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Primary forearm arteriovenous fistula for hemodialysis access — an integrated approach to improve outcomes☆

D. Shemesh, C. Zigelman, O. Olsha, J. Alberton, J. Shapira and H. Abramowitz
Department of Surgery 'B', Vascular Surgery Unit, and Anesthesiology Department, Shaare Zedek Medical Center, P.O. Box 3235, Jerusalem 91031, Israel

Purpose: Maximizing the ratio of primary arteriovenous fistula (PAVF) over bridge graft fistula (BGF) for hemodialysis access is a primary recommendation of the National Kidney Foundation published as Dialysis Outcomes Quality Initiative (DOQI). Imaging, anesthetic and surgical techniques were taken into account to achieve this and other goals, including extensive use of forearm vessels to lower immediate and early failure rates and prolong the useful life of PAVFs.

Design: Prospective non-randomized study.

Methods: High-resolution duplex ultrasonography (DUS) was added to careful clinical assessment in planning and follow-up of the dialysis access. Brachial plexus block, which allowed the use of an arterial tourniquet and gave a postoperative sympathectomy type effect, was used for anesthesia, and together with meticulous surgical technique, prevented spasm. Access puncture, post-operative follow-up and surgical revisions were planned in close cooperation with the nephrology team.

Findings: Ninety (57.3%) of the 157 fistulas constructed for new hemodialysis access between August 1998 and March 2000 were PAVFs. Seventy-three (81.1%) of these were confined to the forearm and comprise the study population, with a mean follow-up of 8.4±4.4 months. There were no immediate failures in the study group. The early failure rate (1 month) was 6.8% and revisions based on DUS were easily accomplished in all cases. The one year assisted primary patency rate was 81.8% and the secondary patency rate at 18 months was 98.6%.

Conclusions: DUS for planning and follow-up of PAVF along with careful surgical technique under a brachial plexus blockade can achieve a PAVF/BGF ratio well above 50% with a low early failure rate and a high secondary patency rate. Algorithms are presented to achieve these goals.

Keywords: vascular access, hemodialysis, arteriovenous fistula, duplex ultrasonography

Introduction

The publication of the first description of primary arteriovenous fistula (PAVF) by Brescia, Cimino, Appel and Hurwich in 1966 irrevocably altered the management of end-stage renal disease (ESRD) patients [1]. Early occlusion and failure to develop are the major problems in PAVF. In the first series described by Brescia *et al.*, 14% (2/14) of PAVFs never functioned. Over the years several attempts have been made to improve results using microsurgical techniques and other methods [2, 3]. However a certain rate (about 10%) of early and late failures

Correspondence to: Harry B. Abramowitz

☆This paper was presented at the 2nd International Vascular Access Congress, London May 30–June 1, 2001 continues to be described [3, 4]. The later introduction of the bridge graft fistula (BGF) presented an alternative, which unfortunately became very popular because of its technical simplicity [5]. In 1997 the National Kidney Foundation published a Dialysis Outcomes Quality Initiative (DOQI) proposing recommendations including a proportion of PAVF to BGF of at least 50% [6] because of the advantages of PAVF over BGF in cost and long-term patency. We have developed an integrated approach to maximizing the proportion of PAVFs and extending patency. This approach was expressed as an algorithm and applied prospectively to all patients presenting over a recent 18-month period.

Methods

Patients

From August 1998 to March 2000, 157 patients referred from three dialysis units in Jerusalem underwent fistula construction for new hemodialysis access. Ninety (57.3%) of the 157 underwent PAVFs. Seventy-three of these (81.1%) were forearm fistulas, and comprise the study population. The homogeneous Caucasian population included 55 males and 18 females with a mean age of 54±18 (range 4–92). The etiology of ESRD was diabetes mellitus in 42.6%, recurrent pyelonephritis 8.2%, glomerulonephritis and nephrotic syndrome 8.2% and polycystic kidney in 6.8%. A variety of other causes accounted for 13.7% and the cause was unknown in the remaining 13.7%. They underwent 71 radial artery to cephalic vein fistulas and 2 transposed basilic vein to ulnar artery fistulas.

Of the 73 patients, 27 were already on dialysis, two of whom were on peritoneal dialysis. All of the 25 on hemodialysis had an indwelling central venous catheter. Five of the 25 had had occlusion of a previous fistula at entry to the study. Forty-six patients had never had dialysis of any kind. No patients were excluded from the study for any reason.

