The relative importance of graft surveillance and warfarin therapy in infrainguinal prosthetic bypass failure

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Background: **We sought to describe modes of failure and associated limb loss after infrainguinal polytetrafluoroethylene bypass grafting in patients lacking a saphenous venous conduit and to define specific clinical or hemodynamic factors prognostic for bypass failure.**
Methods: **We identified 121 patients (mean age, 67 years; 90 men and 31 women) with determinable outcomes (minimum follow-up, 2 months; mean, 17 months) after 130 prosthetic infrainguinal bypasses between 1997 and 2005. Ischemic presentation was rest pain in 52%, tissue loss in 34%, and disabling claudication and/or popliteal aneurysm in 14%, with 24% of patients requiring a redo bypass. Distal targets were the above-knee (n = 44), distal popliteal (n = 27), or tibial/pedal (n = 59) arteries. Sixty-six (77%) of the below-knee (BK) target (distal popliteal or tibial) bypasses had distal anastomotic adjuncts (vein cuff or patch). Duplex graft surveillance was performed at 1, 4, and 7 months after surgery and twice yearly thereafter, with recording of midgraft velocities and imaging encompassing inflow and outflow vessels. Arteriography and open/endovascular intervention was performed for stenoses identified by duplex scanning (peak systolic velocity >300 cm/s; velocity ratio >3.5). An attempt was made to salvage occluded grafts by using catheter-directed thrombolysis or open techniques. Eighty-six patients (74% of BK bypasses) were placed on chronic warfarin therapy with a target international normalized ratio range between 2 and 3. Prognostic factors were identified by using univariate statistics and multivariate logistic regression analysis.**
Results: **Three-year primary, assisted, and secondary patency rates were 39%, 43%, and 59%, respectively, for all bypasses, with no difference noted between above-knee and BK grafts ($P = .5$). At 3 years, freedom from limb loss was 75%, and patient survival was only 70%, with no adverse effect on survival imparted by amputation. Sixty-nine total adverse events occurred as a result of thrombotic occlusion (n = 51), duplex scan–detected stenosis (n = 13), or graft infection (n = 5). Forty-nine percent of all initial graft occlusions eventually led to amputation. Twenty-three grafts (27% of 86 patients) in patients maintained on chronic warfarin were subtherapeutic at the time of occlusion. Use of a distal anastomotic adjunct with BK bypasses reduced graft thrombosis (35% with vs 60% without) but did not impart a significant patency advantage ($P = .07$). Multivariate analysis revealed low graft flow (midgraft velocity ≤45 cm/s; odds ratio [OR], 6.1; 95% confidence interval [CI], 1.9-19.2), use of warfarin (OR, 8.4; 95% CI, 2.1-34.5), and therapeutic warfarin (OR, 24.6; 95% CI, 5.7-106) to be independently predictive for bypass patency. Graft patency was maintained in 89% of grafts remaining therapeutic on warfarin compared with only 55% of subtherapeutic or nonanticoagulated grafts ($P < .001$). Low-flow grafts (n = 61) occluded more frequently than higher-flow grafts (46% vs 13%; $P < .001$). Therapeutic warfarin augmented the patency of low-flow ($P < .001$) but not high-flow ($P = .15$) grafts.**
Conclusions: **Low graft flow was a more common mode of prosthetic bypass failure than development of duplex scan–detected stenotic lesions during follow-up. Early duplex scanning may be more important for characterizing midgraft velocity and related thrombotic potential and selecting patients for chronic anticoagulation. Maintenance of therapeutic warfarin is paramount in optimizing prosthetic bypass patency and limb preservation. (J Vasc Surg 2007;46: 1160-6.)**

Acknowledging the superior patency of infrainguinal saphenous vein bypass grafts (60%-85% at 5 years[1]), especially to distal popliteal, tibial, or pedal target vessels, debate continues regarding the choice of alternative conduit when a great saphenous vein is unavailable (ie, has been previously harvested) or is unusable (diameter <2.5 mm, dilated with varicose changes, or of limited length). Comparable patency rates of lower limb bypasses performed with arm vein have ranged from 40% to 90% at 3 years[2-4] but incur the added time and morbidity of vein harvest, frequent need for composite or spliced conduit construction, and a high incidence of early conduit restenosis. Although having the potential advantage of a more expeditious and less invasive procedure, infrainguinal prosthetic bypasses extended to below-knee (BK) targets have had disappointing patency rates of 12% to 40% at 3 to 5 years.[5-7] Numerous adjuncts have been suggested to improve patency and potential limb salvage rates for infrain-

