Duplex-guided endovascular treatment for occlusive and stenotic lesions of the femoral-popliteal arterial segment: A comparative study in the first 253 cases

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Objective: **The standard technique of balloon angioplasty with or without subintimal dissection of infrainguinal arteries requires contrast arteriography and fluoroscopy. We attempted to perform this procedure with duplex guidance to avoid the use of nephrotoxic contrast material and eliminate or minimize radiation exposure.**

Methods: **From September 2003 to June 2005, 196 patients (57% male) with a mean age of 73 ± 10 years (range, 42-97 years) had a total of 253 attempted balloon angioplasties of the superficial femoral and/or popliteal artery under duplex guidance in 218 limbs. Critical ischemia was the indication in 38% of cases, and disabling claudication was the indication in 62%. Hypertension, diabetes, chronic renal insufficiency, smoking, and coronary artery disease were present in 78%, 51%, 41%, 39%, and 37% of patients, respectively. The TransAtlantic Inter-Society Consensus (TASC) classification was used for morphologic description of femoral-popliteal lesions. The common femoral artery was cannulated under direct duplex visualization. Still under duplex guidance, a guidewire was directed into the proximal superficial femoral artery, across the diseased segment(s), and parked at the tibioperoneal trunk. The diseased segment(s) were then balloon-dilated. Balloon diameter and length were chosen according to arterial measurements obtained by duplex scan. Hemodynamically significant defects causing diameter reductions greater than 30% and peak systolic velocity ratios greater than 2 were stented with a variety of self-expandable stents under duplex guidance. Completion duplex examinations and ankle-brachial indices were obtained routinely before hospital discharge.**

Results: **There were 11 (4%) TASC class A lesions, 31 (12%) TASC class B lesions, 177 (70%) TASC class C lesions, and 34 (14%) TASC class D lesions in this series. The overall technical success was 93% (236/253 cases). Eight of the 17 failed subintimal dissections belonged to TASC class C and the remaining 9 to TASC class D. End-stage renal disease was the only significant predictor of subintimal dissection failure in patients with femoral-popliteal occlusions (5/17 cases; $P < .04$). Intraluminal stents were placed in 153 (65%) of 236 successful cases. Overall preprocedure and postprocedure ankle-brachial indices changed from a mean of 0.69 ± 0.16 (range, 0.2-1.1) to 0.95 ± 0.14 (range, 0.55-1.3), respectively ($P < .0001$). The mean duration of follow-up was 10 ± 7 months (range, 1-29 months). The overall 30-day survival rate was 100%. Overall limb salvage rates were 94% and 90% at 6 and 12 months, respectively. Six-month patency rates for TASC class A, B, C, and D lesions were 89%, 73%, 72%, and 63%, respectively. Twelve-month patency rates for TASC class A, B, C, and D lesions were 89%, 58%, 51%, and 45%, respectively.**

Conclusions: **Duplex-guided balloon angioplasty and stent placement seems to be a safe and effective technique for the treatment of infrainguinal arterial occlusive disease. Technical advantages include direct visualization of the puncture site, accurate selection of the proper size balloon and stent, and confirmation of the adequacy of the technique by hemodynamic and imaging parameters. Additional benefits are avoidance of radiation exposure and contrast material. (J Vasc Surg 2006;44:1230-8.)**

Over the last two decades, surgeons have increasingly embraced endovascular techniques as an alternative mode of treatment for symptomatic infrainguinal occlusive disease. When conservative measures fail, patients are commonly offered bypass operations rather than balloon angioplasties and subintimal dissections either to enhance their walking distance or to achieve limb salvage. This approach stems mainly from the fact that these bypasses, particularly when performed with a healthy saphenous vein, provide excellent long-term graft patency rates.[1,2] However, the functional results may not be as good as previously believed, and concern has been voiced regarding a liberal approach with open arterial reconstructions.[3]

Although minimally invasive techniques in the lower extremities are associated with less morbidity and mortality as compared with bypass surgery, they are not as durable, and repeat intervention is often required.[4] Moreover, standard balloon angioplasties require contrast material and radiation exposure. Nephrotoxic contrast material can become a challenge in patients presenting with diabetes mellitus or in those with pre-existing renal insufficiency.[5-7] As

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the proportion of minimally invasive arterial procedures increases, vascular surgeons have to be more aware of the potential complications of radiation exposure, particularly to the eyes and gonads. The deleterious effects are cumulative and irreversible.[8]

In an attempt to avert these potential health hazards for the patients, the interventionists, and the medical personnel in the procedural suite, we have evaluated the alternative of using duplex techniques to guide these endovascular procedures. This article has three purposes: (1) to report on our increased experience with this approach, (2) to describe our technique of subintimal dissection and balloon angioplasty of the femoral/popliteal segment under duplex control, and (3) to analyze and compare the results obtained between occluded and stenotic arterial segments in this anatomic location.

