tract was limited and disadvantaged at operation and has remained so.

Use of PTA

Since 1978, if the procedure was technically feasible, we have used PTA to treat all gradient-producing or potentially gradient-producing (after distal papaverine administration) iliac artery stenoses and all potentially flow-reducing, high-grade (more than 70% reduction of luminal diameter) stenoses in the femoral arteries (common, superficial, deep) and popliteal artery.[1] If a patient with a high-grade iliac stenosis with no measurable gradient across it required an infrainguinal bypass of any sort (femorofemoral, femoropopliteal, or femoro-to-infrapopliteal), PTA of the iliac lesion also was performed.

In the last 8 years we also have extended the use of PTA with improved balloon catheters to treat stenotic lesions of the tibioperoneal trunk and the tibial or peroneal arteries at all levels in the leg, even the perimalleolar level.[17] During the last 11 years, we also have used PTA to treat lesions that have developed proximal or distal to PTFE or vein grafts and to treat stenotic lesions developing within vein grafts.[18] However intermediate (more than 1 year) results with vein graft lesions longer than 2 cm have been so poor that PTA is no longer attempted for them and vein patch angioplasty or bypass are used instead. Percutaneous transluminal angioplasty, if technically feasible, is still used for short (less than 2 cm long) vein graft lesions.

Indications for Multilevel or Sequential Bypasses

These operations consisted of axillary artery or aorta-to-femoral-to-popliteal bypasses in patients with bilateral iliac disease not amenable to PTA and femoral-to-popliteal-to-infrapopliteal artery bypasses. In the last 10 years, they were performed in one stage when extensive gangrene or infection was present in the foot and the more proximal insertion site artery ended blindly without direct luminal continuity to the lower leg or foot. In such circumstances, a simple bypass to the isolated segment would often remain patent but would not produce healing of foot lesions until a secondary distal sequential bypass was performed.[19,20] If patients had only one limb with extensive gangrene and required an axillary artery or aorta-to-femoral-to-popliteal bypass, we usually performed a unilateral procedure if the opposite limb was asymptomatic. This simplified a complicated operation, and if the opposite limb later became threatened, a simple crossover femorofemoral or femoropopliteal procedure from the unilateral prosthetic graft could be performed easily.

Postprocedural Patient Follow-up

Frequent patient observation to detect the development of flow-reducing lesions in, proximal to, or distal to the arterial reconstruction before thrombosis occurs has been important to achieving the ultimate goal of limb salvage in these patients, except for those with only an aortofemoral bypass.[1,18,21-23] Failure with thrombosis of the arterial reconstruction or PTA site can occur from intimal hyperplasia involving vein grafts, anastomotic sites, or segments treated by PTA. Usually this process becomes apparent 2 to 24 months after the arterial manipulation.[22-25] Thereafter disease progression is the most important threat to the arterial intervention. Fortunately these processes often can be detected before they cause thrombosis of an arterial reconstruction and corrective measures taken in the 'failing' state. Improved extended patency and limb salvage thus can be achieved.[18,25-27] Clinical observation with careful pulse examination by the operating surgeon every 1 to 2 months for the first postoperative year, every 3 months for the second year, and every 3 to 6 months thereafter largely has enabled us to detect 252 failing arterial reconstructions in the last 10 years (Table 2). Urgent arteriography usually was performed, and patent arterial reconstructions that were threatened were confirmed and treated by PTA (145 cases) and/or by reoperation (107 cases).

TABLE 2. *Secondary Procedures Performed for Our Failed and Failing Primary Procedures During the Last 10 Years*

Years	1980–1984	1985–1989	Total
Total number of patients with primarily threatened limb	1055	1015	2070
Number of our patients requiring a secondary procedure (% of total patients)	286 (27%)	376 (37%)	662 (32%)
Number of secondary procedures on these patients*	394	495	889
Reoperations for failed procedures (% of secondary procedures)	295 (75%)	342 (69%)	637 (72%)
Suprainguinal	47	46	93
Infrainguinal	248	296	544
Reoperations for failing procedures			
Suprainguinal	8	8	16
Infrainguinal	24	67	91
PTAs for failing procedures			
Suprainguinal	25	15	34
Infrainguinal	42	63	111
Total reinterventions for failing procedures (% of secondary procedures)	99 (25%)	153 (31%)	252 (28%)

* Many patients had more than one secondary intervention.