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guinal polytetrafluoroethylene (PTFE) bypass. The addition of a venous cuff or patch to the distal anastomotic region of lower limb PTFE bypasses has modestly improved graft patency rates in numerous series.[5,8-10] Despite the failure to demonstrate efficacy for warfarin anticoagulation after "routine" infrainguinal bypass performed with a venous conduit from two randomized trials,[11,12] warfarin has improved patency in other "high-risk" bypass experiences[13] and may also possess a role for infrainguinal PTFE bypasses.[12,14,15] Use of duplex ultrasound surveillance may not augment the patency of infrainguinal PTFE bypasses because bypass-threatening stenoses develop most commonly in the inflow and outflow vessels,[16] but graft velocity may prove prognostic, as we recently found for prosthetic cross-femoral bypasses.[17] We reviewed our experience with infrainguinal PTFE grafts to specifically gauge limb salvage potential and the relative effectiveness of distal anastomotic adjuncts and long-term warfarin anticoagulation and to determine what role duplex ultrasound surveillance may have in patency augmentation.

METHODS

Patient cohort. A retrospective review was performed from our vascular division database identifying 121 patients (mean age, 67 years; range, 45-90 years; 90 men and 31 women) undergoing 130 PTFE infrainguinal bypasses for lower limb ischemia. This represents 16% of all infrainguinal bypasses performed between 1997 and 2005 at Tampa General Hospital or James A. Haley Veterans Hospital (Tampa, Fla). In the absence of adequate or available ipsilateral or contralateral saphenous vein, single-segment or spliced arm vein conduits were used preferentially in 14% of patients during this interval. No patient undergoing PTFE bypass had a usable saphenous vein. Seventy-eight patients (64%) did not have an adequate length or caliber (>2.5 mm) of arm vein for bypass construction according to preoperative ultrasound vein mapping. Cadaveric vein was not considered a viable option for bypass construction. PTFE bypasses were placed for rest pain alone in 52% (n = 68), ischemic ulceration or gangrene in 34% (n = 44), severe disabling claudication (grade III[18]) in 10% (n = 13), and popliteal aneurysm with associated occlusive disease in 4% (n = 5). Comorbidities included diabetes mellitus in 50 patients (39%), dialysis-dependent renal failure in 7 (6%), and previous contralateral major amputation in 13 (10%). Prior or concomitant ipsilateral inflow reconstruction (open or endovascular) was performed in 26 patients (20%), and 24 % (n = 31) had experienced failure of previous infrainguinal ipsilateral bypasses. Twelve (9%) infrainguinal PTFE bypasses were considered urgent (performed within 24 hours of ischemic presentation).

Perioperative management. All new bypasses were constructed with 6-mm PTFE conduits originating from proximal femoral arteries. Distal targets were to above-knee (AK; n = 44) and distal (n = 27) popliteal arteries or to tibial or pedal vessels (n = 59) according to preoperative or intraoperative arteriography. Distal anastomotic adjuncts were used with 67 (52%) of all bypasses and with 66 (77%) BK grafts (to distal popliteal or tibial targets; Table I). Distal vein patches (Linton or Taylor) were used in 18 cases, Miller cuffs were used in 30 patients, and composite PTFE grafts with a short length (<15 cm) of vein spliced into the BK segment were used in 15 cases. Basilic vein was the most common source for the autologous distal adjuncts. Precuffed 6-mm PTFE grafts (Impra Distaflo; Bard Inc, Murray Hill, NJ) were used in only four patients (one to an AK popliteal target). Forty-three (98%) of 44 bypasses to the AK popliteal artery were performed without distal anastomotic adjuncts.

