10 Duplex-Guided Balloon Angioplasty from the Carotid to the Plantar Arteries

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Over the last 12 years, our group has explored advantages and limitations of preoperative duplex arteriography of lower extremities as a sole imaging modality [1, 2]. This experience has taught us that duplex scanning offers multiple unique features such as (1) arterial visualization regardless of its patency, (2) imaging of the arterial wall, (3) real-time visualization in the presence of limb motion, (4) up to five times magnification, (5) instant precise measurements, and (6) readily available various hemodynamic parameters such as flow direction, velocity, and waveform. These distinctive features have manifested into the use of duplex imaging for guidance of various venous and arterial therapies such as endovenous procedures and thrombin injection of pseudoaneurysms and have helped to establish the field of interventional vascular ultrasound.

The preliminary experiments with transcutaneous ultrasound in the guidance of infrainguinal arterial procedures reported by Ahmadi et al. [3] and Ramaswami et al. [4] were the impetus for us to further extend this approach. The implementation of this exciting and novel technique approach for endovascular interventions at our institution proved to be viable, safe, and effective. Over the last 5 years we were able to complete duplex-guided lower extremity angioplasties of femoral–popliteal arterial segment in 360 cases, infrapopliteal arteries in 80 cases, and infrainguinal arterial bypasses in an additional 47 cases [5–9]. In addition, we successfully used duplex-guided interventions to treat 40 non-maturing or failing upper extremity arteriovenousfistulas [10, 11]. Duplex-assisted balloon angioplasties and stenting of 41 internal carotid arteries represent yet another unique application of this approach [12, 13]. Herein, we describe our experience with these procedures.

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Infrainguinal Arterial Angioplasty

Preoperative Evaluation

In our institution, arterial balloon angioplasty is offered to patients based on the results of preoperative duplex imaging only. Preoperative duplex arteriography in our Intersocietal Commission for the Accreditation of Vascular Laboratories (ICAVL) accredited vascular laboratory is performed by experienced registered vascular technologists (RVT) and includes assessment of pattern and extent of occlusive disease in the femoral–popliteal arterial segment as well as infrapopliteal arteries. Aortoiliac stenoses are ruled out by analysis of the common femoral artery (CFA) spectral waveform. Biphasic or monophasic waveform of the CFA warrants duplex assessment of the aortoiliac segment. Those with triphasic waveform in the CFA do not require further evaluation. Patients with significant ipsilateral suprainguinal stenoses undergo adjunctive iliac balloon angioplasty.

The Intersociety Consensus (TASC) classification can be used for morphological description of femoral–popliteal lesions. The length of the occluded and stenotic lesions is measured knowing that a L7-4 MHz probe foot has a length of 4 cm and by adding lengths of isolated images or by marking the beginning and end of the lesion on the skin using duplex image and measuring it with a tape.

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Technique

It is essential that duplex-guided procedures be performed by experienced RVT with an extensive expertise in preoperative duplex arteriography. Guidance of balloon angioplasty procedures requires the technologist to be gowned and gloved and the duplex scanner's keyboard covered by a sterile film. We routinely used an HDI 5000 scanner with SonoCT feature (Philips Medical Systems, Bothell, WA). A variety of scan heads inserted into a sterile plastic sleeve with coupling gel were used to insonate the arteries according to the anatomic location and depth. Generally, the arteries on the thigh and calf (1–4 cm deep) are being assessed with a 7-4 MHz linear probe. More superficial (<1 cm deep) arterial structures at the ankle and foot can be insonated by a 15-7 MHz compact linear "hockey stick" probe. The addition of a curved 5-2 MHz transducer is necessary for visualization of deeper arterial segments including the distal superficial femoral artery (SFA) and above-the-knee popliteal artery (PA).

All duplex-guided procedures in our institution were performed in the operating room under local anesthetic infiltration of the puncture site and light sedation. One of the distinct differences of the proposed technique is the possibility to perform the majority of the procedures via an ipsilateral puncture. The ipsilateral approach for infrainguinal interventions has several advantages: (1) it is shorter and therefore easier to manipulate endovascular devices, (2) it avoids potential difficulties and complications of aortoiliac disease and variable anatomy, (3) and prevents potential complications associated with contralateral groin puncture. Additionally, duplex guidance helps avoid dissections, posterior wall puncture, bleeding, and other potential problems associated with blind arterial puncture.

Ipsilateral CFA access is possible in the majority of cases. In our experience with 360 femoral–popliteal angioplasties, 328 (91%) cases were performed via ipsilateral CFA while contralateral cannulation was necessary in the remaining 32 cases (9%). Contralateral CFA access required fluoroscopy (alone in six cases and with 10–20 ml of contrast in the remaining 26 cases) for the ipsilateral common iliac artery cannulation. Contraindications to antegrade ultrasound-guided CFA puncture are high bifurcation and/or deep location (≥3 cm from the skin).

After successful ipsilateral CFA cannulation, a guidewire is directed into the proximal SFA, across the diseased segment(s) and parked at the tibioperoneal trunk or one of the tibial arteries under duplex guidance. In cases of contralateral CFA access, fluoroscopy is used to cross the aortic bifurcation. After the guidewire is identified by duplex in the ipsilateral proximal CFA, the procedure should be continued with duplex guidance as described above.