In the last 4 years, frequent noninvasive, Duplex examination of *in situ* vein grafts has been helpful in detecting threatening lesions before they produce graft thrombosis (graft flow velocity less than 45 cm/second).[26] Simple and effective operative intervention to improve graft patency is thereby facilitated. Accordingly we have begun to supplement clinical follow-up with Duplex examinations. However this has not always been feasible with large numbers of patients, and cost factors remain a consideration. Furthermore some grafts to disadvantaged outflow tracts have had flows less than 45 cm/second and remained patent for several years.

Management of Failed (Thrombosed) Arterial Reconstructions

Throughout the 16-year period of this review, we maintained an aggressive diagnostic and therapeutic attitude toward reintervening when a patient had a threatened limb because of failure with thrombosis of a previous arterial intervention performed at our own or some other institution.[1,24] Such patients were subjected to arteriographic examination and correction of the problem that caused or contributed to the thrombosis. In the first 10 years of this review reoperations tended to involve graft thrombectomy and salvage with patch grafting of hyperplastic outflow lesions and graft extension for progression of proximal or distal arteriosclerosis.[24] In the last 6 years, although we sometimes performed thrombectomies of prosthetic grafts terminating above the knee, we tended to perform totally new bypasses to previously undissected arteries using vein grafts where possible and a variety of new or unusual approaches to gain access to the arteries *via* unscarred and uninfected tissue planes.[28,29] Failed PTA generally was treated by a bypass, except for some focal iliac artery lesions. Not every failure of a limb salvage procedure produced a renewed threat to a limb because the original toe or foot lesion may, in part, be due to infection that never recurred. When a graft thrombosis did not threaten a limb, careful observation and expectant treatment were carried out.[24,28] Although intra-arterial lytic agents have been used sporadically in the management of thrombosed reconstructions and although they may prove helpful in the future, they were rarely valuable and not used routinely during the study period.

Management of Wound Hematoma, Necrosis, and Infection

Wound complications were frequent after infrainguinal operations in these patients, the majority (more than 60%) of whom were diabetic and who had lengthy operations with extensive vein harvest incisions. When these processes, which often occurred together, were extensive or involved more than the skin and superficial subcutaneous tissue, treatment usually involved operative debridement, evacuation of blood and exudate, and excision of all necrotic tissue. With appropriate bedside care, healing by secondary intention usually occurred, even when an autologous vein or prosthetic graft and its anastomosis to a native artery were exposed in the involved wound.[30] Skin grafts and muscle flaps were used only rarely but were helpful.

Data Maintenance and Analysis

Data for this study was culled from Vascular Service census sheets and logs of operations and PTAs. Since 1976 data on patients, their operations, PTAs, and their follow-up was entered prospectively into an IBM microcomputer relational database (Dataease International, Trumball, CT) that was specifically adopted to the monitoring of vascular patients.[31] Statistical evaluations of data were by the chi square test. The present review was performed by addressing specific queries to this database. Information on apparent disease patterns and their therapeutic significance was determined from the operations or other therapeutic interventions performed to treat the lesions deemed important. Amputation rates were derived from the number of amputations and the patients presenting primarily in the same period. Primary amputation rates minus 4% (for patients with severe organic mental syndrome and hopelessly extensive gangrene) were a reflection of untreatable arterial disease patterns. Secondary amputation rates were a reflection of early and late failures of arterial interventions that could not be salvaged by some form of secondary procedure. Although these fail-

ures and the resulting secondary amputations may have occurred remote to the arterial intervention, the overall rate calculations have validity because the number of patients treated annually remained relatively constant and eventual failures, no matter how remote, would affect the secondary amputation rate of a subsequent year if it did not increase the rate for the same year.

Results

Table 1 shows the number of patients presenting with a threatened limb from arteriosclerotic ischemia during the 16 years of the study and the therapeutic procedures performed on these patients. In the first 6 years of the study (period 1) there was a sharp rise in the number of procedures extending to infrapopliteal arteries and a corresponding decrease in the number of sympathectomies and primary amputations. This is a reflection of our increasing recognition of the therapeutic significance of infrapopliteal lesions and our increasing ability to deal with them effectively. These trends continued and increased in the latter 10 years of the study (periods 2 and 3) and were associated with the introduction of iliac and femoral artery PTAs and increasing numbers of distal origin bypass grafts and popliteal and infrapopliteal PTAs. The latter were indicative of our increasing recognition that limb-threatening ischemia could be associated mainly with distal occlusive disease below the midthigh or knee, and that these patterns of disease often occurred without therapeutically significant, more proximal disease.