Table I. Distal anastomotic and anticoagulation adjuncts used for 130 infrainguinal prosthetic bypasses

Variable	*Distal target vessel*	
	AK popliteal (n = 44)	*BK targets (n = 86)*
Distal anastomosis	1 (2%)	66 (77%)
Vein cuff or patch	0	48
Composite/spliced vein	0	15
Distaflo graft (Bard Inc., Murray Hill, NJ)	1	3
None	43	20
Anticoagulation		
Warfarin	22	64
None	22	22

AK, Above knee; *BK,* below knee.

Perioperative administration of an antiplatelet agent (aspirin 81 or 325 mg/d or clopidogrel 75 mg/d), dextran 40 (25 mL/h for 24 hours after surgery), and low-molecular-weight heparin (40-60 mg/d subcutaneously) was routinely used in the absence of excessive early postoperative hemorrhage. On the basis of surgeon preference but generally considered for all BK bypasses lacking major contraindications (significant risk of falls or active or recent hemorrhage), warfarin anticoagulation was initiated on the first or second postoperative day with a long-term target international normalized ratio (INR) of 2 to 3. Warfarin was used with 86 (66%) of all bypasses and 64 (74%) BK grafts (Table I). Most patients with AK popliteal bypasses were continued on warfarin prescribed for other indications (atrial fibrillation, prosthetic cardiac valves, or a known hypercoagulable state). Therapeutic low-molecular-weight heparin ($1\ mg \cdot kg^{-1} \cdot d^{-1}$) was used for most bypasses as a bridge (1-2 weeks) during early warfarin dosing after hospital discharge. Our division regulated warfarin dosing (3-6 weeks) until primary care physicians could assume management in most patients. Regardless of warfarin use, daily aspirin (81 or 325 mg) was prescribed indefinitely in all patients. Clopidogrel (75 mg daily) was prescribed indefinitely with daily aspirin for patients not receiving warfarin.

Duplex ultrasound surveillance protocol. Intraoperative duplex ultrasound assessment was performed in only 41% of patients with spectral velocity recordings obtained in the inflow and outflow arteries and autologous vein segments of the distal anastomosis. Operative revision was

generally performed for peak systolic velocities (PSVs) greater than 250 cm/s within these vessel segments. Color Doppler flow in the newly placed PTFE graft could not be visualized during surgery. However, duplex imaging of the midbypass segment (remote from operative incisions), recording of midgraft peak velocity (MGV), and measurement of Doppler imaging–derived ankle systolic (ankle-brachial index) and toe pressures were performed in most patients before hospital discharge.

Long-term surveillance included clinical assessment for recurrent limb ischemia, measurement of ankle-brachial indexes and toe pressures, and color duplex scanning. Graft surveillance was performed 4 to 6 weeks after surgery, 3 months later, and then at 6-month intervals thereafter. Color scanning after infrainguinal PTFE bypasses differed from the techniques used for lower limb vein bypasses[19] in that additional imaging was performed over a longer length (10-15 cm) of inflow and outflow arteries, and spectral recording was made from only three nonanastomotic, intragraft sites without contiguous imaging along the entire bypass in the absence of changes in waveform morphology between sites. MGV was calculated as the average PSV of these three proximal, mid, and distal bypass values, and a low-flow graft was defined as an MGV of 45 cm/s or less. The threshold criteria recommended for repair of duplex scan–detected high-grade stenosis included PSV greater than 300 cm/s and a local velocity ratio greater than 3.5.[19] Arteriography and potential intervention were also considered for a decrease in the ankle-brachial index by 0.15 or toe pressure by 20 mm Hg or a decrease in the MGV by greater than 20 cm/s associated with an adverse change in spectral waveforms in the absence of identification of a stenosis. Development of a moderate-grade stenosis (PSV >225 cm/s and a velocity ratio >2.0) prompted repeat duplex imaging at 3-month intervals. Duplex criteria for reintervention to correct recurrent repair-site abnormalities were identical to those used for the initial procedure.