METHODS

Patients. From September 2003 to June 2005, 196 patients had a total of 253 attempted balloon angioplasties of the superficial femoral (SFA) and/or popliteal artery under duplex guidance in 218 limbs. There were 112 (57%) men and 84 (43%) women in this group. The mean patient age was 73 ± 10 years (range, 42-97 years). Concomitant risk factors included hypertension, diabetes, chronic renal insufficiency (serum creatinine level ≥1.5 mg/dL), smoking, and coronary artery disease in 78%, 51%, 41%, 39%, and 37% of patients, respectively. Thirteen patients (6.6%) were on chronic hemodialysis. Three patients (1.5%) had a history of contrast allergy.

Overall, disabling intermittent claudication was the indication for 156 procedures (62%), and critical ischemia was the indication for the remaining 97 procedures (38%). Of these, 15 (6%) were for rest pain, 53 (21%) were for nonhealing ulcer, and 29 (12%) were for gangrene.

Failed ipsilateral bypasses were present in seven limbs (3%). Five of these were in patients with TransAtlantic Inter-Society Consensus (TASC) class C lesions, and the remaining two were in patients with TASC class D lesions. Aspirin and clopidogrel were started 48 hours before the procedure and continued during the follow-up period.

Preoperative evaluation. None of the patients in this series had preoperative contrast arteriography. Balloon angioplasty was offered to patients according to the results of preoperative duplex arteriography performed by experienced registered vascular technologists (RVTs). Preoperative duplex arteriography included assessment of the pattern and extent of occlusive disease in the femoral-popliteal arterial segment and infrapopliteal arteries.[9-11] Aortoiliac stenoses were ruled out by analysis of the common femoral artery (CFA) spectral waveform. A biphasic or monophasic waveform of the CFA warranted duplex assessment of the aortoiliac segment. Those with triphasic waveform in the CFA did not have further evaluation. Patients with significant ipsilateral suprainguinal stenoses underwent adjunctive iliac balloon angioplasty.

TASC classification was used for morphologic description of femoral-popliteal lesions.[12] The length of the occluded and stenotic lesions was measured by knowing that the L 7-4 MHz probe foot has a length of 4 cm and adding lengths of insolated images or by marking the beginning and end of the lesion on the skin by using duplex imaging and measuring it with a tape. "Flush" occlusion was defined as a totally occluded vessel within the first 5 mm of its origin.

We also complemented imaging findings with physiological studies—pulse-volume recordings (PVRs) and ankle-brachial indices (ABIs)—routinely. Whenever ABIs were unobtainable or unreliable because of noncompressible calcified arteries or nonaudible pulses, we registered ankle tracing amplitudes.

Technique. All interventions were performed with help of Philips HDI 5000 scanner with the SonoCT feature (Phillips Medical Systems, Bothell, Wash). Duplex guidance for all cases was performed by a single RVT (N.A.M.) with extensive experience in preoperative duplex arteriography. All procedures were performed in the operating room. Choice of wires, directional catheters, balloon angioplasty catheters, and stents was not affected by the type of imaging modality. The ipsilateral (227 cases; 90%) or the contralateral (26 cases; 10%) CFA was cannulated with patients under local anesthesia and with direct duplex imaging. Contraindications to antegrade ultrasound-guided CFA puncture were high bifurcation and/or deep location (≥3 cm from the skin). High bifurcation precluded antegrade CFA puncture in 12 cases, and a deep CFA did so in 10 additional cases. The remaining four contralateral access cases were in patients with ipsilateral iliac stenoses. Introducer sheath diameter varied from 5F to 7F according to the sizes of the balloons and stents. Contralateral CFA access required ipsilateral common iliac artery cannulation under fluoroscopy alone (4 cases) or with 10 mL of contrast (22 cases). Visipaque (Amersham Health, Princeton, NJ) was used in 18 cases, and Magnevist (Berlex Laboratories, Wayne, NJ) was used in the remaining 4 cases. In cases of antegrade cannulation, a 0.035-inch Glidewire (Boston Scientific Corp, Natick, Mass) was directed into the proximal SFA, across the diseased segment(s), and parked at the tibioperoneal trunk or one of the tibial arteries.