Another fact that can be derived from Table 1 was the increase in the number of procedures performed per patient from 1.2 in period 1 to 1.6 in period 2 and 1.8 in period 3. This was due to our increasing inclination to treat the multiple levels of disease these patients had and our willingness to reintervene when a primary procedure thrombosed or failed to save the limb.

Changing Patterns of Therapeutically Significant or Apparent Disease

These patterns are reflected in Table 3, in which the location and number of levels of therapeutically significant disease are derived from the number of threatened limbs that received a particular treatment or had an operation or PTA to overcome a significant arterial lesion. Of the patients undergoing therapeutic arterial procedures, the proportions with therapeutically significant disease above and below the inguinal ligament did not change significantly in the 16 years of the study. However the proportion of patients undergoing treatment at multiple levels, either above and below or all below the groin, increased from 28% to 49%. Even the high proportions of multilevel procedures in the last 5 years of the study (44% to 51%) are misleadingly low because many patients with multilevel disease often could be adequately treated by overcoming only one of several lesions in series.

From 56% to 72% (mean, 63%) of threatened limbs were associated only with therapeutically significant disease below the inguinal ligament. Almost always this oc-

TABLE 3. *Locations and Level or Levels of Therapeutically Significant Arteriosclerotic Lesions in all First-time Threatened Limbs as Determined by the Arterial Procedures Performed*

Period	1						2					3					
Year	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Total
Total limbs threatened for first time	132	124	117	163	147	191	255	244	247	264	290	240	262	281	220	188	3365
Primary major amputation	52	48	34	26	29	23	45	42	36	32	41	18	36	32	11	10	515
Sympathectomy alone	31	29	7	0	2	1	0	1	1	1	1	0	0	1	0	0	75
Arterial procedures	54	49	78	135	118	168	210	202	210	232	249	222	226	249	209	178	2789
Suprainguinal procedures alone*	19	16	17	33	32	29	63	53	56	52	58	63	57	73	51	41	713
	35%	33%	22%	24%	27%	17%	30%	26%	27%	22%	23%	28%	25%	29%	24%	25%	26%
Infrainguinal procedures alone*	32	32	56	85	75	113	118	131	132	159	169	132	141	145	131	111	1762
	59%	65%	72%	63%	64%	67%	56%	65%	63%	69%	68%	59%	62%	58%	63%	62%	63%
Multilevel supra and infrainguinal procedures*	3	1	5	17	11	26	29	18	22	21	22	27	28	31	27	26	314
	6%	2%	6%	13%	9%	15%	14%	9%	10%	9%	9%	12%	12%	12%	13%	15%	11%
Multilevel infrainguinal procedures*	12	11	16	39	31	56	59	70	72	82	85	71	82	84	80	62	912
	22%	22%	21%	29%	26%	33%	28%	35%	34%	35%	34%	32%	36%	34%	38%	35%	33%
Total multilevel procedures	15	12	21	56	42	82	88	88	94	103	107	98	110	115	107	88	1226
% Total multilevel procedures*	28%	24%	27%	41%	36%	49%	42%	44%	45%	44%	43%	44%	49%	46%	51%	49%	44%

* Percents represent fraction of total arterial procedures in that year receiving that treatment.

TABLE 4. *Therapeutically Significant Patterns of Arteriosclerotic Lesions in 2829 patients with a First-time-Threatened Limb**

Years	Period 1 1974–1979	Period 2 1980–1984	Period 3 1985–1989
Total number of patients	759	1055	1015
Number treated by sympathectomy alone (%)	70 (92%)	4 (0.4%)	1 (0.1%)
Number treated by primary major amputation (%)	212 (28%)	196 (19%)	107 (11%)
Number treated by operation or PTA for aortolliac lesion (%)	146 (19%)	252 (24%)	252 (25%)
Number treated by operation or PTA for superficial femoral and popliteal artery lesions (%)	238 (31%)	374 (35%)	336 (33%)
Number treated by operation or PTA for infrapopliteal artery lesions (%)	98 (13%)	229 (22%)	320 (32%)

* When patients treated by sympathectomy and primary amputation were excluded, the initial arterial intervention indicated the pattern of arteriosclerotic lesions. Arterial interventions were classified on the basis of the most proximal lesion treated, except for the group undergoing treatment of infrapopliteal artery lesions. Many of these latter patients also had treatment for lesions of the superficial femoral and proximal popliteal arteries. PTA, Percutaneous transluminal angioplasty.

curred at two or more levels, although only 21% to 38% (mean, 33%) required a therapeutic procedure for at least two of these infrainguinal levels of disease. Another 2% to 15% (mean, 11%) of threatened limbs were associated with suprainguinal and infrainguinal lesions, which both required interventional treatment.