Secondary interventions. Thrombotic occlusions of bypasses confirmed by duplex scanning were treated immediately with unfractionated heparin infusion and considered for salvage interventions depending on the associated limb ischemia severity. Catheter-directed thrombolysis was considered for moderate degrees of ischemia (some distal neurologic sensory loss), especially when arteries beyond the occluded graft contained significant thrombus. Open surgical thrombectomy was emergently performed for more severe ischemia (any distal motor loss) with liberal use of intraoperative thrombolytic agents in the outflow vessels. After adequate recanalization of the occluded bypass, any underlying arteriography-detected stenoses greater than 50% were treated by either endovascular or open techniques (endarterectomy, patch angioplasty, interposition graft segment replacement, or jump bypass to a new distal target artery). Anatomic criteria for transluminal balloon angioplasty of proximal or distal anastomotic graft or outflow artery stenoses revealed after recanalization of occluded bypasses or duplex scan–detected stenoses occurring in patent grafts included a stenosis length of less than 2 cm in a bypass more than 3 months after original construction. Iliac inflow stenoses of any length were generally treated with primary stenting. Repeat duplex evaluation was performed within 1 to 4 days after secondary interventions to confirm adequate repair at stenotic sites (widely patent lumen by color Doppler imaging, PSV <200 cm/s, and a velocity ratio <2). Replacement with a new PTFE bypass graft was performed after inadequate open and endovascular recanalization of failed grafts. Wide local excision and ligation of thrombosed grafts was performed at anastomotic sites to reduce the risk of new prosthetic infection. Thrombosed or patent PTFE grafts presenting with perigraft fluid collections and local signs of infection more than 3 months after construction were treated in staged fashion, as previously described.[20] Local sterilization (negative cultures and no residual purulent fluid) of prosthetic graft infections after repeated debridement procedures allowed in situ replacement with rifampin-treated PTFE. Incompletely eradicated infections or infections associated with virulent bacterial strains (gram-negative strains) were treated by in situ or extra-anatomic replacement with arm vein or other autologous vessel (endarterectomized superior femoral artery).

Data analysis. Adverse patient outcomes, including death, bypass thrombosis, graft revision, graft infection, and amputation, were recorded throughout follow-up. All patients had determinable follow-up beyond 2 months that ranged to 82 months and averaged 17 months. Patients with perioperative deaths (<60 days) were excluded to focus on longer-term modes of graft failure. Primary, assisted primary, and secondary patency; limb salvage; and patient survival were calculated by using Kaplan-Meier techniques as recommended by the reporting standards committee of the Society for Vascular Surgery.[18] Comparisons between patency curves for different treatment groups were assessed by a log-rank statistic. Potential prognostic factors associated with graft failure (thrombotic occlusion) were evaluated for categorical variables by using contingency table (χ^2 or Fisher exact tests) analyses and confirmed with a multivariate stepwise logistic regression analysis. This retrospective study was approved by our institutional review board.

RESULTS

Late outcomes. An average of 4.2 graft surveillance studies were performed after hospital discharge for each patient. Duplex studies identified 13 (10%) high-grade stenoses in patent bypasses that occurred in the inflow/proximal anastomotic graft segment in 5 cases and in the outflow/distal anastomotic graft segment in 8 cases (Table II). No stenosis was found within the body of the prosthetic grafts. Stenoses were treated by endovascular techniques in eight cases (transluminal balloon angioplasty of four proximal anastomotic graft and distal anastomotic graft stenoses each) and open revisions in five bypasses (three patch angioplasties and two segmental distal graft/distal anastomotic graft replacements). Low graft flow (MGV ≤45 cm/s) was detected in just less than half of all

Table II. Outcomes of all threatened or failed prosthetic bypasses

Occlusions (n = 51)		*Stenosis (n = 13)*		*Infection (n = 5)*	
Secondary intervention (n = 32)		n = 13		n = 4	
Open thrombectomy with revision	8	Transluminal balloon angioplasty	8	Rifampin-soaked replacement graft	2
Thrombolysis with transluminal balloon angioplasty	8	Open revision	5	Autologous conduit graft	2
Thrombolysis with open revision	2				
New replacement graft	14				
Amputation, n = 25 (49%)		n = 0 (0%)		n = 1 (20%)	