In cases of femoral and/or popliteal occlusions, a 5F angle taper directional catheter (Boston Scientific) supporting the guidewire was pointed against the wall 3 to 5 mm proximally to the occlusion to alleviate initiation of subintimal dissection. Wire loop formation was noted. The advancement of the wire through the occlusion was followed to the patent arterial segment identified by a color signal in the lumen. We attempted the re-entry within the first 1 to 2 cm after flow reconstitution to minimize the length of angioplasty. The arterial segment with the least amount of calcification and thinnest intima-media layer was chosen for re-entry. If the guidewire did not enter the true lumen after several attempts, the directional catheter was advanced and pointed toward the lumen for additional wire support. Re-entry efforts were continued cautiously to prevent extension of the dissection plane to the popliteal artery below the knee. We always tried to spare the outflow artery for

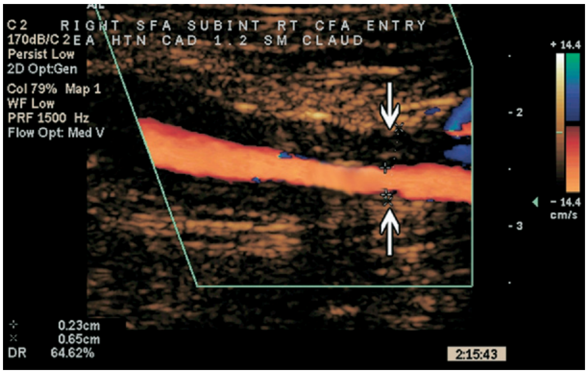

Fig 1. Intraoperative color Doppler image of the recoiling plaque in the superficial femoral artery causing 64.6% stenosis (between the *white arrows*).

possible femoral-popliteal bypass in the case of subintimal angioplasty failure. After the guidewire entered the true arterial lumen, its position was confirmed with color flow imaging in both longitudinal and transverse views.

The diseased segment(s) were then balloon-dilated under duplex guidance. Balloon diameter and length were chosen according to direct arterial measurements obtained by duplex scan. Duplex image magnification (up to 5 times) and a small error of the measurements (0.1 mm) ensured precise measurements of the arterial diameter, as well as lumen and wall thickness, and therefore eliminated oversizing or undersizing balloons and stents.[13-15]

We often used 8- and 10-cm balloons for the long lesions. Inflation times averaged 60 seconds. Completion color duplex scans of the entire ballooned segment in sagittal and transverse planes allowed identification and spectral analysis of plaque recoils and dissections (Fig 1). Dissections were diagnosed by bidirectional flow pattern or divided flow with clearly different velocities as shown by color Doppler imaging, and they were assessed by using the same peak systolic velocity (PSV) ratio criteria as recoiling lesions. Hemodynamically significant defects causing diameter reductions greater than 30% and PSV ratios greater than 2 were stented with a variety of self-expandable stents under duplex guidance. Assessment of infrapopliteal arteries by using standard imaging techniques (B-mode, color, and spectral analysis) allowed detection of distal arterial thromboses.

Postprocedure evaluation and follow-up. Arterial duplex scan and PVRs, including ABIs, were routinely obtained before hospital discharge and at regular postprocedural follow-ups in our clinic at 1 month and every 3 to 4 months thereafter. Restenosis-free patency during every follow-up duplex scan was described as the absence of a diameter reduction (≥70%) by color image and the absence of PSV step-up (>3).

Statistical analysis. The Fisher exact test (Instat version 3.06 for Microsoft Windows; GraphPad Software, San Diego, Calif) was used to compare technical success between different TASC classes of lesions—factors predictive of technical failure for subintimal dissections. Instat (paired *t* test; parametric distribution) was also used to compare preangioplasty and postangioplasty ABIs and forefoot PVR tracings. Similar analysis was used to compare technical success between different TASC classes of lesions and the incidence of infrapopliteal angioplasties in the TASC C and D groups. Arterial patency life tables (Kaplan-Meier survival test and log-rank comparison of the survival curves for different TASC classes of lesions and limb salvage rates) were calculated by using GraphPad Prism version 4.00 (GraphPad Software).

Fluoroscopy-guided femoral-popliteal angioplasties excluded from the study. There were 110 fluoroscopy-guided procedures performed during the same period of time. The reasons duplex guidance was not performed in these patients were (1) lack of RVT availability in 86 cases (78%), (2) severe circumferential calcifications preventing puncture of the CFA or visualization of the arterial lumen in 19 cases (17%), and (3) morbid obesity and overall depth from the skin to the target artery more than 5 cm in the remaining 5 cases (5%).

RESULTS

TASC classification and description of the femoral-popliteal disease. There were 11 (4%) TASC class A lesions, 31 (12%) TASC class B lesions, 177 (70%) TASC class C lesions, and 34 (14%) TASC class D lesions in this series. Of the 149 stenotic SFAs, 52 (35%) involved its origin. In 16 cases (11%), the SFA stenosis extended into the CFA. Fifteen (19%) of 81 SFA occlusions began from the CFA bifurcation ("flush" occlusions).

The overall average number of patent disease-free infrapopliteal arteries was 2.15 ± 0.93. There were 116 cases (46%) in which all 3 infrapopliteal arteries were patent and not diseased, 73 cases (29%) with 2 arteries, and 50 cases (20%) with 1 artery. The remaining 14 cases (5%) had all 3 arteries diseased or occluded.