Vascular investigations

Arterial evaluation

Doppler-assessed blood pressure was measured in both brachial arteries. The forearm brachial artery, radial and ulnar arteries were carefully assessed by DUS [Acuson SEQUOIA 512 (Mountain View, CA, USA) with a 7 MHz linear array transducer], for minimal diameter, degree of calcification and quality of flow. A minimal inner diameter in the radial or ulnar artery of 1.5 mm was accepted in adults, and the measured diameter determined the size of the intra-arterial occluder to be inserted during surgery (see below). Doppler traces or pressures indicating proximal disease resulted in additional noninvasive studies and, if necessary, preoperative angiography with or without endovascular procedures. The radial artery in the non-dominant forearm was preferred if inflow was considered to be adequate and the ulnar artery provided sufficient vascularization to the hand.

Venous assessment

Meticulous mapping by DUS of the cephalic and basilic veins from the wrist to the axillary and subclavian veins was done after application of a high arm venous tourniquet inflated to 50 mm Hg and 2 min of vigorous hand exercise to engorge the veins. A minimal venous diameter of 2.5 mm was accepted, avoiding segmental stenoses. Multiple segmental stenoses were considered a relative contraindication to use of that specific vein. Proximal high grade subclavian vein stenosis or occlusion due to the prior use of subclavian catheters were considered an almost absolute contraindication to using that extremity. Suspicion of such stenosis resulted in preoperative venography, with or without endovascular treatment. Collateral vessels were never used for PAVF.

Skin marking

A deeply sited cephalic or basilic vein, which might pose problems for venipuncture during dialysis, was marked for transposition. The optimal planned PAVF was then clearly marked on the skin.

Surgical technique

Brachial plexus block was performed by the supraclavicular approach [7]. A 25 gauge 90-mm spinal needle was used to inject 25–35 ml of anesthetic solution consisting of equal volumes of preservative-free 2% lignocaine and 0.5% bupivicaine, over a 2 min period. The patients were monitored for signs of toxicity and onset of block was indicated by loss of fine motor control and decreased stereotactic sensation by the 'finger nose test'.

A pre-sterilized arterial tourniquet cuff was applied to the upper arm. The skin incision was performed to comfortably allow the PAVF to be carried out according to the skin markings placed previously. Hemostasis was accomplished by metallic clips rather than electro-coagulation. Using 3.5× loupes, or an operating microscope for small children, the marked vein was gently dissected to the length needed to comfortably reach the arterial anastomotic site. The upper aspect of the vein was marked during dissection while the vein was in its normal position, in order to prevent rotation. Inflation of the tourniquet cuff to 60 mm Hg facilitated identification and dissection of the vein when necessary. Only the anterior surface of the artery was exposed. No arterial branches were ligated. At this point, 0.8–1.0 mg/kg of unfractionated heparin was given intravenously. The arm was exsanguinated using an Esmarch bandage and the tourniquet cuff was inflated to twice the arterial blood pressure. A 10-mm arteriotomy was performed with an ophthalmic knife (Alcon surgical, Alcon laboratories, Fort worth, TX 76134 USA) and micro scissors. A Flo-Rester occluder (Bio-Vascular, Inc. 2670 Patton Road, Saint Paul, MN 55113 USA) of the size determined pre-operatively by DUS, was inserted into the arterial lumen, keeping the vessel walls widely open without the need for holding sutures. The vein was sharply cut and an end-to-side anastomosis was performed with two running sutures of 7/0 Prolene (BV-1, 8-mm needle Ethicon Limited, PO Box 408, Bankhead Avenue, Edinburgh EH11 4HE, UK) from the heel and toe, removing the Flo-Rester occluder just before completion of the anastomosis at the mid point of the arteriotomy. The tourniquet cuff was deflated, hemostasis was assessed and the wound was closed in two layers using 4/0 absorbable sutures for the subcutaneous layer and 4/0 nylon mattress sutures for skin.

When the basilic vein was used, it was freed from the cubital fossa to the area of anastomosis and transposed to a subcutaneous tunnel near the ulnar artery.