Table 4 summarizes data for the three time periods on numbers and percentages of patients who had sympathectomy, primary amputation, or initial therapeutic interventions at various levels of the arterial tree. The groups treated by arterial procedures reflect the predominant patterns of therapeutically significant arteriosclerotic lesions, although these data do not stratify for single-level and multilevel lesions requiring treatment. The most striking change in the therapeutically significant disease patterns in these patients was the increase in the proportion receiving treatment of infrapopliteal artery lesions. This increased from 13% in the first period to 32% in the latter period ($p < 0.001$). Because there was a concomitant decrease in the proportion of patients treated by primary amputation and sympathectomy, it is probable that many of these latter patients in the earlier periods could have been better treated by an intervention extending to the infrapopliteal arteries. However the significance of their distal disease was unrecognized and often techniques and strategies for dealing with it were not yet developed.

Table 5 summarizes for the three periods the increasing frequency of recognized therapeutically significant disease restricted to the arterial tree distal to the midthigh and distal to the knee joint. More than one fourth of our patients in the last 5 years were recognized to have these distal disease patterns. Undoubtedly many other patients, in the early periods of the study, had similar patterns of disease, although they were not recognized. Many of these patients probably were treated less effectively by sympathectomy and amputation.

Impact of PTA

Table 6 shows that 34% of all 2221 patients presenting for the first time with a threatened limb in the last 11 years were treated by PTA. However only 19% (or 426 patients) had PTA alone. The remaining 15% (or 331 patients) of the total had a PTA and an operation. Usually this was for another lesion proximal or distal to the one treated by PTA. However in 11% (or 86) of patients treated with PTA, the operation was because the PTA had a complication or failed.

Secondary Procedures

Secondary interventions performed for failed or failing previous procedures in the latter two 5-year periods are recorded in Table 2. Of all patients treated in those 10 years, 32% required a secondary procedure. Reoperations for failed or thrombosed procedures comprised 72% of the secondary procedures, while 28% of the secondary

TABLE 5. *Numbers and Percentages of First-time-Threatened Limb Patients who Had Therapeutically Significant Disease Only Distal to the Midthigh or the Knee Joint, as Indicated by the Performance of Therapeutic Procedures Only Distal to These Levels*

Years	Period 1 1974–1979	Period 2 1980–1984	Period 3 1985–1989
Total number of patients	759	1055	1015
Number treated with operation or PTA only distal to midthigh (%)	8 (1.1%)	182 (17%)	262 (26%)
Number treated with operation or PTA only distal to knee joint (%)	6 (0.8%)	107 (10%)	160 (16%)

PTA, percutaneous transluminal angioplasty.

TABLE 6. *Role of PTA in Treating Patients Presenting for the First Time with a Threatened Limb from January 1, 1979 to December 31, 1989**

	Number		Percent of All Patients	Percentage of PTA-treated Patients
Total patients	2221		100%	—
Total patients treated by PTA	757		34%	100%
Total patients treated by PTA alone	426		19%	56%
Iliac arteries		347		
SFA/PA		342		
DA		72		
Deaths/%		4/0.9%		
Total patients treated by PTA and operation	331		15%	44%
Proximal to bypass		184	8%	24%
Iliac arteries			136	
SFA/PA			48	
In or distal to bypass		61	3%	8%
SFA/PA/DA			11	
Vein graft			50	
For PTA complication or failure		86	4%	11%
Iliac arteries			36	
SFA/PA			36	
DA			14	

* PTA, percutaneous transluminal angioplasty; SFA, superficial femoral artery; PA, popliteal artery; DA, infrapopliteal artery. Patients having PTA alone often had lesions treated at several levels.

procedures (either reoperation or PTA) were performed for failing or threatened but unthrombosed previous interventions. The total number of secondary procedures and the proportion for failing interventions increased significantly ($p < 0.001$) in the most recent 5-year period.