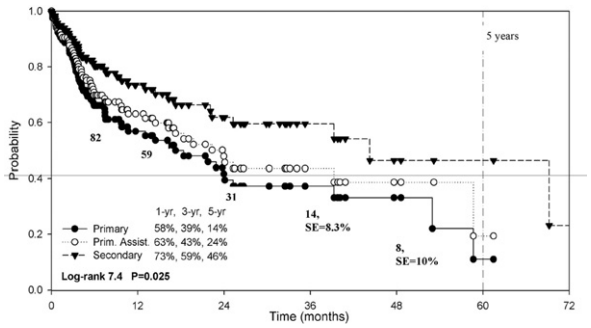

Fig 1. Kaplan-Meier estimates of primary, assisted, and secondary patency for 130 infrainguinal polytetrafluoroethylene bypasses according to duplex surveillance. The number of at-risk bypasses is shown at 6 months and annual follow-up intervals; standard error (*SE*) remained less than 10% until 4 years. Significant patency augmentation (log rank; $P = .025$) was accomplished through secondary interventions on stenotic and occluded bypasses.

bypasses (n = 61; 47%), and most was detected either during predischarge or at the initial 1-month imaging and persisted during follow-up. Eleven of 13 stenotic grafts developed low graft flow during follow-up and before secondary intervention. Bypasses to an AK popliteal target exhibited a larger proportion of high-flow characteristics (61%; 27/44) than low-flow characteristics (39%). Low flow was found in half (51%; 44/86) of BK bypasses.

Despite surveillance, 51 (39%) bypasses occluded during follow-up (Table II). There were 30 single thrombotic events and 21 multiple (recurrent) thromboses. Secondary interventions were performed for 32 (63%) occlusions. Salvage of the existing bypass was possible in 18 cases, and 14 necessitated new bypass construction. Segmental PTFE graft infection occurred in five patients (4%), with four bypasses salvaged by an interposition rifampin-treated PTFE conduit (n = 2) or autologous (arm vein or endarterectomized superior femoral artery) interposition (n = 2). One infected (and thrombosed) graft necessitated amputation, and the other 25 major amputations were performed after bypass occlusions. Graft occlusion eventually led to amputation in 49% (25/51) of afflicted patients. A single patient presenting initially with claudication (1/18; 6%) required amputation after multiple secondary interventions for multilevel disease and recurrent bypass failure.

The mean interval between bypass construction and an initial secondary intervention was 9.5 ± 12.5 months. The average time between initial and recurrent interventions was 8.9 ± 10.5 months. The overall 3-year primary, assisted, and secondary graft patency rates were 39%, 43%, and 59%, respectively (Fig 1). There was no difference ($P = .5$) in 3-year patency rates for AK popliteal (37% primary, 40% assisted, and 67% secondary) and BK (38%, 44%, and 55%) bypasses. The overall limb salvage rate for the series was 83% at 1 year and 75% at 3 years. Twenty patients died during follow-up, with two deaths attributed to treatment complications for recurrent limb ischemia. Survival was only 70% at 3 years and was not adversely affected by the need for eventual amputation (71% with amputation vs 70% without; $P = .4$).

Table III. Univariate (contingency table) analysis of potential factors associated with PTFE bypass occlusion

Variable	*Thrombosis (n = 51)*	*Patent (n = 79)*	P *value*
Sex (female)	11 (22%)	22 (28%)	.39
Smoking	25 (49%)	40 (51%)	.86
HTN	33 (65%)	52 (66%)	.90
Hyperlipidemia	18 (35%)	35 (44%)	.31
Diabetes mellitus	19 (37%)	31 (39%)	.82
CAD (angina, MI)	21 (41%)	38 (48%)	.44
COPD	6 (12%)	12 (15%)	.58
Contralateral amputation	3 (6%)	10 (13%)	.21
Prior ipsilateral bypass	13 (26%)	18 (23%)	.72
Prior/concomitant inflow procedure	12 (24%)	14 (18%)	.42
Claudication/pop aneurysm	3 (6%)	15 (19%)	.04*
Rest pain	32 (63%)	36 (46%)	.06
Tissue loss (ulcer, gangrene)	16 (31%)	28 (35%)	.60
BK target (distal pop, tibial)	35 (69%)	51 (65%)	.89
Distal anastomotic adjunct	23 (45%)	44 (56%)	.24
Distaflo graft	3 (6%)	1 (1%)	.14
Warfarin	36 (71%)	50 (63%)	.39
Therapeutic warfarin	7 (14%)	56 (71%)	<.001*
Low-flow graft (MGV ≤45 cm/s)	28 (57%)	33 (41%)	.03*

PTFE, Polytetrafluoroethylene; *HTN,* hypertension; *CAD,* coronary artery disease; *MI,* myocardial infarction; *COPD,* chronic obstructive pulmonary disease; *BK,* below knee; *MGV,* midgraft peak velocity; *pop,* popliteal.
*Significant difference between groups, $P < .05$.