Following return of motor function, patients were discharged with instructions to begin hand exercises with a solid foam-rubber ball the size of a tennis ball on the 1st post-operative day, adding the use of a venous tourniquet (similar to that used for venipuncture and which the patient was taught to apply) during the hand exercises from the 3rd post-operative day. They were instructed to perform the exercises at least five times a day for a minimum of 5 min each time. Sutures were removed on the 10th to the 14th post-operative day.

Post-operative follow-up

Four weeks after surgery the PAVF was examined by DUS, the preferred puncture sites for draw and return were marked on the skin for draw and return, an anatomical record of the fistula was drawn schematically for the attending nephrologist and any problematic areas were recorded for follow-up. Hemodialysis was begun if the PAVF reached a diameter of more than 4.5 mm. If the vein failed to reach the desired diameter, we recommended an additional 2–4 weeks of exercise to mature the fistula.

Within 3 months of the initiation of hemodialysis, the fistula was re-examined by DUS. Stenoses were corrected only if they were markedly hemodynamically significant or the quality of dialysis was impaired.

Outcomes and statistical analysis

Separate charts were kept (in addition to hospital files) for each patient in the study group comprising all DUS examinations, operation notes, and follow up data. All the patients in the study group were examined every 3 months by DUS to detect segmental occlusion or stenosis. *Assisted Primary Patency* included all patent fistulas which never occluded, including those which had been revised prophylactically, despite being adequate for dialysis, to prevent impending occlusion as detected by DUS. *Secondary Patency* was defined as re-establishment of adequate patency in the same PAVF after revision of an occlusion. Analysis of results was carried out by linear regression, paired *t*-test and life table analysis [8, 9]. Means are expressed as mean±SD.

Results

Of the entire 157 patients who underwent fistula construction for new hemodialysis access, only three required invasive studies prior to performing the dialysis access procedure. Of the 73 with forearm PAVFs in the study group, none had invasive studies.

The time from fistula construction to maturation (according to the above criteria) was 4 weeks for 62 of the patients and up to 8 weeks for another 10. One patient did not progress to the need for dialysis during the study period. The mean follow-up was 8.4 ± 4.4 months.

The mean DUS-measured diameter of the 71 radial and two ulnar arteries was 2.4 ± 0.4 mm and the mean vein diameter was 3.3 ± 0.4 mm. Fifteen of the arteries used were significantly calcified, and seven had an internal arterial diameter less than 2.0 mm. The correlation between DUS-measured and actual arterial diameter (2.5 ± 0.4 mm) was excellent (r^2 = 0.38, F-statistic 28.2, P<0.001), allowing arterial occluder size to be chosen pre-operatively to minimize damage from multiple passage of dilators and occluders of varying sizes into the vessel.

At one month post-operatively, the DUS-measured vein diameter was 5.3 ± 0.7 mm, significantly dilated from the preoperative mean (P<0.001, two tailed *t*-test). The mean feeding artery diameter was also significantly increased to 4.1±0.8 mm (P< 0.001, two tailed *t*-test).

PAVF failures

Immediate failure (within 1 week) did not occur in any patient.

Early failure (1 week to 1 month) occurred in 5 of the 73 patients (6.8%). These patients had revision of the PAVFs, again planned according to the findings on DUS, and all these patients were found to have venous disease within 3 cm of the anastomosis, proven by either macroscopic or histological examination. All have maintained patency following revision, without the need for further surgery.

Late failure occurred in 6 patients (8.2%) at a mean follow-up of 5±2.7 months. Five presented with occlusion of the PAVF and were revised immediately. The 6th patient had an extensively atherosclerotic radial artery, which deteriorated further after initiation of hemodialysis causing poor inflow to the PAVF, and its use was abandoned after 2 months.

Revisions

Fistula maintenance surgery (patent fistulas in adequately dialyzed patients). Three patients had a fistula revised prophylactically because of follow-up DUS findings of impending fistula occlusion, two with remote high-grade venous stenosis, and one other with occlusion of the cephalic vein at the cubital fossa and flow maintained through collateral vessels. One had interposition vein graft for severe stenosis at the mid-arm cephalic vein location, one had anastomosis of the cephalic vein to the basilic vein near the cubital fossa, and the third patient underwent successful PTA for high-grade proximal vein stenosis. Dialysis was continued immediately, using the same access. These three are included in the primary assisted patency group below.