In cases of femoral and/or popliteal occlusions, a directional catheter supporting the guidewire is pointed against the wall, 3–5 mm proximal to the occlusion, to initiate subintimal dissection. Wire loop formation is confirmed by duplex imaging. The advancement of the wire through the occlusion is followed to the patent arterial segment identified by the presence of color signal in the lumen. Reentry attempts should be initiated within the first 1–2 cm after flow reconstitution to minimize the length of angioplasty. The arterial segment with the least amount of calcification and thinnest intima-media layer should be preferably chosen for reentry. If the guidewire fails to enter the true lumen after several attempts, the directional catheter should be advanced and pointed toward the lumen for additional wire support. Reentry efforts are usually cautiously continued to prevent extension of the dissection plane to the popliteal artery below the knee. We make every effort to spare the outflow artery for possible femoral–popliteal bypass in the case of subintimal angioplasty failure. After the guidewire enters the true arterial lumen, its position is confirmed with color flow imaging in both longitudinal and transverse views.

The diseased segment(s) is then balloon-dilated under duplex guidance (Figs. 10.1, 10.2, 10.3, 10.4,

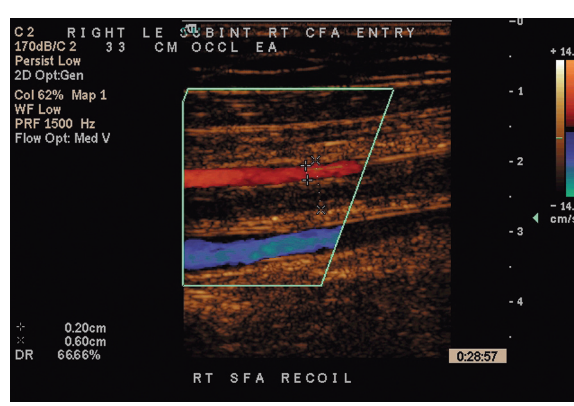

Fig. 10.1 Intraoperative color image of the distal superficial femoral artery after subintimal angioplasty demonstrates significant plaque recoil creating moderate (66.66%) stenosis

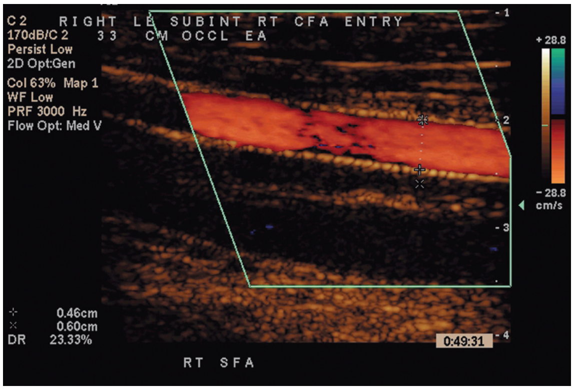

Fig. 10.2 Intraoperative color image of the superficial femoral artery depicted in Fig. 10.1 after placement of self-expandable stent. Residual stenosis (23.33%) created by the recoiled plaque is not significant after stent placement

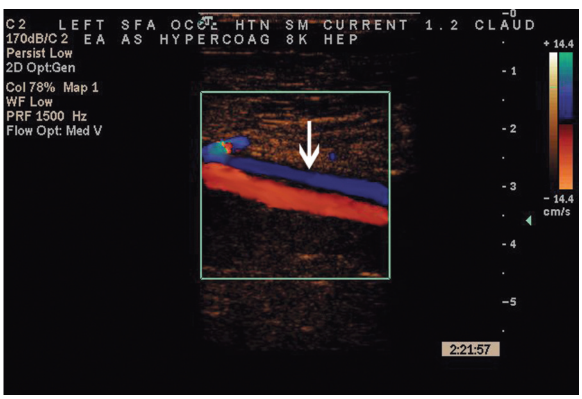

Fig. 10.3 Intraoperative color image of the superficial femoral artery after subintimal angioplasty demonstrated long arterial dissection (*arrow*). Dissection is confirmed by bidirectional flow pattern with antegrade flow (*red*) in the true arterial lumen and retrograde flow (*blue*) in the false lumen

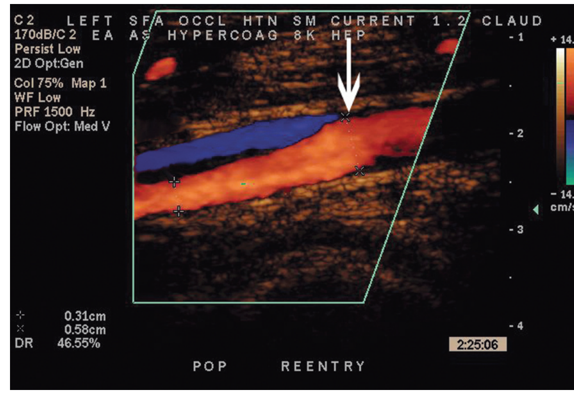

Fig. 10.4 Intraoperative color image of the popliteal artery depicted the origin (*arrow*) of the arterial dissection shown in Fig. 10.3. This dissection creating 46.55% diameter reduction originated at the point of the wire reentry to the true arterial lumen

