CLINICAL RESEARCH STUDIES

Efficacy of dorsal pedal artery bypass in limb salvage for ischemic heel ulcers

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Purpose: **Although pedal artery bypass has been established as an effective and durable limb salvage procedure, the utility of these bypass grafts in limb salvage, specifically for the difficult problem of heel ulceration, remains undefined.**

Methods: **We retrospectively reviewed 432 pedal bypass grafts placed for indications of ischemic gangrene or ulceration isolated to either the forefoot (n = 336) or heel (n = 96). Lesion-healing rates and life-table analysis of survival, patency, and limb salvage were compared for forefoot versus heel lesions. Preoperative angiograms were reviewed to evaluate the influence of an intact pedal arch on heel lesion healing.**

Results: **Complete healing rates for forefoot and heel lesions were similar (90.5% vs 86.5%, P = .26), with comparable rates of major lower extremity amputation (9.8% vs 9.3%, P = .87). Time to complete healing in the heel lesion group ranged from 13 to 716 days, with a mean of 139 days. Preoperative angiography demonstrated an intact pedal arch in 48.8% of the patients with heel lesions. Healing and graft patency rates in these patients with heel lesions were independent of the presence of an intact arch, with healing rates of 90.2% and 83.7% (P = .38) and 2-year patency rates of 73.4% and 67.0% in complete and incomplete pedal arches, respectively. Comparison of 5-year primary and secondary patency rates between the forefoot and heel lesion groups were essentially identical, with primary rates of 56.9% versus 62.1% (P = .57) and secondary rates of 67.2% versus 60.3% (P = .50), respectively.**

Conclusion: **Bypass grafts to the dorsalis pedis artery provide substantial perfusion to the posterior foot such that the resulting limb salvage and healing rates for revascularized heel lesions is excellent and comparable with those observed for ischemic forefoot pathology. (J Vasc Surg 1999;30:499-508.)**

Treatment of ulcerative lesions of the heel remains a challenging and often frustrating problem for the vascular surgeon. The absence of available soft tissue coverage in combination with the often debilitated nature of this patient population makes these lesions among the most difficult for which to care. Although multiple reconstructive procedures are available for soft tissue coverage of the chronic heel lesion,[1-3] their success is ultimately dependent on the restoration of adequate local blood flow.[4,5]

Multiple reports have demonstrated pedal artery bypass to be a durable and effective procedure for limb salvage in the critically ischemic foot.[6-13] Most notably in the diabetic population, in which the dorsalis pedis artery is usually spared of extensive atherosclerotic disease, restoration of pulsatile blood flow to the foot has proven to be an effective treatment for ulcerative or gangrenous lesions of the forefoot. Less clear is the role of pedal artery bypass in the treatment of ischemic lesions of the hindfoot. Although a limited subgroup analysis of pedal bypass has suggested poor limb salvage in the face of heel ulcers,[14] no detailed analysis of this difficult problem has been performed. The current review draws on our extensive experience with pedal artery revascularization to examine its role in the treatment of ischemic heel ulceration.

PATIENTS AND METHODS

From January 1990 to December 1995, 2213 infrainguinal bypass procedures were performed,

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Table I. Patient demographics

	Forefoot ulcers (n = 336)	*Heel ulcers (n = 96)*	*P value*
Mean age (y)	65.1	67.5	.21
Sex (male)	72.6%	64.6%	.13
Indications for surgery			
Ulcer	89.2%	95.8%	.05
Gangrene	40.0%	25.0%	.01
Cellulitis	18.0%	11.5%	.13
Previous operations			
Infrainguinal bypass	32.3%	35.8%	.53
Aorto-iliac bypass	1.5%	2.11%	.75
Carotid endarterectomy	5.4%	8.4%	.27
Major leg amputation	5.4%	7.4%	.71
Preoperative risk factors			
Diabetes	95.5%	90.6%	.07
Tobacco use			
Current	12.1%	18.3%	.14
Former	62.3%	49.0%	.02
Coronary artery disease			
History of *congestive heart failure*	16.0%	28.2%	.01
Angina	8.3%	13.8%	.11
Previous myocardial infarction	31.6%	32.7%	.85
Previous coronary revascularization	21.0%	19.0%	.66
Hypertension	59.3%	65.6%	.27
Renal disease			
Serum creatinine >2.0	12.1%	17.7%	.15
Hemodialysis	4.5%	9.4%	.07
Renal transplant	1.5%	2.1%	.69

with 572 grafts using the dorsalis pedis artery as the outflow vessel. This report specifically examines the 517 pedal bypasses that were placed for the indications of critical foot ischemia manifested by gangrene or a nonhealing ulcer. Patient data was extracted from a computerized database in conjunction with review of the medical records.