Correlative analysis. Potential univariate correlates of bypass occlusion are detailed in Table III. Claudication or popliteal aneurysm at presentation and therapeutic warfarin during follow-up were associated with continued graft patency, whereas low graft flow (MGV ≤45 cm/s) was associated with thrombosis. Use of a distal anastomotic adjunct

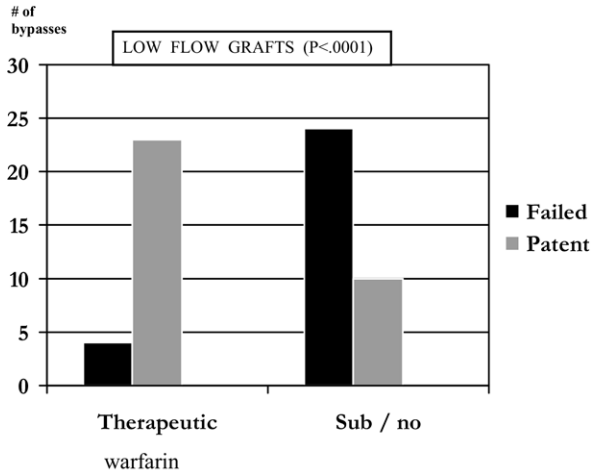

Fig 2. Thrombotic outcome of low-flow (midgraft peak velocity ≤45 cm/s) infrainguinal bypasses (n = 61). A significant patency benefit was seen for therapeutic warfarin over subtherapeutic or no anticoagulation (*sub/no*) for both above-knee popliteal ($P = .03$) and below-knee target grafts ($P = .0004$).

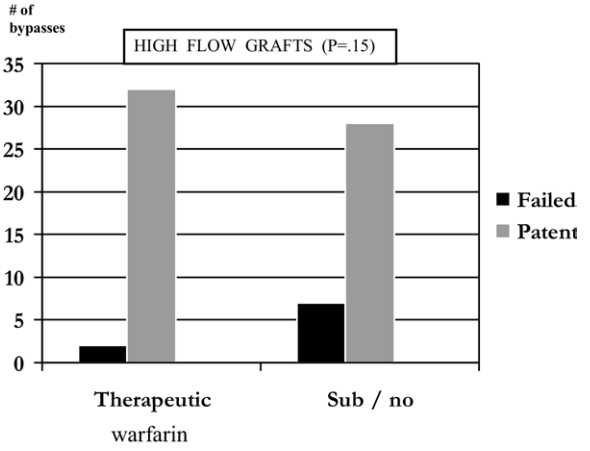

Fig 3. Thrombotic outcome of high-flow (midgraft peak velocity >45 cm/s) bypasses (n = 69). No additional benefit of therapeutic warfarin was found for infrainguinal bypasses ($P = .15$), including above-knee ($P = .27$) and below-knee ($P = .38$) target subgroups. S*ub/no,* Subtherapeutic or no anticoagulation.