Length of the procedure. Overall, the average procedure time was 59 ± 30 minutes (range, 14-180 minutes).

Technical success. Whereas the overall technical success rate was 93% (236/253 cases), it was 100% for TASC class A and B lesions, 95% (169/177 cases) for TASC class C lesions, and 74% (25/34 cases) for TASC class D lesions. There was no statistically significant difference between technical success rates for primary (82%) and secondary (86%) occlusions.

Adjunctive techniques. Overall, ipsilateral iliac balloon angioplasties for improvement of inflow were performed in four cases (1.6%): three in the external iliac artery and the remaining one in the common iliac artery. Also, infrapopliteal angioplasties of 60 arteries were deemed necessary in 40 cases (16%) in an attempt to improve the runoff. Of these, 33 cases (19%) were in TASC class C group, and the remaining 7 cases (21%) were in TASC class D group (P = .8).

Failed subintimal dissections. Eight of the 17 failed subintimal dissections belonged to TASC class C, and the remaining 9 belonged to TASC class D. Of the 17 cases of

Table I. Description of 11 fluoroscopy-guided angioplasty procedures in which duplex assistance was necessary for diagnosis, management, or both

No. cases	*Procedure/difficulty*	*Duplex assistance*
3	Failed re-entry to popliteal artery during subintimal dissection of SFA	Confirmation of wire position in the false popliteal lumen
2	"Flush" SFA occlusion	Initiation of subintimal dissection
2	Popliteal stenosis in patient with knee prosthesis	Popliteal artery angioplasty
1	Severe stenosis of the SFA origin in patient with hip prosthesis	SFA cannulation
1	Peroneal artery subintimal dissection	Confirmation of wire position in the true peroneal lumen
1	Guidewire deviation from the occluded SFA anatomic location	Guidewire found to be in the short occluded prosthetic bypass (not identified before surgery)
1	Failure to enter SFA occlusion with the guidewire at the midthigh level	Absent SFA (ligated after old war injury), procedure aborted

SFA, Superficial femoral artery.

failed duplex-guided subintimal SFA/popliteal artery dissection, only 2 (12%) were successfully completed with fluoroscopic guidance. Of the remaining 15 patients, 5 underwent femoral-popliteal bypasses (3 with polytetrafluoroethylene and 2 with vein), 1 required below-the-knee amputation because of a lack of revascularization options, and the remaining 9 patients are being observed. Comparison of risk factors such as age, presence of diabetes mellitus (12%), chronic renal insufficiency (CRI) (11%), combination of both diabetes mellitus and chronic renal insufficiency (CRI) (13%), and hemodialysis (38%) in these patients demonstrated that hemodialysis was the only statistically significant predictive factor of technical failure for duplex guided subintimal dissection ($P < .04$).

Stenting. Overall, stents were deemed necessary in 153 (65%) of 236 cases. The number of stents used per case ranged from 1 to 5. One stent was sufficient to treat luminal defects in 90 cases (59%), 2 stents in 38 cases (25%), 3 stents in 20 cases (13%), 4 stents in 4 cases (2%), and 5 stents in the remaining case (1%). The reasons for stenting were plaque dissections and recoils in 73 (48%) and 80 (52%) cases, respectively. Stents were placed in 6 (55%) of 11 cases in TASC class A lesions, in 17 (55%) of 31 cases in TASC class B lesions, in 111 (66%) of 169 cases in TASC class C lesions, and in 19 (76%) of 25 in TASC class D lesions.

Intraoperative and early postoperative complications. All patients left the operating room with a short sheath (5F, 6F, or 7F) in the femoral artery. It was removed in the recovery room after normalization of the activated clotting time (ACT; <150 seconds) within 60 to 120 minutes after the procedure. Early in the series, two patients bled from the ipsilateral puncture site and required groin exploration. Three additional patients (1.2%) developed bleeding in the ipsilateral calf muscles that ceased with the administration of protamine sulfate to normalize the ACT. One of these cases required leg fasciotomy.

There were 10 cases (4.2%) of intraoperative thrombosis. The proximal end of the thrombus was located at the popliteal artery in two cases, the tibio-peroneal (TP) trunk in seven cases, and the peroneal artery in the remaining case. In all these patients, the ACT was less than 250 seconds, with a mean of 213 ± 26 seconds (range, 158-248 seconds) despite adequate doses of heparin given according to weight. Additional infusion of heparin (2000-8000 U) was required to achieve ACT greater than 300 seconds until the completion of the procedure in this group.

Six of these patients required duplex guided suction thrombectomy and intra-arterial pulse-sprayed infusion of tissue plasminogen activator. The remaining four cases were treated with thrombolysis only. Two patients developed postoperative deep vein thrombosis in the ipsilateral leg.