Patients were selected for operation on the basis of the presence of severe tibial disease in association with ischemic ulceration or gangrene limited to the heel or forefoot. Lesions of the heel were defined as tissue loss inferior to the malleoli and overlying the calcaneous, and forefoot lesions consisted of tissue loss overlying the metatarsal heads or more distally. Patients with ischemic soft tissue breakdown between the calcaneous and metatarsal heads (plantar region) were excluded from further analysis.

Digital angiography was performed preoperatively to assess available revascularization options. Short bypasses originating from the popliteal artery were performed when angiographic studies excluded significant proximal occlusive disease. The dorsalis pedis artery was chosen as the outflow vessel when no tibial vessels were in direct continuity with the foot. Biplanar views of the foot were obtained to clearly demonstrate the pedal anatomy.

Patients discharged with patent grafts were seen in follow-up at 2 weeks, then every 3 months for 1 year, and then at 6- to 12-month intervals. Additionally, patients with open wounds were seen at 2-week intervals until the wounds were healed. Graft patency was determined by the presence of a palpable graft or dorsalis pedis artery pulse. Patient survival was verified through a search performed by using the Social Security Death Index. Primary and secondary patency, limb salvage, and patient survival were analyzed by the life-table method by using standardized reporting criteria.[15] Life tables were compared by log-rank testing. Patient characteristics, graft characteristics, healing rates, and complication rates were compared between groups with χ^2 analysis.

To assess the role of an intact pedal arch in ulcer healing, available preoperative angiograms for patients in the heel lesion group were retrospectively reviewed to assess for a connection between the dorsal and plantar circulation of the foot. Patency of the dorsalis pedis from its origin to the lateral plantar through the deep plantar artery was considered as an intact pedal arch.

RESULTS

Five hundred seventeen consecutive pedal artery grafts were available for analysis. Patients in whom the location of tissue loss could not be accurately

Table II. Graft characteristics

	Forefoot ulcers (n = 336)	*Heel ulcers (n = 96)*	*P value*
Inflow vessel			
External iliac artery	0.6%	0.0%	.44
Common femoral artery	25.6%	30.2%	.37
Superficial femoral artery	12.2%	8.3%	.29
Profunda femoris artery	0.3%	0.0%	.59
Above-knee popliteal artery	13.4%	9.4%	.29
Below-knee popliteal artery	42.0%	46.9%	.39
Tibial artery	0.6%	1.0%	.64
Vein graft	4.8%	3.1%	.49
Prosthetic graft	0.6%	1.0%	.64
Conduit			
In situ saphenous vein	27.1%	27.1%	.99
Reversed saphenous vein	28.9%	20.8%	.12
Nonreversed saphenous vein	26.8%	35.4%	.10
Arm vein	8.9%	6.3%	.40
Composite vein	6.3%	8.3%	.47
Composite vein/PTFE	2.1%	2.1%	.99
Sequential graft	4.8%	2.1%	.25

PTFE, Polytetrafluoroethylene.

determined (n = 39) and in whom ulcer healing could not be followed for greater than 3 months (n = 40) were excluded from the analysis. Of the 79 patients who were excluded from further analysis, 13 patients (16%) experienced primary graft occlusions ranging from 1 to 29 months, with five of these occlusions occurring within 1 month and an additional three occurring within 6 months of the initial operation.