did not protect against occlusion when all grafts were included. For BK bypasses, there was a stronger trend toward reduced graft thrombosis (35% [23/66] with distal adjunct vs 60% [12/20] without; $P = .07$). Multivariate logistic regression analysis revealed low graft flow (odds ratio [OR], 6.1; 95% confidence interval [CI], 1.9-19.2; $P = .002$), use of warfarin (OR, 8.4; 95% CI, 2.1-34.5; $P = .003$), and therapeutic warfarin (OR, 24.6; 95% CI, 5.7-106; $P < .001$) to be independently predictive for bypass patency. Continued patency was more frequent for higher-flow grafts (87%; 60/69) than low-flow (MGV ≤45 cm/s) bypasses (54%; 33/61; $P < .01$). Subtherapeutic anticoagulation (INR <2) was found at the time of bypass occlusion in 23 (27%) of the 86 patients treated with chronic warfarin. Graft patency was maintained in 89% (56/63) of patients with therapeutic warfarin (INR >2) dosing, compared with only 55% (37/67) of subtherapeutic or nonanticoagulated grafts ($P < .01$). Forty-five (52%) of the 86 patients placed on long-term warfarin possessed low-flow grafts, whereas 41 patients exhibited MGV greater than 45 cm/s. Alternatively, 45 (74%) of the 61 low-flow grafts were in patients taking warfarin, whereas 41 (59%) of 69 patients with high-flow bypasses received warfarin. Eighty-five percent (23/27) of low-flow grafts in patients receiving therapeutic warfarin remained patent, compared with only 29% (10/34) of grafts in patients receiving subtherapeutic doses or not receiving anticoagulation and having an MGV of 45 cm/s or less ($P < .0001$; Fig 2). The beneficial effect of therapeutic warfarin on the patency of low-flow grafts was present for both AK popliteal (100% [6/6] vs 36% [4/11] subtherapeutic/no anticoagulation; $P = .03$) and BK (81% [17/21] vs 26% [6/23] subtherapeutic/no anticoagulation; $P = .0004$) bypasses. By contrast, therapeutic warfarin was not protective for either high-flow BK ($P = .38$) or AK ($P = .27$) bypasses as a result of the overall low incidence (9/69) of high-flow graft occlusions (Fig 3).

DISCUSSION

This study sought to define failure modes related to infrainguinal PTFE grafts constructed principally for limb threatening ischemia and to define potential prognostic factors. The addition of an autologous vein patch, cuff, or short interposition segment to the distal anastomotic region was performed in most PTFE bypasses to BK targets (distal popliteal or tibial; 77%) but did not improve patency for the entire study cohort. Despite a trend toward reduced bypass occlusion when only BK grafts were studied, distal anastomotic adjuncts had less effect on patency than graft flow rate or warfarin. Although the benefit of adding a distal anastomotic adjunct to BK target PTFE bypasses has been suggested in several studies,[5,9,10,21] definitive evidence has been shown in only one randomized prospective trial.[8]

We observed that low graft flow, defined by an MGV less than 45 cm/s, was present in 47% of PTFE bypasses and was associated with twice as many bypass occlusions as development of graft-threatening stenotic lesions detected by duplex surveillance (29 vs 13). Low graft flow was most common in BK target PTFE conduits (51%) and possessed a sixfold higher risk of occlusion than high flow (MGV >45 cm/s) according to multivariate analysis. Early in-hospital duplex scanning after bypass construction can easily be performed through the typically unoperated midthigh region to characterize the graft flow regimen and aid selection of patients for chronic anticoagulation because therapeutic warfarin improved the patency of low-flow PTFE grafts to both AK popliteal and BK targets. Because of the compromised longevity of infrainguinal PTFE bypasses, we recommend that duplex surveillance be performed at pre-

scribed intervals (1, 4, and every 6 months). With added imaging of inflow and outflow arteries 10 to 15 cm beyond anastomoses, serial duplex scanning may capture the stenotic development responsible for roughly one fifth of all graft failures. Thirteen (19%) of 69 threatened or failed bypasses and 10% of all bypasses in the series had stenoses detected by duplex surveillance. The most common location of stenosis found by surveillance was at the distal anastomotic site, and it was successfully remediated by both endovascular and open techniques. Accordingly, secondary interventions performed for duplex scan–detected stenoses increased assisted patency by 5% to 10% over the primary patency distribution for PTFE grafts. Because of the high incidence of PTFE bypass failure and risk of limb loss, we recommend ongoing duplex surveillance to provide this incremental improvement in graft patency.