Intraoperative contrast arteriography. Intraoperative completion arteriograms were used to confirm the adequacy of the procedure and duplex results in the beginning of this series in 41 cases (17%). Visipaque was used in 25 cases (61%) and Magnevist in the remaining 16 cases (39%). The discrepancies were found in three cases (7%) represented by two distal SFA dissections and a severe tibioperoneal (TP) trunk stenosis obscured by arterial wall calcification shadows. Conversely, there were two cases (5%) in which completion arteriograms failed to demonstrate distal SFA plaque recoil (causing 60% stenosis) and popliteal artery dissection (causing 55% stenosis), both identified by duplex scan. One (2.4%) of 41 patients who had intraoperative contrast arteriography with 30 mL of Magnevist had a postprocedure serum creatinine increase from 1.8 to 2.6 mg/dL.

Overlap of duplex and fluoroscopy guidance. The procedures for which duplex assistance was necessary to complete fluoroscopy-guided angioplasties are described in Table I. Procedures for which fluoroscopy assistance was needed to complete duplex-guided angioplasties are listed in Table II.

Periprocedural physiological parameters. For 236 successful angioplasties, reliable ABIs were obtained before and after the procedure in 203 cases (86%). Similarly, ankle PVR amplitude tracings were available for comparison in 33 remaining cases (14%). In the latter cases, ankle arterial pressure was deemed spuriously high because of severe calcification[16] or pulses were not audible.[17]

Table II. Description of four duplex-guided angioplasty procedures in which fluoroscopy and/or contrast arteriography assistance was necessary for diagnosis and/or management

No. cases	*Procedure/difficulty*	*Fluoroscopy/contrast arteriography assistance*
2	Very wide wire loop in the occluded SFA segment during attempted subintimal dissection; extravasation suspected	Small extravasation confirmed in one case; procedure aborted
1	Inability to advance the wire to the tibioperoneal trunk because of calcification and poor visualization	Tibioperoneal trunk cannulated with fluoroscopic guidance
1	Suspected rupture of heavily calcified SFA after balloon deflation	Small extravasation confirmed by arteriogram; stopped after protamine administration

SFA, Superficial femoral artery.

Overall preprocedure and postprocedure ABIs for the 203 cases changed from a mean of 0.69 ± 0.16 (range, 0.2-1.1) to 0.95 ± 0.14 (range, 0.55-1.3), respectively ($P < .0001$). Ankle tracing amplitudes before and after the procedure for the 33 cases changed from a mean of 3 ± 1 mm (range, 0-7 mm) to 8 ± 3 mm (range, 2-21 mm), respectively ($P < .0001$). The average ABI increase in 203 cases was 0.28 ± 0.11 (range, 0.03-0.63). The average ankle tracing amplitude increase in 33 cases was 6 ± 3 mm (range, 2-14 mm). One hundred eighty-eight patients (93%) demonstrated a significant ('0.15) increase of ABI after the procedure.

Follow-up, patency, morbidity, mortality, and limb salvage. The mean duration of follow-up was 10 ± 7 months (range, 1-29 months). Six-month patency rates for TASC class A, B, C, and D lesions were 89%, 73%, 72%, and 63%, respectively. Twelve-month patency rates for TASC class A, B, C, and D lesions were 89%, 58%, 51%, and 45%, respectively. The overall 30-day survival rate was 100%. Overall limb salvage rates were 94% and 90% at 6 and 12 months, respectively. One above-the-knee amputation was performed in a hypercoagulable patient with limited runoff after one failed popliteal balloon angioplasty and two failed femoral-infrapopliteal bypasses within 2 months after the initial procedure. The second above-the-knee amputation within 4 months after the balloon angioplasty was in a hypercoagulable patient who had a redo subintimal dissection and developed reocclusion of the SFA and popliteal artery in 2 months. This patient underwent femoral to anterior tibial vein bypass, which became infected, ruptured, and thrombosed 2 months after surgery.

DISCUSSION

Our experience with duplex arteriography for more than 800 lower extremities, as well as our policy of performing primary and secondary bypasses based solely on this methodology in more than 80% of the cases, gave us sufficient confidence to start using duplex scanning as a guide to endovascular therapy in the lower extremities.[16,17] This approach has been particularly advantageous for patients who are at increased risk of developing contrast-induced renal failure because of diabetes mellitus and/or pre-existing chronic renal insufficiency.[5-7] The advent of modern duplex scanners capable of delivering high-quality images of the arterial wall and lumen while providing reliable hemodynamic parameters of the infrainguinal arteries facilitated our proposed technique. The magnification (up to ×5) provided by these scanners allows better definition of anatomic details. As previously demonstrated, duplex scanners can be used not only to identify the exact location and severity of the occlusive disease process, but also to precisely measure the extent of the lesion.[16,17] In this manner, balloons and stents can be selected according to precisely measured parameters.[13-15]

The role of an experienced RVT before and during these procedures cannot be underestimated. This individual should be very familiar with the anatomy of the arterial tree in the lower extremities and must have demonstrated an acceptable degree of accuracy with duplex arteriography as confirmed by other diagnostic modalities.[9-11,18] Duplex arteriography obtains information encompassing the vessels extending from the aorta to the pedal vessels. The vascular technologist should participate in the decision-making process of whether duplex-guided intervention is feasible and safe in each case on the basis of preprocedural duplex imaging. Preferentially, the same person performing the preprocedural arterial mapping should be assigned to participate in the duplex-guided intervention.