Mortality, Failures, and Amputations

Table 7 lists the proportion of prosthetic grafts and the 30-day mortality, failure (thrombosis), and major amputation rates for the various surgical procedures during the last 5 years. The overall 30-day mortality rate was 3.3%, the failure rate was 4.1%, and the major amputation rate was 2.4%. The procedural mortality rate for PTA alone during an 11-year period was 0.9% (Table 6).

Major Amputation Rates

Overall major primary, secondary, and total amputation rates for the entire 16 years of the study are shown in Figure 2. The gradual decrease in total amputation rates from 49% to 14% is highly significant ($p < 0.001$) and reflects overall improvement in the treatment of this disease process. The gradual decrease in the primary amputation rate from 41% to 5% is also highly significant ($p < 0.001$) and approaches the 4% of our patients who are subjected to primary amputation because of extensive midfoot infection or necrosis or severe organic mental syndrome. This means that few recent patients (less than 1%) were undergoing primary amputation because of arterial disease that was deemed impossible to treat. The decrease in the secondary amputation rate after 1978 from 28% to 9% also was significant ($p < 0.001$). It means that more aggressive arterial interventions and increasing operability were providing durable limb salvage and not merely delaying amputation by converting primary major amputations to secondary ones.

Discussion

This review of 16 years' experience with patients who have lower-limb–threatening ischemia from infrarenal arteriosclerosis establishes several facts and raises several questions. Patients who present with this problem generally have diffuse, multilevel disease that often requires treatment by PTA or bypass procedures above and below the inguinal ligament or at multiple levels below the groin to save the limb. Furthermore the occlusive or stenotic disease process involves infrapopliteal arteries in at least one third of these patients and in about one fourth it involves the arterial tree predominantly below the midthigh or knee. Although patterns of arteriosclerotic disease in the lower extremity have been studied for many years and the frequency of distal popliteal and infrapopliteal disease appreciated,[32] only recently has the therapeutic significance of this distal disease been realized and methods developed for visualizing it arteriographically and treating it with a high degree of success. Recognition of the importance of distal disease and development of effective techniques for overcoming it have contributed importantly to recent improved operability rates and declining primary amputation rates. In the last few years, less than 1% of patients who had threatened limbs and had not been invasively treated before had patterns of arterial disease that were unsuitable for some attempt at revas-

TABLE 7. *Operative Procedures Initially Performed for Threatened Limbs in the Last 5 Years (January 1, 1985 to December 31, 1989) and 30-day Mortality, Failure, and Amputation Rates**

Operation	Number Performed	Percentage of Prosthetic Grafts	30-day Mortality Rate (%)	30-day Failure Rate (%)	30-day Major Amputation Rate (%)
Aorta or iliac to femoral bypass	116	100	2	2	1
Axillofemoral bypass	56	100	6	4	2
Femorofemoral bypass	118	100	2	3	1
Femoropopliteal bypass	433	42	3	4	2
Femorotibial/peroneal bypass	191	16	4	5	4
Popliteal or tibial to tibial/ peroneal bypass	233	4	3	4	4
Total	1147	44	3.3	4.1	2.4

* When multilevel lesions were treated, the operation performed for the most proximal lesion was the one included in this table.

cularization. Although our data document a progressive increase in the proportion of therapeutic procedures to overcome multilevel and distal arteriosclerotic lesions (Tables 1 and 3), these changes in treatment do not indicate that the actual pattern of the disease is changing, but rather that our perception or recognition of its therapeutic significance is changing.

Opinions diverge about the frequency of predominantly infrainguinal disease and that mainly or only below the midthigh and knee. Although our review suggests that these therapeutically significant patterns of disease are common (Tables 3 to 5), we may be seeing a selected population of patients with a misleadingly high incidence of predominantly infrainguinal and distal disease. This can be determined only when data from other centers becomes available. Similar confirmation of the high incidence of multilevel disease in limb salvage patients also should be sought. However our therapeutically derived data (Table 3) tends to underestimate the frequency of multilevel disease because many hemodynamically significant lesions were present in our patients but did not require treatment to save the involved limb.