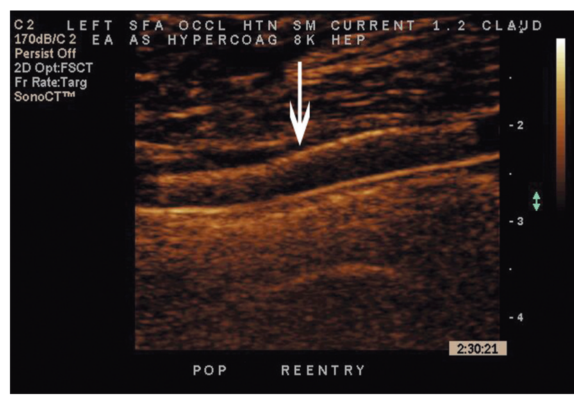

Fig. 10.5 Intraoperative B-Mode image of the self-expandable stent (*arrow*) placed in the popliteal artery to seal the beginning of the long arterial dissection

10.5, and 10.6). Balloon diameter and length can be chosen according to direct arterial measurements obtained by duplex. Duplex image magnification (up to five times) and small error of the measurements (0.1 mm) provide precise measurements of the arterial diameter as well as lumen and wall thickness and therefore eliminate over- or under-sizing of balloons and stents.

A detailed duplex examination of the entire treated segment should be performed following removal of the balloon angioplasty catheters to identify possible areas of residual disease, thrombi, plaque dissection, or recoil. Residual disease and plaque recoils are identified as luminal defects partially obstructing the flow. Partial or occlusive arterial thrombi have an anechoic intraluminal appearance. Dissections can be diagnosed by identification of bidirectional flow pattern or divided flow with clearly different velocities as shown by color Doppler. All suspected abnormalities are carefully evaluated by direct diameter reduction measurement on color and/or power images as well as spectral analyses including peak systolic velocities (PSV) ratios. Luminal defects of >30% diameter reduction with PSV ratio ≥2 across the stenosis can be treated by placement of self-expanding stents under duplex guidance. Significant technical defects were treated with a variety of stents (from one to five per case) in 233/342 cases (68%) in our series. Finally,

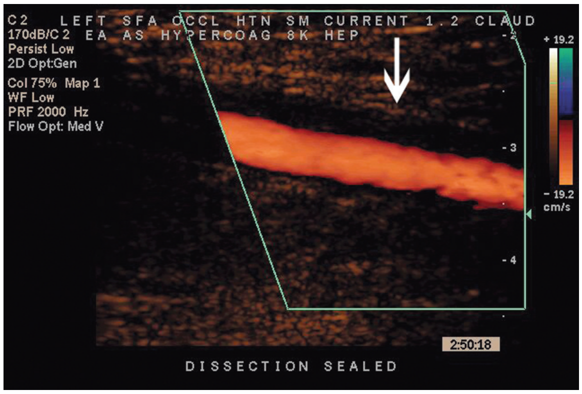

Fig. 10.6 Intraoperative color image of the same superficial femoral artery segment depicted in Fig. 10.3 after stent placement at the origin of dissection in the popliteal artery. No flow noted in the false arterial lumen at this time, former dissection is thrombosed (*arrow*)

infrapopliteal arteries are insonated to reassure the absence of embolization or thrombosis.

Technical Success and Predictors of Technical Failure of Femoral–popliteal Duplex-Guided Balloon Angioplasty

The overall technical success in our experience was 95% (342/360 cases), while it was 100% for TASC class A and B lesions, 96% (236/245 cases) for TASC class C lesions, and 74% for TASC class D lesions (26/35 cases) ($p < 0.0001$). Of the 17 cases where subintimal SFA/PA duplex-guided balloon angioplasty (DGBA) failed, only 2 (12%) were successfully completed under fluoroscopic-guidance. Comparison of multiple risk factors such as age, presence of diabetes (12%), CRI (11%), a combination of both diabetes and CRI (13%), or hemodialysis (38%) revealed that only hemodialysis was a statistically significant predictive factor of technical failure for duplex-guided subintimal angioplasties with $p < 0.04$.

Thromboembolic Complications

It was encouraging to note that some of the complications associated with balloon angioplasty, such as embolization or thrombosis, could be accurately identified by duplex examination and successfully corrected under duplex guidance. Completion duplex scans of the treated segment and infrapopliteal arteries were identified in 10 (2.9%) cases as thromboemboli. The proximal thrombus end was located at the below-the-knee popliteal artery in two cases, tibioperoneal trunk in seven cases, and peroneal artery in the remaining case. Six of these cases were treated with duplex-guided suction thrombectomy and intra-arterial pulse-sprayed infusion of thrombolytic agent and the remaining four cases resolved after thrombolysis only.

Follow-Up, Patency, and Limb Salvage

Arterial duplex scans are routinely performed before hospital discharge and during follow-up visits in our office at 1 month after the procedure and every 3–4 months thereafter. Severe recurrent stenoses are identified by arterial diameter reduction ≥70% measured and local PSV step-up of >3. The absence of color or power in the arterial lumen documents total occlusion.

The mean duration of follow-up was 12 ± 8.3 (range 1–41) months. Six-month patency rates by log rank analysis for TASC class A, B, C, and D lesions were 90, 74, 71, and 64%, respectively. Twelve-month patency rates for TASC class A, B, C, and D lesions were 90, 59, 52, and 46%, respectively. Overall limb salvage rates were 94 and 90% at 6 and 12 months, respectively (two amputations).