Obviously, severe arterial calcification that prevents insonation of the vessel lumen should discourage one from proceeding with duplex guidance in favor of fluoroscopy and contrast material. If the length of the segment of the vessel that cannot be visualized well is greater than 1 cm, then alternative imaging modalities should be used. This further stresses the importance of preoperative duplex imaging, because this can help determine whether a duplex-guided angioplasty is safe and should be attempted.

In cases of a "flush" occlusion of the proximal SFA, where angiography may fail to demonstrate the origin of the SFA, it can be difficult to initiate a subintimal dissection. In these cases, we have found that duplex guidance helps locate the origin of the SFA and can allow an attempt at subintimal dissection. Balloon placement and inflation across the origin of the SFA did not cause deep femoral artery occlusion in any of these cases. Whenever stent placement was necessary for recoiling or dissected lesions in the SFA origin, we ensured their precise positioning to

prevent extension of the struts across the origin of the deep femoral artery.

The incidence of SFA "flush" occlusions (as it would seem if procedures were standard fluoroscopy guided) may be lower in our duplex-guided group because duplex scanning is more sensitive in the detection of low flow and preocclusive lesions that may appear as total occlusions on an angiogram. This assumption comes from the fact that we detected a patent proximal segment with low flow (PSV <10 cm/s) in two of the four cases believed to be occluded by arteriography.

Because duplex imaging offers different information than fluoroscopy, the entire thought process of the operating team needs adjustment. During a fluoroscopy-based subintimal angioplasty, we rely on the knowledge of the anatomy and experience with fluoroscopic imaging of the arteries to guide the procedure. Before using duplex guidance, both the surgeon and technologist need to be familiar with differences in the imaging of the vessels between the two modalities. This requires experience with duplex arteriography and image interpretation to construct an idea of the anatomy to guide the procedure. In the initial cases, we would suggest attempting a duplex-guided angioplasty of isolated SFA stenoses in thin patients with easily visualized vessels before progressing to more complex cases. Getting used to the visualization of the wires, balloons, stents, sheaths, and guiding catheters is not actually the difficult portion. Visualization and orientation of the arteries on duplex screen and their relation to the extremity landmarks can be more challenging. This can be achieved by becoming familiar with preoperative duplex arteriography before embarking on duplex-guided interventions.

During subintimal angioplasty with fluoroscopy, the guidewire is advanced through the occluded vessel on the basis of an imaginary trajectory of the corresponding artery and anatomy knowledge. Because the lumen of the distal reconstituted artery is visualized only during contrast injection, it is not surprising that the wire may be directed to the adjacent parallel branch or even outside the arterial wall according to the fluoroscopy image. We have noticed few such incidents while performing standard femoral-popliteal subintimal angioplasties. Conversely, duplex guidance allows constant real-time monitoring of the wire tip in the occluded arterial segment and may alleviate its early re-entry to the patent distal arterial segment, therefore shortening the length of the arterial segment to be ballooned and possibly stented. However, by early detection of the wire tip deviation from the main vessel lumen (patent or occluded) to the branch or outside the adventitia, the incidence of perforations can be decreased.

Standard x-ray guidance of the balloon angioplasty procedures provide faster advancement of wires and catheters during the intervention because the fluoroscopic image encompasses a wider field. Duplex guidance, with its known limited field of view, requires slower guidewire motions for sufficient visualization, at least during the learning-curve period. While the focus is directed to the angioplasty of the lesion, it becomes easy to forget to check

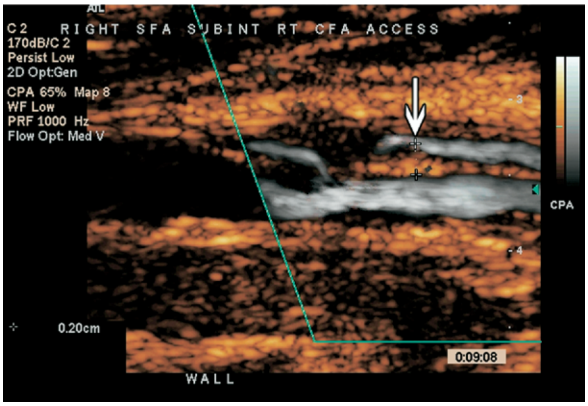

Fig 2. Intraoperative power Doppler image of the popliteal artery behind the knee at the level of an unfavorable re-entry site for the subintimal dissection procedure. Note the thick (2-mm) calcified intima-media layer *(white arrow)*.

the tip of the wire with the duplex image to make sure that is has not migrated during the insertion/removal of balloons, stents, or guiding catheters. Nevertheless, the average time for the duplex-guided interventions does not seem to exceed those previously reported in literature or our experience with fluoroscopy-based interventions.