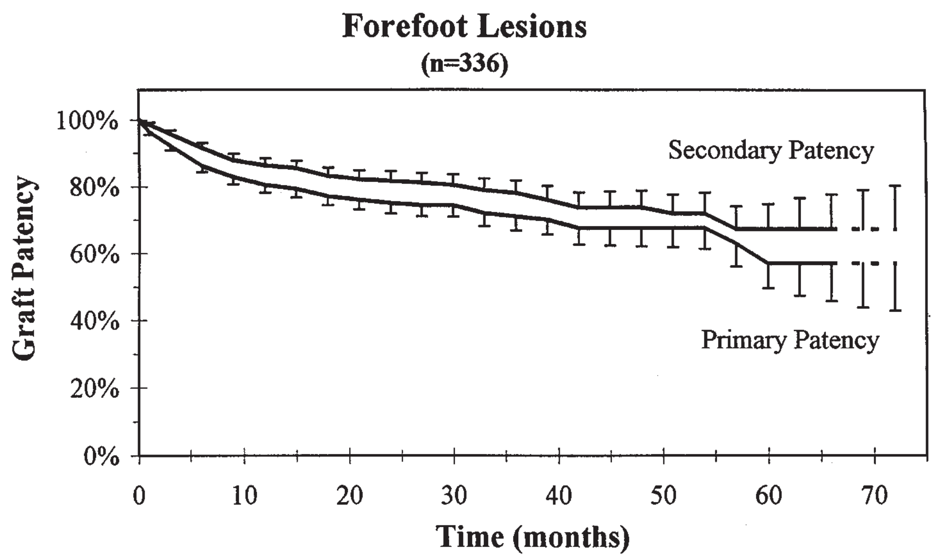
As such, we reviewed the results of 336 patients who underwent pedal bypass for forefoot lesions, 67 patients who underwent revascularization for isolated heel lesions, and 29 patients who underwent revascularization for both forefoot and heel tissue loss. For subsequent analyses, patients with combined forefoot and heel lesions were included in the heel lesion group. Review of these 29 patients demonstrated no significant difference from those patients with isolated heel lesions. Additionally, six patients with isolated plantar ulcers were excluded from the analysis. Within this latter group, three of the six patients did not demonstrate complete healing during the study period, with one patient ultimately requiring a major amputation.

Preoperative patient characteristics and atherosclerotic risk factors for the forefoot and heel lesion groups are summarized in Table I. Groups were similar with regard to sex and age. Not unexpectedly, preoperative indications for surgery differed between the two groups, with a higher proportion of gangrene in the forefoot lesions and a higher incidence of ulceration in the heel lesions. The incidence of previous infrainguinal or aorto-iliac bypass, carotid endarterectomy, or major limb amputation was similar between the groups. Vascular risk factors were notable for a greater incidence of former smokers in the forefoot group and patients with a history of congestive heart failure in the heel group.

Table II summarizes the graft characteristics for each patient group. Greater than 40% of the grafts originated from the below-knee popliteal position, and this was comparable in both groups. The next most common sites of inflow were the common femoral, above-knee popliteal, and superficial femoral arteries, respectively. Inflow from a previously placed vein or prosthetic graft was only used 4% of the time.

The conduit of choice was the greater saphenous vein, being equally used in an in situ, reversed, or nonreversed configuration. An arm vein was used in 8.7% of the cases, whereas a composite vein graft (with or without prosthetic material) was used 8.6% of the time. No significant differences in the type of conduit were noted between the two groups.

Life-table analysis for primary and secondary patency of the entire dorsalis pedis artery bypass experience (Tables III and IV) demonstrates 5-year primary and secondary patency rates of 61.6% and 66.8%, respectively. Focusing on the subset of patients with ischemic foot lesions, 6-year primary and secondary graft patency, limb salvage rates, and patient survival for the forefoot and heel lesion groups are presented in life-table format in Figs 1 and 2. Error bars represent the standard error for each data point, and the dashed line illustrates the portion of the curve where the standard error



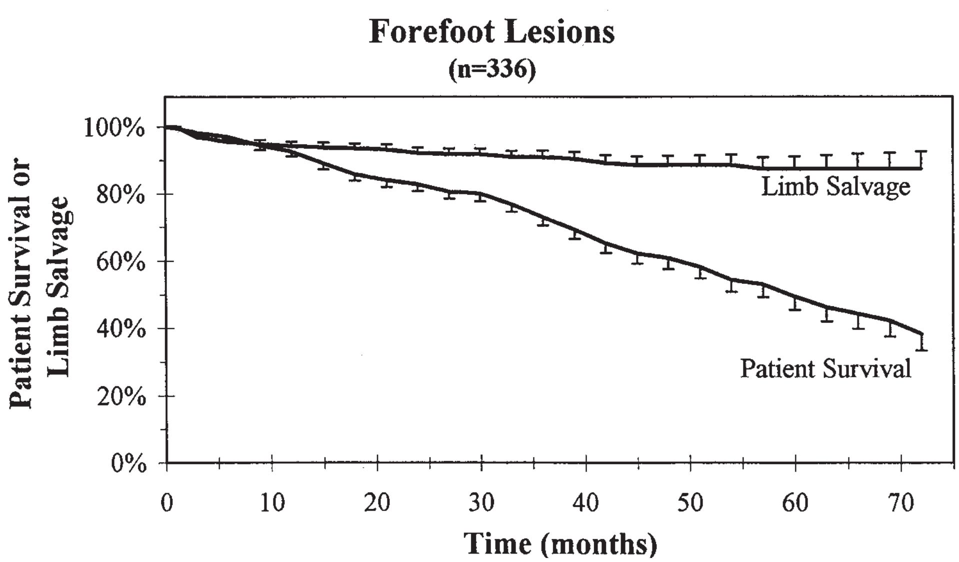


Fig 1. Cumulative primary patency, secondary patency, limb salvage rate, and patient survival for forefoot lesions.