Adjunctive Infrapopliteal Balloon Angioplasty

Endovascular interventions for the infrapopliteal vessels are not widely accepted as the standard of care [14–16]. The reluctance to treat tibial vessels originates mostly from the limited patency rates achieved with this technique and uncertain long-term results. We believe that infrapopliteal balloon angioplasty may be beneficial in several settings: (1) run-off improvement during balloon angioplasty of femoral–popliteal arterial segment, (2) in patients with critical ischemia and multiple co-morbidities unsuitable for bypass surgery, and (3) in patients with inadequate autogenous vein for bypass surgery.

Our overall experience with infrapopliteal angioplasties included 80 arteries in 54 cases (15% of all infrainguinal arterial balloon angioplasty cases). All infrapopliteal angioplasties were attempted after completion of more proximal femoral–popliteal procedures in order to improve the run-off. Seventy cases (88%) had arterial stenoses (48 tibioperoneal trunks, 10 peroneal arteries, seven posterior tibial arteries, and five anterior tibial arteries). The remaining 10 cases (12%) had arterial occlusions (four tibioperoneal trunks, five peroneal arteries, and one anterior tibial artery). Low-profile balloons of an appropriate diameter (2–4 mm) and length were used for the infrapopliteal angioplasties. The diseased arterial segments are balloon-dilated starting from the most distal lesion.

A careful completion infrapopliteal duplex examination should be performed in each case for detection of possible plaque recoils, dissections, or distal thromboemboli. Hemodynamically significant plaque recoils (diameter reduction of >30%, a peak systolic velocity step-up of >2, or both) can be successfully treated with cutting balloons. Immediate technical success was achieved in 77 of 80 treated infrapopliteal arteries, for an overall success rate of 96%. Failure of the wire to cross two stenotic peroneal lesions and one occlusion of the peroneal artery accounted for the remaining three failure cases. Residual defects after angioplasty were documented in 10 (13%) of 77 infrapopliteal arteries. However, none of these cases was hemodynamically significant by duplex criteria. The 6- and 12-month patency rates of balloon-dilated infrapopliteal arteries were 78 and 66%, respectively.

Duplex-Guided Angioplasty of Infrainguinal Arterial Bypass Grafts

The long-term patency of lower extremity bypasses and limb salvage rates are significantly dependent upon diagnosis and timely repair of recurrent stenoses [17–19]. Modern duplex scanners provide reliable diagnostic information by identification of the exact location and degree of bypass stenosis. Endovascular treatment of failing bypasses has been proved to have comparable results and postprocedure patency rates as compared to a surgical approach [20–26]. While fluoroscopic-guidance for these treatments is considered standard, one of the major limitations of balloon angioplasty procedures under fluoroscopic-guidance is lack of hemodynamic information.

Duplex guidance offers several indispensable technical advantages. Measurements of graft and arterial depth and diameter and precise localization of the stenotic lesions in reference to the anastomotic sites facilitate the best access site selection for the procedure. Direct visualization of the access site assures accurate entry of the arterial puncture needle and prevention of dissections, posterior wall bleeding, and other arterial injuries. This technique is especially beneficial in obese patients and patients with previously operated groins in whom pulse identification becomes more difficult.

Patient Population

Forty-seven duplex-guided balloon angioplasty procedures were performed in 36 patients in our institution. Primary interventions were performed in 31 cases, first redo angioplasties in 11 cases, second redo angioplasties in three cases, third redo in one case, and fourth redo in the remaining case. Nineteen patients (53%) had renal insufficiency (serum creatinine level ≥1.5 mg/dl). Of the 47 attempted balloon angioplasties included in this study, 36 (77%) were performed in vein grafts and 11 (23%) were in polytetrafluoroethylene (PTFE) grafts. Nineteen autologous grafts were CFA to PA (7) and infrapopliteal (12) bypasses, 11 were SFA to PA (4) and infrapopliteal (7) bypasses, and the remaining six were PA to PA (3) and infrapopliteal (3) bypasses. Of the 11 prosthetic grafts, one was a femoral–femoral bypass, seven were CFA to popliteal (4) and infrapopliteal (3) bypasses, and the remaining three were superficial femoral artery to popliteal bypasses. Bypass operations were performed from 3 to 78 months prior to the current procedure (mean 28 ± 21 months).

Preoperative Evaluation

Diagnosis of a failing graft was made based on preoperative duplex scans performed during routine office follow-up visits in our vascular laboratory. The follow-up graft duplex scan protocol included insonation of the entire bypass conduit, infrainguinal inflow and outflow arteries for at least a 3 cm length proximal and distal to the anastomotic sites. After color and/or power imaging in longitudinal plane, the following points were evaluated with spectral analysis: proximal artery, proximal anastomosis, proximal, mid- and distal bypass conduit, distal anastomosis, and distal artery. Any areas of color aliasing created by elevated velocities were also assessed for calculation of PSV step-up ratios in order to estimate the degree of stenosis. Biphasic or monophasic waveform detected in the inflow artery warranted insonation of the more proximal ipsilateral arteries extended up to the ipsilateral common iliac artery. Graft duplex scans identified at least one severe stenosis along the bypass conduit or in the native inflow and/or outflow arteries in all cases. Stenosis was characterized as severe when local diameter reduction was measured to be ≥70% on color or power image and the corresponding PSV step-up across the lesion was ≥3. Twenty-two balloon angioplasties (47%) were performed on a single stenosis, while the remaining 25 cases (53%) had a mean of 2.9 ± 1 stenoses (range 2–5). The most significant stenotic lesion was found to be at the proximal inflow artery in eight cases, bypass conduit in 26 cases, and distal outflow artery in the remaining 13 cases. The highest PSV at the areas of stenosis were recorded and compared before and after the procedure. Additionally, we routinely measure preoperative bypass volume flows (VF) × 3 in all cases and report the mean value. VF is automatically calculated by the scanner's software using color duplex image and spectral analysis at the non-tapered bypass segment with Doppler angle adjusted at 60° and with the sample volume equal or larger than the lumen outlined by the calipers.