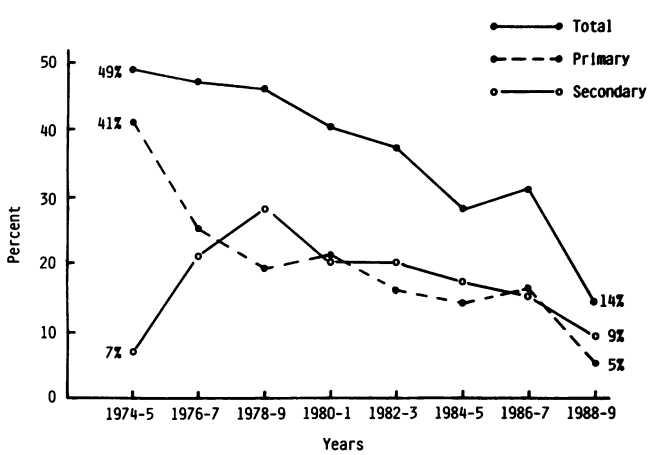

FIG. 2. Amputation rates in all patients with threatened limbs. Primary amputations were those at the above-knee or below-knee levels without previous vascular interventions. Secondary amputations were major amputations performed any time after an arterial intervention. Total amputations were all major amputations.

Our review underscores the importance of careful follow-up of limb salvage patients with reintervention if an initial procedure thromboses and fails and the limb is rethreatened. Such secondary procedures are worthwhile in terms of enhanced limb salvage.[1,24,25,27] Even more important is reintervention for a failing graft, which is not yet thrombosed but is threatened because of intimal hyperplasia or progressive disease in its inflow or outflow tract or in the graft itself.[18,21-27] Even though the need for some secondary procedures may be reduced due to improving surgical management, the number remains high (Table 2). This indicates that secondary treatment of disease progression and other problems and failures of primary procedures remain an important part of the management of these patients and one that must be pursued diligently if the optimal limb salvage results are to be achieved.

In situ vein graft techniques have been credited with much of the improvement that has occurred in the management of patients with threatened lower limbs.[33] We believe that this is true but not because *in situ* vein grafts have been proved to have better patency than reversed vein grafts.[34] As *in situ* techniques have become popular, they have led to more widespread use of careful microtechniques using special instruments, headlight illumination, and sometimes loupe magnification, all methods we have used and advocated for many years.[1,35] When such methods are used with reversed vein grafts, excellent results also can be obtained even in disadvantaged circumstances.[7,34] Furthermore *in situ* techniques are not feasible in many patients requiring a secondary operation, while use of an ectopic reversed vein graft is. Thus it is important that vascular surgeons not restrict themselves to *in situ* techniques.

Another technical modification that facilitates use of autologous vein grafts, particularly in the increasingly

common group of patients requiring a secondary operation, is use of short distal origin grafts. Our data suggests that such grafts work well and have other advantages besides increasing vein use.[7,13] However proximal disease progression is a consideration, although it rarely causes graft thrombosis in our experience.

The present review demonstrates that PTA, when it was feasible in limb salvage patients, was usually a simpler, safer, often complimentary mode of therapy. In the last 10 years, 34% of our limb salvage patients were treated by PTA (Table 6). However 44% of these patients required an operation as well. Usually the operation was needed for a second lesion that could not be treated by PTA. Overall treatment thus was simplified, as has been found by others.[36] On other occasions PTA of a lesion in, proximal to, or distal to a bypass graft improved graft flow and relieved ischemia or prevented graft thrombosis. In only 11% of patients treated by PTA was an operation needed because a PTA failed or had a complication. Usually these latter operations, although more urgent, were the same or only slightly more complex than the operation that would have been required had the PTA not been attempted.[37] Furthermore when PTAs failed early or late, reintervention, usually by operation, almost always was possible. Therefore we remain enthusiastic about PTA when it is feasible in this group of patients. It is more an adjunct and aid to the surgical treatment than a competing mode of therapy. This may not be true with other forms of endovascular treatment by lasers, stents, and atherectomy devices, but this must be determined. It is not true in the treatment of patients with intermittent claudication, who generally have easier lesions to treat within a less diseased arterial tree. If treatment is warranted in such patients, it may be accomplished more safely by endovascular means alone than by open operation. However this remains to be proved, and the long-term risks and benefits of these treatments have yet to be determined. Until they are determined, we believe that patients with arterial lesions that are easy to treat generally do not need treatment. In contrast the limb salvage patients, who clearly need improved circulation but are difficult to treat by any interventional method, should be treated by whatever method proves safest and most effective. Because of the complexity and extensive nature of their disease, some form of operative bypass treatment was required in 81% of recent limb salvage patients, although often it was simplified or facilitated by PTA. In the future other newer endovascular methods may provide additional improvements in the management of these patients.