Because duplex imaging offers multiple projections, magnification, and hemodynamic information, very precise placement of the balloon and stent can be performed. Once a postangioplasty dissection or recoil is visualized, its hemodynamic effects can be assessed objectively. This determines its significance and the need for stenting. The occlusion length may be overestimated by angiography because of a lack of contrast enhancement of the distal artery. Because ultrasound imaging can precisely identify the reconstituted segment's location even with very slow flow, shorter segments may need treatment with duplex guidance. Given that duplex scanning can assess the exact diameter of the vessel from the adventitia to adventitia, exact sizing of the vessel can be performed for balloon angioplasty and stenting rather than just assessing the lumen itself.

Upon attempting re-entry, we have found that the magnification of duplex imaging can assist in identifying the re-entry plane, the thinnest wall, and minimal calcifications (Fig 2). Once re-entry has been suggested, confirmation of the wire placement into the true lumen can be made within millimeters of the reconstitution (Fig 3). This can limit further dissection of the native distal artery. Because duplex scanning can identify the distal artery with high-resolution multidirectional mode-B imaging, free movement of the wire tip and/or directional catheter in the true lumen can assist in confirmation of correct re-entry.

With lesions for which initiation of the subintimal dissection plane is difficult, duplex image magnification helps one specifically place the wire or directional catheter against the wall of the vessel to alleviate wire entrance to the plaque. Furthermore, the accurate location of the dissec-

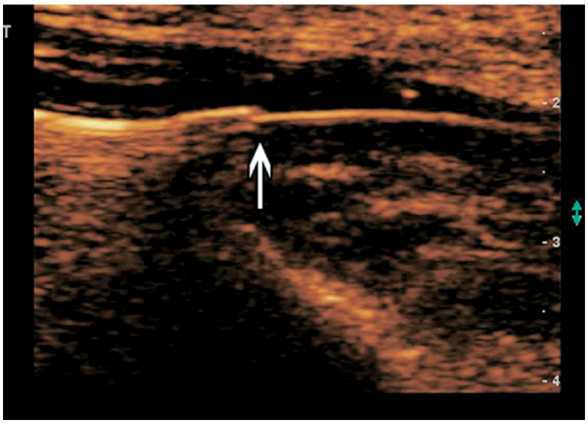

Fig 3. Intraoperative grayscale image of the popliteal artery behind the knee at the re-entry site during the subintimal dissection procedure. Note the 5F Bern (Boston Scientific, Natick, Mass) directional catheter and 0.018 Thruway (Boston Scientific, Natick, Mass) guidewire coming out of the false lumen (dissection plane) and entering the true lumen of the popliteal artery *(white arrow)*.

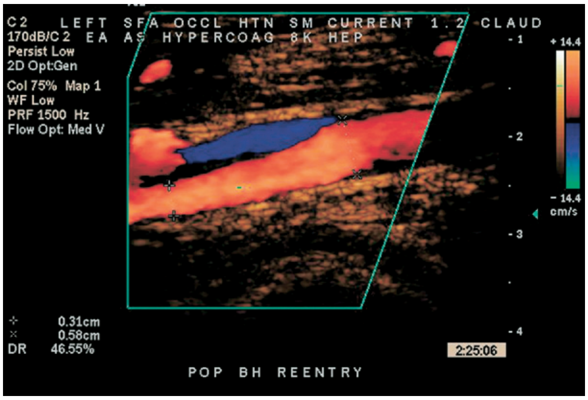

Fig 4. Intraoperative color Doppler image of the popliteal artery behind the knee after re-entry during subintimal dissection, depicting the origin of dissection. Note the typical bidirectional flow pattern represented by *red* (true lumen) and *blue* (false lumen).

tion origin can be identified and stented focally with a shorter stent rather than covering the entire length of the dissection (Fig 4).

From time to time, after fluoroscopy-guided angioplasties, completion arteriograms demonstrate static dye columns. In these cases, we realize that further balloon stenting is needed because of long recoils, dissections, or both. However, because the visualization is incomplete, further intervention is imprecise. One might end up stenting the entire area of subintimal dissection. With duplex guidance, because forward flow is not necessary for visualization, this is not an issue, and, further, accurate well-localized interventions can be added.