Maintenance of therapeutic anticoagulation (INR >2) during chronic administration of warfarin had a profound influence on PTFE bypass patency. Low-dose aspirin (81 mg) was routinely prescribed with warfarin in our series and may have potentiated its protective effect. Therapeutic warfarin markedly reduced the risk of thrombosis of low-flow (MGV ≤45 cm/s) bypasses to both AK and BK targets but not of high-flow grafts because of their lower overall risk of occlusion (13%). "Routine" use of warfarin has not improved the patency of infrainguinal bypass in several prospective trials.[11,12] However, warfarin prescribed for "high-risk" graft indications, including redo, composite saphenous or alternative (arm or small saphenous) vein bypasses, and compromised tibiotarsal outflow, has augmented patency in a randomized prospective trial.[13] Other studies have demonstrated a modest patency benefit of warfarin for infrainguinal prosthetic grafts,[12,14] thus leading to a consensus statement supporting its use with high-risk and prosthetic infrageniculate bypasses.[15] Jackson et al[22] showed a reduction in the severity of limb ischemia encountered when infrainguinal PTFE grafts occlude in patients maintained on chronic warfarin and aspirin compared with those receiving aspirin alone. This observation was potentially due to less extensive thrombus propagation into adjacent native vessels and collateral pathways in patients maintained on more aggressive anticoagulation (warfarin). In the absence of major contraindications, we would recommend long-term warfarin therapy for PTFE bypasses constructed to distal popliteal or tibial (BK) targets and all low-flow grafts, including those to the AK popliteal artery, on the basis of our results. The larger management problem lies in how to reduce the incidence (and deleterious effect) of subtherapeutic warfarin dosing. More than one quarter of our patients were subtherapeutic (INR <2.0) at the time of bypass occlusion. Even a higher rate (>40%) of noncompliance and inadequate warfarin dosing was observed in a prospective randomized study evaluating warfarin for peripheral arterial bypass constructions necessitating patient consent and acceptance of an assigned treatment regimen.[12] Optimizing patient compliance and safety during warfarin administration requires INR blood draws and dosage adjustments best organized through dedicated "Coumadin clinics," but a relative paucity of such centers exists in most hospital, clinic, and group practice systems. Reliance on primary care physicians to coordinate warfarin management may not be the best option for assuring compliance, and ultimately, the responsibility for managing warfarin therapy may lie with the operating surgeon. As we promote complete vascular care for our patients, assumption of warfarin management should become one of our efforts in practicing vascular medicine.

Finally, the most important measure of bypass construction value in treating critical ischemia is limb preservation. Midterm amputation rates more than 50% observed in a large meta-analysis of infrainguinal prosthetic bypasses performed for limb threat[5] has led to questioning offering such bypasses when no autologous venous conduit exists and primary amputation may be indicated. Limb salvage was 75% at 3 years in our series despite overall graft patency rates that were not appreciably better than those in other reported prosthetic series.[5-10,14] PTFE bypasses were a last option for most of our patients, although a small fraction presented without limb threat (grade III severe claudication). Fairly aggressive efforts were directed at salvage of existing grafts or construction of new bypasses after first-time PTFE bypass occlusions; amputation was thus avoided after initial graft failure events in two thirds of cases. Secondary interventions for occlusive lesions were durable and added an average of nine additional months of bypass patency. Treatments of prosthetic graft infections, in addition to interventions for occlusions and stenoses, were all effective in remediating bypass failures. By comparison, only 70% of our patients were alive after 3 years, with 90% succumbing to comorbidities unrelated to management of their limb ischemia. Limb preservation after infrainguinal PTFE bypass is attainable in a significant number of high medical risk patients with limited longevity and should be offered.

CONCLUSIONS

Specific modes of graft failure were detailed from a series of patients, most with limb-threatening ischemia, undergoing infrainguinal PTFE bypasses. Low graft flow threatened graft patency more frequently than development of duplex scan–detected stenoses. Therapeutic warfarin dosing significantly reduced the incidence of bypass occlusion, especially for low-flow grafts. Duplex scanning seems most important for early in-hospital determination of MGV and for selection of patients who may benefit from long-term warfarin administration.

AUTHOR CONTRIBUTIONS

Conception and design: RSB, MRB
Analysis and interpretation: RSB, MRB, DC
Data collection: RSB, MRB, PAA, MLS, BLJ, DFB
Writing the article: RSB, MRB
Critical revision of the article: RSB, MRB, DFB
Final approval of the article: RSB, MRB, PAA, MLS, BLJ, DFB
Statistical analysis: RSB, MRB, DC

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