exceeds 10%. Comparison of 1- and 5-year primary patency rates between the forefoot and heel lesion groups demonstrated no significant difference, with patency rates of 80.5% versus 80.2% (P = .95) and 56.9% versus 62.1% (P = .57), respectively. Secondary patency was restored in 30 grafts (8.9%) in the forefoot lesion group and 7 grafts (7.3%) in the heel lesion group. The most common graft successfully revised was the popliteal to dorsalis pedis artery graft (20 patients), with patency restored with a proximal jump graft from the common or superficial femoral artery in 10 patients, vein patch angioplasty for a midgraft stenosis in 5 patients, and revision of the distal anastomosis in 4 patients. The resulting secondary patency rates at 1 and 5 years were essentially identical between the groups (84.8% vs 84.5% [P = .94] and 67.2% vs 60.3% [P = .50] forefoot vs heel lesions, respectively).

Healing rates for the forefoot and heel lesion groups are provided in Table V. Complete healing of the initiating foot lesion was comparable in the two groups, with healing in 304 of 336 patients (90.5%)

Table III. Primary patency life-table analysis of all dorsalis pedis artery grafts

Internal (mo)	*No. of grafts at risk at start*	*No. of failed grafts*	*No. withdrawn patent*	*Interval patency rate*	*Cumulative patency (%)*	*Standard error (%)*
0-1	538	32	30	0.94	100	1.0
1-3	476	22	35	0.95	94	1.3
3-6	419	27	42	0.93	89	1.7
6-9	350	11	20	0.97	83	1.9
9-12	319	5	30	0.98	81	2.0
12-15	284	9	19	0.97	79	2.2
15-18	256	2	22	0.99	77	2.3
18-21	232	5	26	0.98	76	2.5
21-24	201	2	18	0.99	74	2.7
24-27	181	0	20	1.00	74	2.8
27-30	161	2	21	0.99	74	3.0
30-33	138	4	19	0.97	73	3.3
33-36	115	1	15	0.99	70	3.6
36-39	99	3	11	0.97	70	3.9
39-42	85	1	14	0.99	67	4.2
42-45	70	0	9	1.00	67	4.6
45-48	61	0	8	1.00	67	4.9
48-51	53	0	7	1.00	67	5.3
51-54	46	2	7	0.95	67	5.7
54-57	37	1	4	0.97	63	6.3
57-60	32	1	12	0.96	62	6.7
60-63	19	0	5	1.00	59	8.7
63-66	14	0	4	1.00	59	10.1
66-69	10	0	1	1.00	59	12.0
69-72	9	0	2	1.00	59	12.6
72-85	7	1	6	0.75	59	12.5

with forefoot lesions and 84 of 96 patients (86.5%) with heel lesions. The mean time to complete healing was 139 days, with the distribution of healing times shown in Fig 3. Of the 12 heel lesions that failed to heal, six grafts were patent at the completion of the study period, and six grafts had failed. Within the subgroup of six occluded grafts, five limbs ultimately required major amputations, whereas among the six patent grafts, two limbs required amputation. Comparing the rates of amputation for the forefoot versus heel lesion groups, no significant difference was noted in either above-knee amputations (0.9% vs 1.0%, $P = .89$) or below-knee amputations (8.9% vs 8.3%, $P = .86$). These findings were confirmed by the limb salvage life tables (Figs 1 and 2), in which 1- and 5-year limb salvage rates were 94.2% versus 93.5% ($P = .81$) and 87.4% versus 89.4% ($P = .60$) for forefoot versus heel lesions, respectively. Limb salvage was aided by the use of limited procedures on the foot. Minor amputations were used extensively in the forefoot lesion group (162 of 336 patients), whereas a variety of other local procedures were primarily used in the heel lesion group (21 of 96 patients). The frequency of each of these individual procedures is provided in Table V. Of note, one patient with extensive heel ulceration underwent myocutaneous rotation flap closure of the defect, resulting in successful healing of the lesion.

Eighty-four angiograms (89%) were available in the heel lesion group to evaluate for the presence of an intact pedal arch. Forty-one patients (48.8%) demonstrated continuity between the dorsal and plantar circulation through the deep plantar artery. Healing rates of heel lesions were independent of the presence or absence of an intact pedal arch, with 90.2% healing in patients with a complete arch and 83.7% in patients with an incomplete arch ($P = .38$). Primary patency rates for patients with a complete or incomplete pedal arch were also similar (Fig 4), with 1- and 2-year patency rates of 76.6% versus 83.4% and 73.4% versus 67.0%, respectively.