Ipsilateral puncture of the access artery (CFA or SFA) can be guided by ultrasonography, thus helping to prevent local complications such as arterial dissections and profunda femoris artery puncture. However, ipsilateral duplex-guided puncture does not prevent treating proximal SFA lesions, which can be addressed by controlled withdrawal of the sheath into the CFA and placement of the balloons and stents across the SFA origin. Longer devices used for fluoroscopy-guided interventions performed via contralateral femoral puncture can cause additional problems such as difficulty to cross over the aortic bifurcation or advancement of the guiding sheath to the proximal aorta.

Rarely, joint prostheses can also pose a problem for fluoroscopy-based interventions. Multiple views used to achieve adequate arterial imaging at the artificial hip and/or knee levels, added to the time of procedure, increase radiation exposure and the amount of contrast material required to complete the procedure. Duplex imaging obviates these issues.

Although not all interventions should be performed with duplex guidance, it does add significantly to the armamentarium of the vascular surgeon. On occasion, we started with a contrast-based intervention and switched to duplex imaging or vice versa because of problems encountered during the procedures (Tables I and II). Both techniques offer different information and can be complementary to each other. However, in patients with pre-existing renal insufficiency or allergy to contrast, duplex guidance can allow the intervention to be performed while safeguarding the patient.

Duplex-guided balloon angioplasty and stent placement seems to be a safe and effective technique for the treatment of infrainguinal arterial occlusive disease. Review of our data revealed short-term patency and intraoperative complication rates (thromboembolization, hemorrhage, and failed attempts) similar to those in prior series.[4,19-23] Technical advantages include direct visualization of the puncture site, accurate selection of the proper size balloon and stent, and confirmation of the adequacy of the technique by hemodynamic and imaging parameters. Additional benefits are avoidance of radiation exposure and contrast material.

AUTHOR CONTRIBUTIONS

Conception and design: EA, NAM, APH
Analysis and interpretation: EA, NAM, APH, RWS, MM
Data collection: NAM, APH, MM
Writing the article: EA, NAM, APH
Critical revision of the article: EA, NAM, APH, RWS, MM
Final approval of the article: EA, NAM, APH, RWS, MM
Statistical analysis: NAM, APH
Overall responsibility: EA

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DISCUSSION

Dr Anton Sidawy *(Washington, DC)*. First, please detail how you perform this intraoperatively; specifically, who is performing the sonography while the surgeon is handling the guidewire/catheters for the angioplasty?

And second, in whom do you now use contrast angiography for intraoperative transluminal angioplasty and stenting in this location?

Dr Marks. The procedure requires the presence of the surgeon and the technologist who is guiding it. The surgeon and the technologist are usually on opposite sides of the patient. The surgeon takes the side preferable for arterial puncture. The duplex scanner is positioned with the screen facing the surgeon.

Angioguided procedures in our institution are mostly performed in patients with arterial calcifications, because it is the major limitation that duplex guidance has. If the technologist cannot provide the surgeon with an adequate image because of the calcifications, the surgeon will use fluoroscopy to continue the angioplasty procedure. X-ray is also used for cannulation of a contralateral iliac artery in cases where ipsilateral antegrade access is impossible (5% in this series).

Dr Marc Schermerhorn *(Boston, Mass)*. What's the average procedure time when you do this, and how does it compare to your procedures that are done with fluoroscopic guidance? And also, how do you measure lesion length?

Dr Marks. The average procedure time in our series was about 50 to 55 minutes. Simple angioplasty of a focal mid-SFA lesion can take as little as 14 minutes. On the other hand, a case of redo subintimal angioplasty, with multiple recoils and dissections requiring placement of three or four stents complicated by intraoperative thrombosis requiring suction thrombectomy can go on for as long as 2 to 3 hours. We measure the length by insonating the beginning of the lesion and marking it on the skin and insonating the end of the lesion, marking it on the skin, and then you could either measure it with measuring tape on the skin or you could go by the length of the probe. Because the probe that we use in 99% of the cases is L7-4, which has a 4.5-cm length foot, you could easily measure the lesion by adding up the length of the probe. Shorter lesions fitting the screen, which is 4 cm wide, could be precisely measured with electronic calipers.

Dr John Chang *(Roslyn, NY)*. What are the technical limiting factors? Do you normally do ipsilateral puncture, or do you do contralateral puncture?

And what are the comparisons in terms of long-term patency on an SFA stenosis or SFA occlusion when you do an interventional procedure? What do you compare them with? Do you compare them with bypass? Do you compare them with a vein graft or PTFE [polytetrafluoroethylene] graft? What is your gold standard that you compare to?

Dr Marks. Ninety-five percent of our cases were performed through an antegrade ipsilateral stick. We have such a high incidence of ipsilateral sticks because of another fact. We could easily balloon the origin of the SFA because duplex control allows us to withdraw the sheath together with the balloon while leaving as little as 3 to 5 mm of sheath length in the artery.