Technique

All procedures were performed using the same technique as described above for the arterial infrainguinal duplex-guided balloon angioplasties. Overall, ipsilateral arterial access was possible in 34 cases (72%) and the remaining 13 cases required a contralateral femoral puncture. The femoral artery (15 ipsilateral and 13 contralateral) was used as an access site in 28 cases. The remaining 19 balloon angioplasty procedures were carried out through direct graft puncture (10 venous and 9 PTFE). Duplex scanning was the only imaging tool used to visualize and manipulate all endovascular instrumentation during the 34 procedures (72%) performed via the ipsilateral access. Five of 13 (38%) cases with contralateral CFA punctures in patients with elevated serum creatinine (≥1.5 mg/dl) did not require contrast use for the cannulation of their ipsilateral iliac artery which was completed with fluoroscopic-guidance only.

In all cases, the guidewire supported by a directional catheter of appropriate caliber was advanced from the ipsilateral femoral artery through the bypass conduit to the distal outflow artery under direct duplex visualization.

Duplex measurements of bypass or arterial diameter and lesion extension allowed the precise selection of balloons caliber and lengths. Cutting balloons used in 25 (48%) cases allowed us to successfully treat recoiling lesions.

Thorough completion duplex exams followed the removal of balloon angioplasty catheters in all cases. Sagittal and transverse planes of scanning were used for identification of residual stenoses or recoils. A unique feature of a real-time ultrasound image is hemodynamic monitoring of the intervention. Spectral waveform and PSV ratios are essential for assessment of hemodynamic significance of dissections or recoils. Technical success was defined as patency and absence of diameter reduction areas with a PSV ratio ≥2 along the bypass as well as inflow and outflow arteries. Whenever a PSV ratio ≥2 was registered suggesting residual stenosis or recoil >50%, repeat inflations of larger balloons (if allowed by the adjacent arterial or bypass diameter) or cutting balloons were applied to the corresponding location.

Bypass VF measurements were obtained immediately following completion of the procedure as described above for preoperative measurements. VF average value ± SD as well as ranges were recorded and compared with the preoperative data. There was no intraoperative contrast arteriograms performed after duplex-guided balloon angioplasty procedures in these patients (Figs. 10.7, 10.8, and 10.9).

Intraoperative Technical Success

Overall technical success in our experience was 98% (46/47 cases). One technical failure was encountered in the case of a popliteal-to-plantar vein bypass where

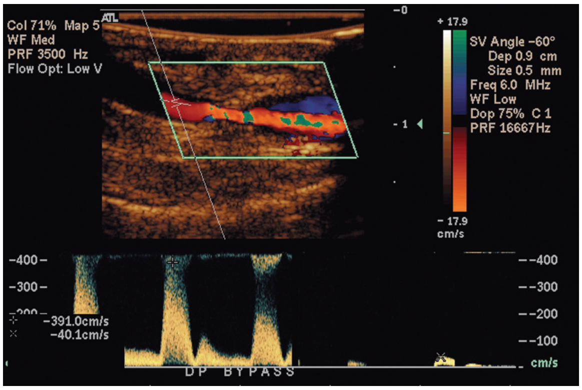

Fig. 10.7 Doppler spectral analysis obtained at the distal femoral to dorsalis pedis artery vein bypass graft demonstrated critical stenosis by PSV step-up ratio of 9.8 (391 cm/s over 40 cm/s)

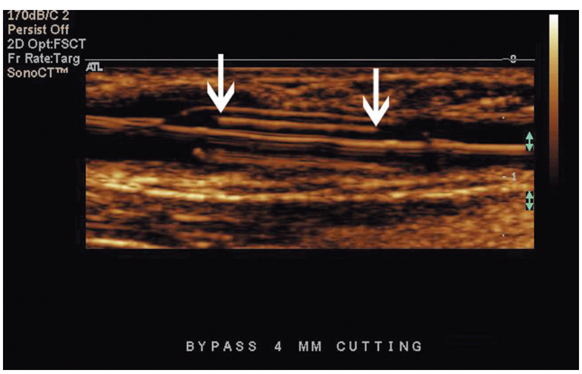

Fig. 10.8 Fully inflated cutting balloon (4 mm diameter × 15 mm length) placed across the stenosis depicted in Fig. 10.1. *White arrows* point to the balloon's blade