Table VI lists the 30-day systemic and local complications encountered in this series. Most frequent were local wound complications, ranging from local cellulitis to wound dehiscence. Two perioperative deaths occurred in the forefoot lesion group, and none occurred in the heel lesion group, leading to an overall perioperative mortality rate of 0.5%.

DISCUSSION

Management of heel lesions continues to be a difficult problem, such that patients with severe heel ulcerations are often treated with primary amputa-

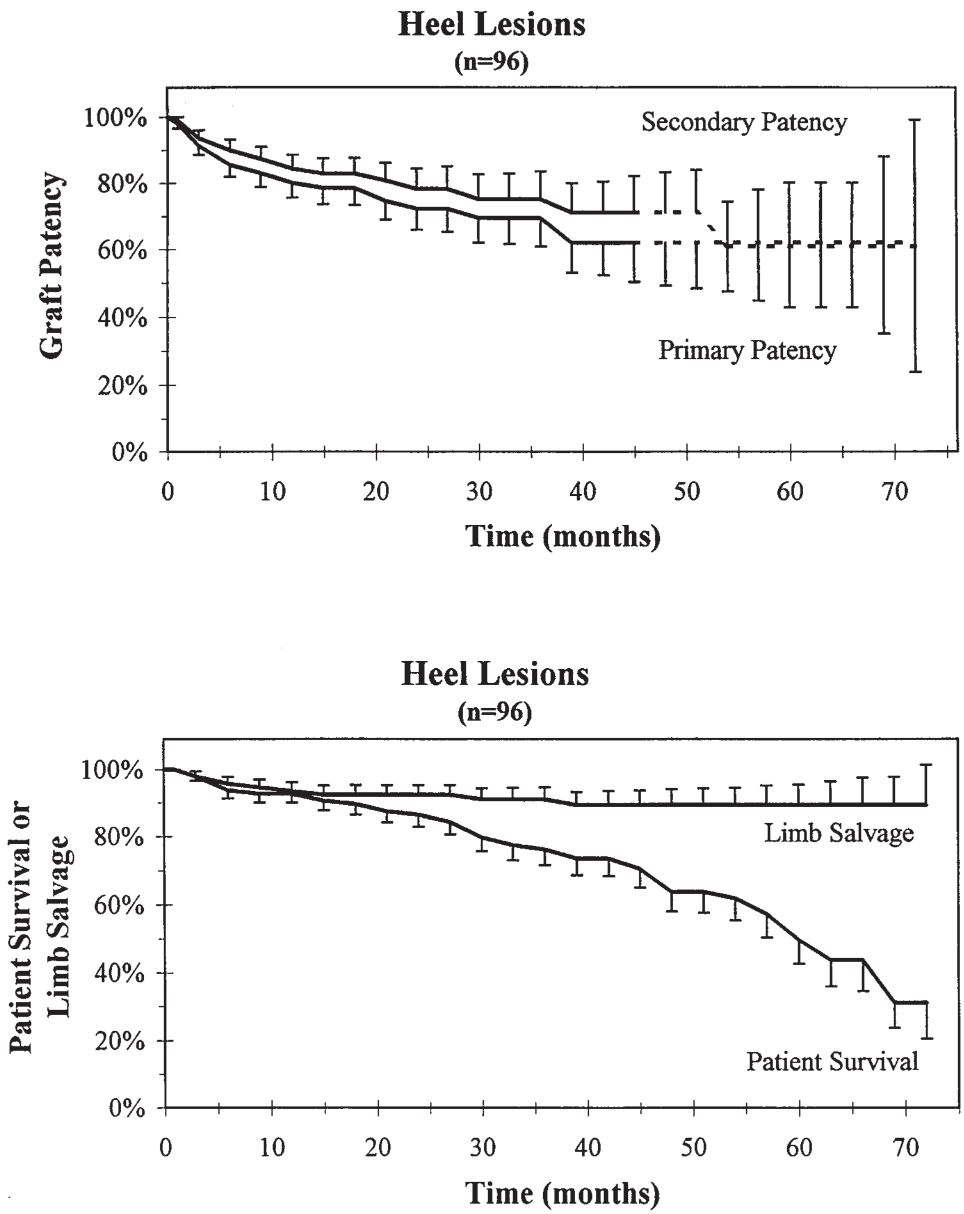


Fig 2. Cumulative primary patency, secondary patency, limb salvage rate, and patient survival for heel lesions.

tion. The combination of distal neuropathy, repeated local trauma, prolonged periods of decubitus pressure, and peripheral arterial disease make these lesions particularly problematic in the diabetic population. This is supported by the greater than 90% prevalence of diabetic subjects in the heel lesion study group of the current report.