Our previous work showed that aggressive efforts by surgeons and other medical specialists to save limbs were effective. Despite the fact that 90% of patients had attempts at limb salvage, the procedural mortality rate averaged 3%, and more than 85% of patients retained a functional limb until they died.[1] The present review provides further documentation of the effectiveness of this aggressive approach. The primary major amputation rate of 5% in the last 2 years approaches the irreducible minimum proportion of patients (4%) who have severe organic mental syndrome and extensive midfoot gangrene or infection. Furthermore the proportion of patients subjected to secondary major amputation ranged between 9% and 15% during the last 5 years. These secondary amputations resulted from final, incorrectible early or late failure of limb salvage procedures. If our extension of limb salvage efforts to additional patients with more difficult distal patterns of disease had not been successful, it would have been reflected in an increasing number and proportion of secondary amputations.

Therefore we conclude that limb salvage efforts are worthwhile and that they should be extended to mentally functional patients with all apparent patterns of arteriosclerotic disease, provided extensive gangrene or infection does not involve the midtarsal region of the foot. Although the operative and radiographic procedures required to treat many of these patients often are difficult and require skill and commitment, they are rewarded with success in most instances. The resulting outcome is beneficial both to the patient and to society.

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Discussion

DR. JONATHAN TOWNE (Milwaukee, Wisconsin): To my knowledge, this is the largest series of surgically treated patients with occlusive disease of the lower extremities. The operability rate of 99% in previously unoperated patients is outstanding. We agree with the desirability of autogenous repair and the good results of grafts originating from the distal superficial femoral artery, popliteal, and in our experience, occasionally tibial vessels. We do not share the author's enthusiasm for sequential bypasses. In our experience it is rarely needed to maintain graft patency or necessary to supply sufficient arterial flow to heal foot lesions. I would ask Dr. Veith to explain his indications for doing sequential bypasses. Also, I was curious, in this series what is the incidence of diabetes and its relatively changing incidence through the years?

As one reads Dr. Veith's manuscript, I wonder if it is possible to identify a group in whom it is technically possible to do a bypass but because short-term results are not as good, primary amputation may be more desirable.

Finally, when is enough, enough? When is the reoperative vascular repair not likely to be successful, and it is better to proceed to primary amputation?

In looking at these patients, some of whom had seven operations, as listed in the manuscript, what is the deterioration of patency and limb salvage curves as one adds additional operative procedures?

DR. ROBERT P. LEATHER (Albany, New York): As you know, Dr. Veith has been an enthusiastic advocate of arterial reconstruction for the prevention of amputation, a concept that originally was popularized in the late 1950s by the late Alfred Humphreys of this society. Dr. Veith's commitment can be best characterized as aggressive, persistent, and creative based on and encouraged by the constantly improving results about which we have just heard.

However I feel compelled to suggest that the title should be changed to 'Changing Management Patterns and Strategies in the Treatment of Limb-threatening Ischemia, Due to Atherosclerosis.'

I say that because I don't believe the occlusive patterns have changed, but our perception of them has, and our confidence in carrying bypasses to evermore distal arteries has steadily increased.

Our own experience in Albany, reported to this society more than 2 years ago, supports this aggressive confidence and is reflected in an even greater proportion of bypasses to the tibial level, representing more than 50% of the 2000-plus arterial reconstructions for limb salvage in the last 10 years, or in the context of infrainguinal bypasses, two tibials for each femoral-popliteal, as in contrast to the one-to-one ratio in this report.

Although we may disagree on methodology, there is complete agreement that the commitment of the surgical team is one of the most important factors in producing optimum results, for it is a tedious, time-consuming, and often frustrating effort.

I have several questions that have already been addressed, but one that struck me was the high incidence or number of revisions, constituting more than one third of the patients operated on, with 85% of these reoperations in the infrainguinal group. Does this reflect the frequent use of prosthetic material? That is, 40% in the femoral-popliteal and 16% in the femoral-tibial level.

DR. NORMAN HERTZER (Cleveland, Ohio): Lower extremity revascularization undoubtedly is the most common type of vascular surgery performed throughout the world, and many of the technical innovations that we now take almost for granted were introduced in the Bronx by