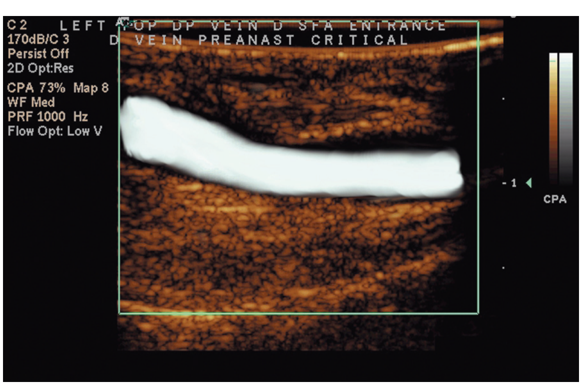

Fig. 10.9 Power Doppler image of the same location taken after balloon deflation and removal demonstrated complete stenosis resolution and absence of luminal defects in the bypass

the plantar artery anastomosis stenosis could not be crossed with the guidewire due to extreme tortuosity. Two cases of the inflow SFA dissections after balloon angioplasty were successfully treated by placement of self-expanding stents under duplex guidance. We did not use stents along the bypass conduit in any of these 47 cases.

Early Postoperative Complications

The overall local complication rate was 4% (two cases). In one case, the vein bypass developed a pseudoaneurysm at the site of rupture by a cutting balloon, which was repaired by patch angioplasty. In the second case, the patient was on Coumadin and had a persistent CFA pseudoaneurysm at the puncture site and required open repair after two unsuccessful thrombin injection attempts.

Duplex-Measured Hemodynamic Parameters

PSV obtained at the tightest stenosis level decreased in all 46 successful cases from a preoperative 408 ± 148 (range 191–807) cm/s to 97 ± 29 (range 53–152) cm/s after angioplasty procedures ($p < 0.0001$). Conversely, bypass VF in all cases increased from a preoperative 66 ± 38 (range 9–144) ml/min to postoperative 137 ± 72 (range 52–900) ml/min ($p < 0.0001$).

Patency and Limb Salvage Rate

The average follow-up was 29 ± 14 (range 3–46) months. Overall 6- and 12-month primary patency rates were 70 and 50%, respectively. Of the 10 patients whose procedures were performed via direct vein bypass access, 3 (30%) developed restenosis at the puncture site.

Duplex-Guided Angioplasty of Failing or Non-maturing Arteriovenous Fistulas

Arteriovenous (AV) hemodialysis access fistulas are known to be predisposed for development of multiple stenoses and eventual failure during their lifetime

[27–29]. Patency and functional ability of autologous AV fistulas have a tremendous influence on quality of life and survival for dialysis-dependent patients with chronic renal failure. Over the last decade, endovascular interventions have become the primary treatment option and almost entirely replaced surgical repair of failing or non-maturing permanent dialysis accesses [30–32]. Although contrast administration may not be harmful for individuals on hemodialysis, patients with borderline renal function and non-maturing AV accesses present a therapeutic challenge [33, 34]. Additionally, an allergy to contrast material makes the endovascular treatment option in some of these patients more challenging.

Despite very high flow creating a substantial current, real-time imaging facilitates accurate positioning and monitoring of the balloon location, in relation to the stenosis. Real-time Doppler spectral analysis assures confirmation of hemodynamic significance of the stenosis after balloon deflation, the presence of recoil, and the need for stenting. Residual stenoses due to elastic recoil were detected in 6 of 11 (55%) cases in this series. These recoiling lesions were successfully treated with cutting balloons in four cases, larger diameter conventional balloon in one case, and self-expanding stent implanted in the remaining case.

Patients

We performed 40 duplex-guided balloon angioplasties of autologous AV fistulas in 32 patients with chronic renal insufficiency. These were 17 males and 15 females with a mean age of 68.5 ± 10.3 (range 38–85) years. The 40 fistulas included 27 radial–cephalic, 12 brachial–cephalic, and one brachial–basilic. Of these, 17 accesses were failing and 23 were non-maturing fistulas in patients who were not yet on dialysis.

Preoperative Evaluation

Diagnosis of failing or non-maturing AV access was established based on a combination of physical examination (decreased thrill, present pulse), dialysis success (prolonged dialysis, suboptimal creatinine clearance, prolonged post-dialysis bleeding), and results of duplex scanning. Distinctive flow patterns such as very high velocities (often ≥ 500 cm/s) and major turbulence inherent to arteriovenous accesses present a diagnostic challenge for duplex surveillance. Although sonographic criteria indicating AV access abnormalities remain inconsistent, contemporary high-resolution ultrasound scanners and growing technical expertise among vascular technologists have established duplex scanning as a very reliable diagnostic tool in the detection of failing or non-maturing AV accesses. Duplex criteria defining compromised AV access included the presence of severe stenoses (>70%) measured on color image and confirmed by PSV ratio of ≥3 in the inflow artery, anastomosis, along the access conduit, or in the outflow vein. VF measurements were routinely obtained in a non-tapered fistula segment, at least 3 cm away from the anastomosis using the same method as described for infrainguinal bypasses. B-mode imaging of the entire fistula added information regarding the presence of luminal webs and "frozen" venous valves creating flow obstruction. The highest PSVs at the most significant stenosis were recorded and compared with postprocedure values. The mean number of stenoses was 1.9 ± 1.1 (range 1–5 per AV access).