Although many reconstructive options are available for the treatment of heel ulcers,[1-3] cornerstone to their management is the restoration of adequate arterial blood flow to the affected region.[4,5] Although direct revascularization of the hindfoot by means of the posterior tibial artery is often an attractive option, its use is frequently limited, especially in the diabetic population, by significant tibial atherosclerosis.[6,16,17] Alternatively, blood flow to the foot may be restored by means of the dorsal circulation, with perfusion of the hindfoot provided through collateral pathways.[18] The current study draws on our large experience with inframalleolar revascularization to examine the role of

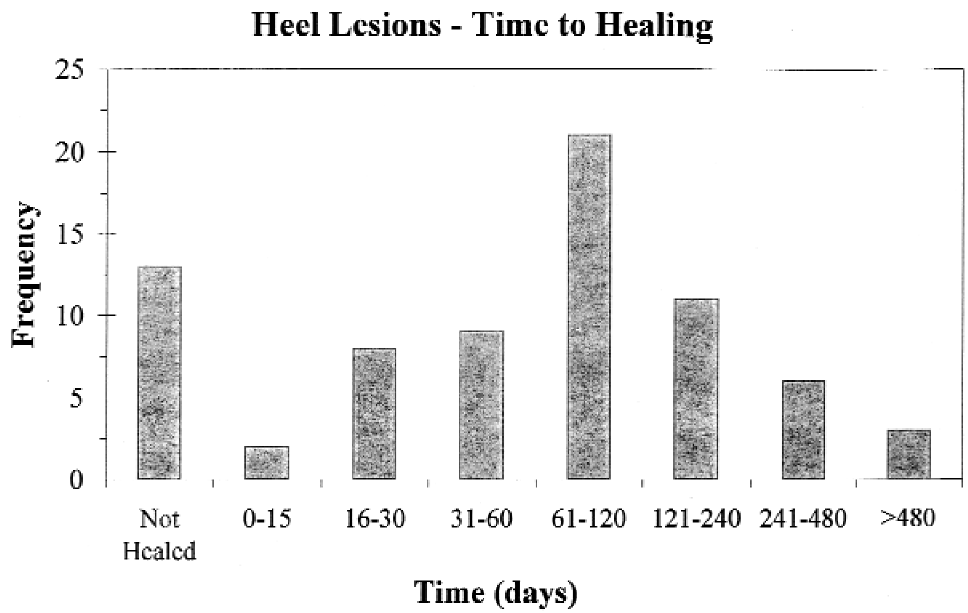


Fig 3. Frequency distribution of time for complete healing of heel lesions.

Table IV. Secondary patency life-table analysis of all dorsalis pedis artery grafts

Internal (mo)	*No. of grafts at risk at start*	*No. of failed grafts*	*No. withdrawn patent*	*Interval patency rate*	*Cumulative patency (%)*	*Standard error (%)*
0-1	538	19	30	0.96	100	0.8
1-3	489	18	35	0.96	96	1.1
3-6	436	21	46	0.95	93	1.5
6-9	369	9	22	0.97	88	1.7
9-12	338	5	32	0.98	86	1.8
12-15	301	6	20	0.98	84	2.0
15-18	275	2	22	0.99	83	2.1
18-21	251	5	27	0.98	82	2.2
21-24	219	2	21	0.99	80	2.4
24-27	196	1	21	0.99	80	2.6
27-30	174	2	22	0.99	79	2.8
30-33	150	3	21	0.98	78	3.0
33-36	126	1	18	0.99	76	3.3
36-39	107	3	12	0.97	76	3.7
39-42	92	1	14	0.99	74	4.0
42-45	77	0	9	1.00	73	4.3
45-48	68	0	9	1.00	73	4.6
48-51	59	1	7	0.98	73	5.0
51-54	51	3	9	0.94	71	5.4
54-57	39	0	4	1.00	67	6.2
57-60	35	0	13	1.00	67	6.5
60-63	22	0	5	1.00	67	8.2
63-66	17	0	5	1.00	67	9.3
66-69	12	0	1	1.00	67	11.1
69-72	11	0	2	1.00	67	11.6
72-85	9	1	8	0.80	67	12.2

dorsalis pedis artery bypass in the treatment of ischemic heel lesions.

One- and five-year patency rates for grafts placed to the dorsalis pedis artery were independent of the location of the lesion. With primary 5-year patency rates ranging between 55% and 60% and secondary patency rates between 60% and 70%, these findings are in agreement with both our previously published

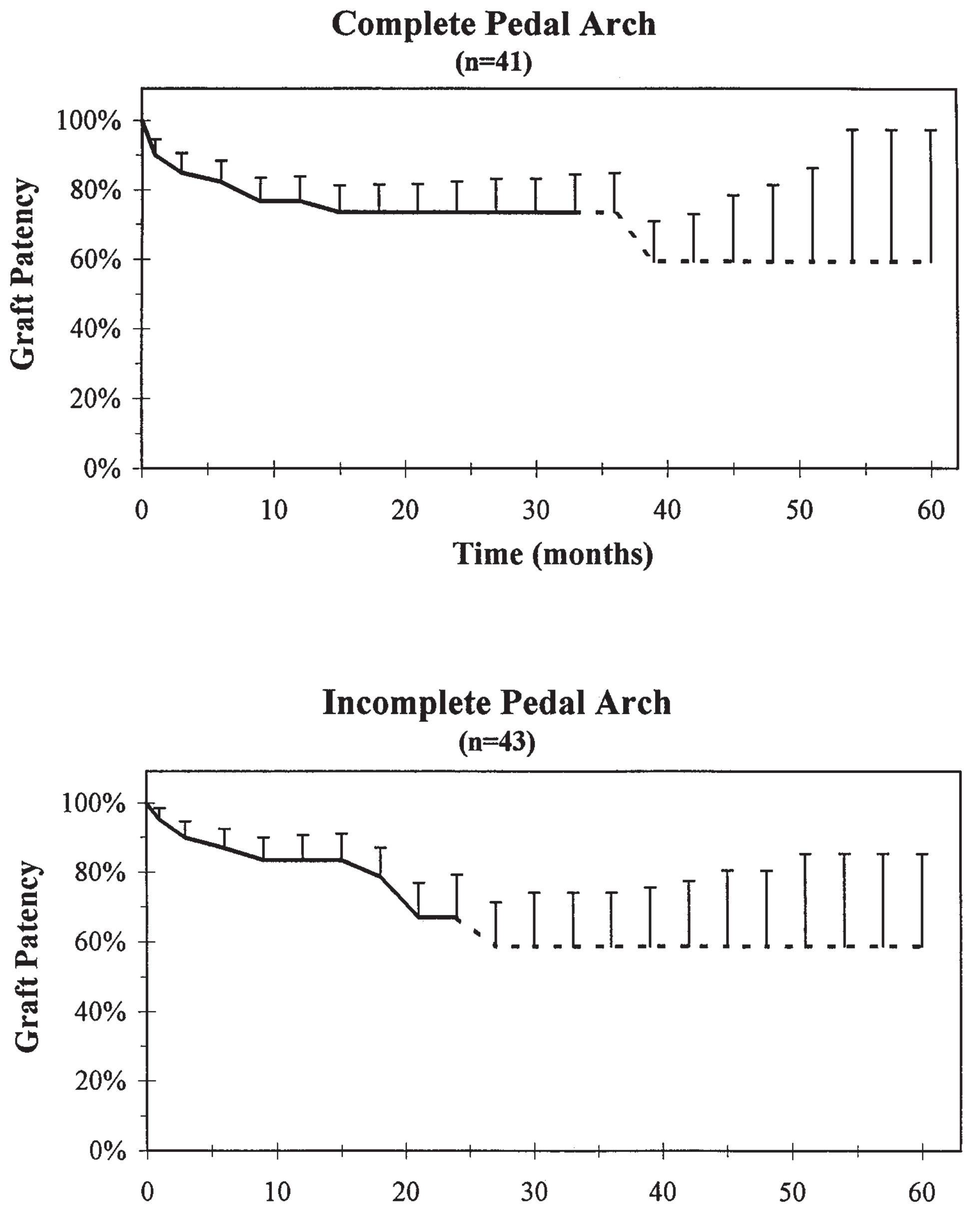


Fig 4. Cumulative primary patency rates for patients with heel lesions demonstrating a complete or incomplete pedal arch.

data[6,7] and those data provided by other groups.[8-13] Although these grafts are now widely recognized as providing adequate and durable treatment for limb-threatening forefoot ischemia, their efficacy in the treatment of hindfoot ischemia has not been systematically addressed. With healing rates approaching 90% for heel lesions, our data demonstrate that dorsalis pedis bypass effectively reverses local hindfoot ischemia to promote tissue healing. This finding is supported by a greater than 85% 5-year limb salvage rate for both forefoot and heel lesions.