Technique

Duplex-guidance of AV access interventions has multiple and distinctive advantages. Real-time visualization of an AV access stenoses and skin marking make possible identification of the most advantageous access site. This choice is made with consideration of multiple factors such as stenoses locations in relation to the anastomosis, fistula diameter, depth and tortuosity, and flow direction. Superficial location and direct visualization with ultrasound make cannulation targeted and easy.

The first 10 cases were performed in the operating room and the remaining 30 in the outpatient office setting. After the patient was comfortably positioned on the operating table, the ipsilateral upper extremity and neck were prepped and draped in the usual sterile manner. A Philips HDI 5000 scanner with SonoCT was feature used for all cases was placed on the side of intervention providing good monitor visibility for both the surgeon and the vascular technologist; the keyboard was covered with a sterile plastic cover. We found it useful to have two scan heads enclosed in sterile plastic and simultaneously available on the field due to anatomic and hemodynamic features inherent to an AV access. A CL 15-7 MHz transducer was used for insonation of superficial structures (<2 cm deep) and an L 7-4 MHz probe was used for deeper (≥2 cm) objects and for measurements of very high velocities present in the AV access.

We were able to complete all procedures via ipsilateral access under local anesthesia. All AV accesses were cannulated under duplex guidance at least 5 cm away from the most proximal stenosis. We attempted to select the access site proximal to the stenosis to use high AV access blood flow as an ally for wire manipulation through tortuosity. Unfortunately, this was possible in only three cases (8%). Two other cases required placement of two access sheaths in opposing directions to address venous and arterial stenoses. The remaining 35 cases were accessed via distal fistula puncture and the stenoses were addressed in a retrograde fashion.

Guidewire and then balloon catheter passage and inflation were performed under duplex guidance. Duplex measurements of arterial/venous lumen diameter adjacent to the stenosis assisted in determining balloon diameters. High-resolution B-Mode duplex images of the arterial and venous wall allow precise selection of proper diameter and length of balloons and stents. We found proper selection of balloons to be extremely important in prevention of AV access and vein overextension and avoidance of rupture while providing adequate dilation of stenotic areas. Ultrathin, symmetry, or sterling balloons of various sizes (3–8 mm) were used.

All cases had intraoperative completion duplex scans prior to access sheath removal. Adequacy of procedures was confirmed by the absence of residual stenoses on color and/or power image and measurements of VF and PSV ratios.

Technical Success

All procedures were completed under duplex guidance alone. One patient with small (3–4 mm in diameter) deep (2 cm from the skin level) brachial–basilic AV fistula had a completion contrast arteriogram which confirmed duplex findings. There were no intraoperative or postoperative local complications in these patients. Eight recoiling lesions (20%) were successfully treated with cutting balloons [35]. One additional patient (2.5%) with brachial–cephalic fistula and recoiling lesion at the junction of cephalic and axillary veins required duplex-guided placement of a self-expandable stent.

Comparison of Pre- and Postprocedure Duplex-Measured Hemodynamic Parameters

The mean preoperative PSVs obtained at the most significant stenosis was 563 ± 100 (range 370–760) cm/s and 200 ± 74 (range 62–354) cm/s after the procedure ($p < 0.0001$). Mean preoperative VF was 411 ± 279 (range 50–980) ml/min and 935 ± 360 (range 370–1,520) ml/min after balloon angioplasty ($p < 0.01$).

Complications and Mortality

One patient had a focal venous rupture with minimal bleeding controlled by manual pressure for 30 min. There were no 30-day mortalities; one patient with multi-organ failure expired 4 months after AV access angioplasty.

Duplex-Assisted Internal Carotid Artery Angioplasty

Superficial location of the cervical carotid arteries and up to five times magnification provided by contemporary duplex scanners result in exceptional clarity and detail resolution of ultrasound images. Duplex scanning of the carotid arteries has established itself as a reliable preoperative imaging modality for evaluation of degree, location, and extent of carotid stenoses in the neck [36, 37].

Hypothetically, the combination of clear-cut duplex images and real-time spectral analyses can offer data superior to the arteriography during multiple steps of the carotid balloon angioplasty and stenting (CBAS) procedure, including (1) selection of exact balloons and stents diameter and length, (2) exact position of the balloons and stents regardless of the artifacts created by the patient's breathing and movements, (3) confirmation of the apposition of the stent to the arterial wall, and (4) hemodynamic and B-mode verification of the procedure success.

Conversely, duplex insonation of the aortic arch is restricted by the chest wall anatomy, and fluoroscopic-guidance is necessary for manipulation of the wires and catheters in the aorta as well as cannulation of the aortic branches. One more maneuver requiring fluoroscopy is cerebral protection devices placement in the intracranial internal carotid artery (ICA).

The combination of both imaging modalities allowed us to perform a series of 41 duplex-assisted CBAS procedures described in the following section.

Patient Population

Forty patients who presented with severe (>70%) ICA stenoses underwent 41 carotid angioplasty and stenting procedures in our institution. Twenty-seven lesions (66%) were primary, 11 (27%) were recurrent stenoses after carotid endarterectomy (CEA), and the remaining three (7%) were restenoses after prior ICA angioplasties; 15 stenoses were symptomatic (37%).

There were 27 males (68%) and 13 females (32%) with a mean of 73 ±10 (range 44–92) years in this group. Twenty-four patients (59%) had elevated serum creatinine levels (≥1.5 mg/dl) and two additional patients had a history of allergy to the contrast material.

Preoperative Imaging

Carotid duplex mapping was the only pre-procedure imaging modality. The duplex mapping protocol included: (1) ICA stenosis degree measurements in sagittal and transverse planes using representative color and/or power images, (2) measurements of disease-free distal common carotid artery (CCA) and ICA lumen, (3) measurements of the plaque extension, (4) identification of severe tortuosity of the cervical ICA (angulation of >90°), and (5) reporting the CCA and ICA calcifications.

Technique

We performed all cases in the operating room with an ATL HDI 5000 scanner (Phillips Medical Systems, Bothell, WA) with SonoCT feature. A linear 7-4 MHz probe was chosen to insonate the CFA, CCA, and its branches. A digital mobile fluoroscopic imaging system with road-map capabilities was used in all cases. The duplex scanner was positioned contralateral to the C-arm at the patient's head; the monitor was turned to reassure the best visibility by the interventionist. It is absolutely crucial for the vascular technologist providing duplex imaging during this procedure to have extensive experience in duplex scanning of the carotid arteries and understanding of various carotid arterial pathologies, as well as their effect on duplex findings. One should not attempt or continue duplex guidance of the CBAS procedure unless the images of the diseased arterial segment and the carotid bifurcation are unquestionably excellent. ICA disease with severe arterial calcification creating shadows covering the lumen for >5 mm should not be treated with duplex-assisted CBAS.

The retrograde cannulation of the CFA was achieved under direct duplex visualization. Manipulation of the guidewire in the iliac arteries, abdominal, and thoracic aorta was performed with fluoroscopic assistance. The Bern selective angiographic catheter (Boston Scientific Corp) or Vitek cerebral catheter (Cook Inc, Bloomington, IN) was used in this series for selective catheterization of the ipsilateral CCA. After guidewire was visualized in the CCA by duplex, it was directed into the external carotid artery (ECA) using the same directional catheter. The next step was a Glidewire wire exchange for a stiff Amplatz (Boston Scientific Corp) wire to allow introduction of a 6F Shuttle SL introducer sheath (Cook Inc), which was positioned in the CCA about 2–3 cm proximal to the carotid bifurcation. All described maneuvers in the neck were completed with duplex visualization alone. The Filterwire embolic protection system (Boston Scientific Corp) was also negotiated into the distal cervical ICA beyond the stenosis under ultrasound-guidance. Further advancement of the filter, its placement and deployment 4–6 cm distal to the ICA stenosis was guided by fluoroscopy.

The next step was duplex-guided dilation of the ICA lesion with a 3 or 4 mm monorail balloon. Following this step, a biliary monorail Wallstent (Boston Scientific Corp) was positioned across the stenosis and deployed under ultrasound visualization A larger balloon (5 or 6 mm in diameter) was inflated once or twice to improve its apposition against the wall and eliminate any residual stenosis. Postprocedure completion Duplex scan confirmed: (1) wide patency of the native and stented CCA and ICA segments, (2) adequate stent apposition, and (3) absence of dissections, flaps, thrombi, or other potential abnormalities. Completion ICA arteriograms with a small amount of contrast material were performed as per the surgeon's preference for medicolegal reasons and correlation with duplex results.

Intraoperative Technical Findings

Completion duplex scans confirmed technical success in all cases. Aortic arch arteriograms were necessary to assist with difficult ipsilateral CCA cannulations in seven (17%) cases. Completion ICA arteriograms were obtained in 26 (63%) cases with 10–15 ml of contrast (Magnavist, Berlex Laboratories, Wayne, NJ, in four cases; Visipaque, Amersham Health, Princeton, NJ, in 22 cases) to validate the duplex findings. Adequate stent apposition and stenosis dilation were achieved in all cases. Biplanar postprocedural cerebral arteriograms performed in 30 patients (73%) for medicolegal reasons did not reveal any defects.

Postprocedure Mortality and Morbidity

There were no early (30-day) postprocedure mortalities. One patient had an ipsilateral stroke (2.4%) with almost complete clinical recovery in 4 months (mild residual hand weakness). This event occurred during the second balloon inflation in the stent. Nevertheless, intraoperative biplanar cerebral arteriogram did not reveal any abnormalities in this patient.

Follow-Up

All patients were advised to have duplex scans performed in our vascular clinic every 6 months after a CBAS procedure. The mean follow-up after duplex-assisted CBAS was 21 ± 14 (range 6–46) months. One patient developed restenosis at 9 months in the proximal end of the stent and underwent repeat duplex-assisted CBAS.

Summary

Unquestionably, duplex-guided arterial interventions are particularly beneficial for patients with allergies to contrast material and for those with chronic renal insufficiency. As vascular surgeons perform more endovascular procedures, they will have increased exposure to the deleterious effects of radiation [38]. Unfortunately, these effects are cumulative and permanent and may cause a delayed onset of symptoms. Our experience with the diverse duplex-guided and duplex-assisted vascular interventions leads us to believe that the duplex-guided angioplasties are safe, beneficial, and effective. The potential of these techniques grows exponentially with the advent of new and improved technology and the positive impact on patient care shows great promise. We anticipate that some of these procedures will eventually be performed in the vascular laboratory or in an office practice setting.

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