Clinical presentation of ischemic heel lesions can extend over a wide spectrum of pathologies, ranging from localized skin fissures extending into the dermis to extensive necrosis of subcutaneous tissues and Achilles tendon with underlying calcaneal osteomyelitis. Of the 96 patients with heel lesions reviewed in the current series, the relative early nature of the lesions is illustrated by the need for operative debridement or reconstruction in only 23%. Those patients not requiring local heel procedures were treated with local wound care,

Table V. Healing and amputation rates

	Forefoot ulcers (n = 336)	*Heel ulcers (n = 96)*	*P value*
Lesion healed	90.5%	86.5%	.26
Major amputation			
Above knee	0.9%	1.0%	.89
Below knee	8.9%	8.3%	.86
Minor amputation			
Toe	30.4%	5.2%	.0001
Ray	8.9%	3.1%	.06
Transmetatarsal	8.9%	5.2%	.24
Local procedures			
Debridement	3.3%	15.6%	.0001
Metatarsal head resection	6.0%	0.0%	.01
Skin graft	3.3%	8.3%	.03

Table VI. Operative and postoperative complications

	Forefoot ulcers (n = 336)	*Heel ulcers (n = 96)*	*P value*
Wound complication	11.1%	10.4%	.85
Graft occlusion (<30 days)	4.3%	4.2%	.99
Hematoma	2.1%	2.1%	.99
Hemorrhage	0.9%	2.1%	.34
Congestive heart failure	1.8%	0.0%	.19
Myocardial infarction	2.1%	3.1%	.55
Death (<30 days)	0.6%	0.0%	.02

packing of open wounds with normal saline or one-quarter strength povodine-iodine solution, and systemic antibiotics as indicated. Of these 75 patients with limited tissue loss, 88% demonstrated complete healing of their lesion. In the 21 patients with more extensive tissue loss requiring operative intervention, initial treatment consisted of prompt drainage of deep space infections with local wound care as described above. After revascularization in these patients, soft tissue coverage was obtained by means of a variety of procedures. If the lesions demonstrated a healthy granulation bed overlying the calcaneous, split thickness skin grafting over the defect was performed. With lesions demonstrating evidence of calcaneal exposure and presumed osteomyelitis, primary therapy consisted of partial calcanectomy with primary closure of the wound. If the extent of skin loss was too extensive for primary closure, skin edges were approximated with retention sutures, and the remaining defect was allowed to heal by secondary intention. Direct skin grafting to an exposed calcaneous or use of radiologic testing for the diagnosis of osteomyelitis were not used in these patients. Soft tissue defects too large for approximation after calcanectomy were treated with myocutaneous grafts. Of the 21 patients who underwent operative debridement and reconstruction, complete healing of their lesions was accomplished in 81%.

Although no direct comparison of our findings to previous studies are available, the influence of chronic heel ulcerations on limb salvage was addressed in the subgroup analysis of Carsten et al.[14] In reviewing 191 infrainguinal bypasses, they determined that 5 of 17 major amputations that were performed despite a patent graft resulted from chronic neuropathic heel ulcers. This is in contrast to our series of 432 dorsalis pedis bypasses in which only two patients with non-healing heel lesions and patent grafts ultimately required amputation.

The difficult problem of heel ulceration in the diabetic patient with peripheral vascular disease is illustrated by the data of Smith et al.[3] Thirteen of twenty-three (57%) patients required an average of 33 weeks after arterial bypass to completely heal their lesions. Six patients (26%) in their study coexisted with some wound areas remaining open, and two patients (9%) required amputation. Although our 90% healing rate, with an average time to healing of 20 weeks, is an improvement over these findings, we report a similar 10% major amputation rate.

The status of the pedal arch and its contribution to outflow resistance (and secondarily pedal graft patency) remains an area of controversy.[8,17-19] Less well studied is the influence of an intact pedal arch on heel lesion healing, notably after placement of a dorsalis pedis bypass graft. Our data demonstrate that both graft patency and lesion healing are not dependent on the angiographic presence of a complete arch. As such, results of this study would argue that in the absence of an intact pedal arch, sufficient collateral pathways are present to revascularize the heel after restoration of pulsatile flow to the forefoot circulation.

In conclusion, although heel lesions remain a difficult problem in the care of vascular patients, dorsalis pedis artery revascularization serves as a useful adjunct to their treatment. With pedal artery bypass in association with adequate local debridement, aggressive wound care, and reconstructive procedures when indicated, healing and limb salvage rates for heel lesions can approximate those seen with forefoot lesions.

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