Surgery for occlusion. Ten PAVFs failed due to occlusion that developed during follow-up and required immediate revision. All had either intimal hyperplasia or sclerosis in the vein just distal to the anastomosis. In all cases, the vein remained patent immediately after the first branch and there was no need for thrombectomy. The five early failures had successful revision by a more cephalad arteriovenous anastomosis, one combined with patch angioplasty to a still more cephalad lesion in the vein. Five other late failures were similarly revised by proximal anastomosis of the vein.

Conversion to BGF. The 6th patient in the late failure group developed inadequate inflow without occlusion after being dialyzed for 2 months. He then had bilateral above knee amputation at another institution after refusing vascular reconstruction. This was the only patient who required conversion to BGF during the follow-up period.

Patency rates

One-year assisted primary patency (including the three patients without occlusion, but who required prophylactic revision) was 81.8% and secondary patency rate (with revision after occlusion) was 98.6% (*Figure 1*).

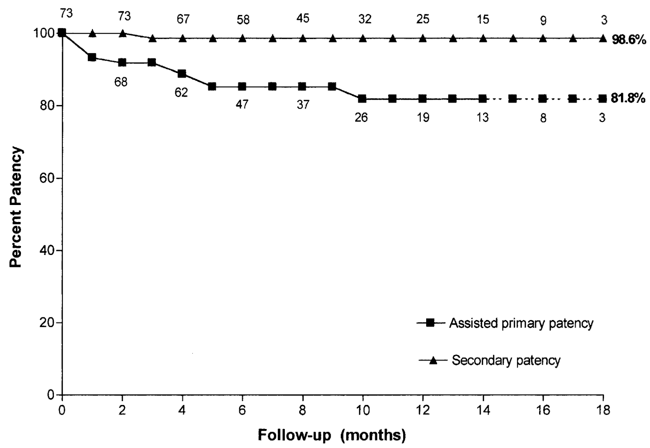

Figure 1 Life-table analysis for assisted primary and secondary patency of the forearm PAVF. The number at each point in the plot indicates the number of PAVFs at risk

Complications

There were three complications, none of which compromised the outcome. One patient had a hematoma that required wound exploration. One patient developed pulmonary edema after brachial plexus block requiring acute dialysis, and surgery was postponed for 3 weeks. Another patient developed an anaphylactic reaction to heparin and was converted to general anesthesia during the procedure.

Impact on clinical practice

The rate of native fistula construction has risen from 34% in 1997 to 62% in 2000, and 81% for the first quarter of 2001 (*Table 1*). There has also been a steady increase in the number of referrals over the same time period.

Discussion

PAVF is the preferred access for hemodialysis. It is both durable and has a lower complication rate than BGF. In the United States, access related morbidity in dialysis patients accounts for over 25% of all hos-

Table 1 New dialysis access 1997–2001

	Total	PAVF
1997	77	26 (34%)
1998	84	31 (37%)
1999	105	58 (55%)
2000	118	73 (62%)
2001(1st qtr.)	47	38 (81%)

pital stays [10–12]. For these reasons, in 1997 the DOQI recommendations called for at least a 1:1 ratio of PAVF to BGF [6]. These considerations have already influenced others to recommend the pre-operative use of Duplex in order to attain this goal [13, 14].

In 1992 we ourselves set out to maximize the use of the forearm vessels, with the aim of allowing for the natural loss of dialysis access areas over prolonged time periods in patients on long-term hemodialysis. This involved maximizing the PAVF/BGF ratio by careful planning and close follow-up of dialysis access procedures primarily using the non-invasive technique of high-resolution Doppler ultrasonography, and close cooperation with the referring nephrologist to optimize use of the fistula so as to prolong its useful life. The full implementation of the practices outlined has resulted in a steady increase in the number of PAVFs performed in our department (*Table 1*).

We progressively built up the algorithms necessary to accomplish these goals (*Figures 2* and *3*). The careful mapping and planning of the access procedure minimized early failures and operative time. The use of DUS to maximize utilization of forearm vessels (81.1% of our PAVFs were forearm PAVFs, and only 18.9% used upper arm vessels), and to avoid preoperatively diagnosed potential pitfalls such as subclavian vein stenosis [15, 16] diseased venous segments and poorly vascularized extremities, in addition to the anesthetic and surgical techniques described, resulted in no immediate failures and a low 6.8% early failure rate.

The choice of anesthesia was ideally suited for these often very ill patients with metabolic derangements. The ventral surface of the forearm is innervated by the musculocutaneous nerve which is posterior to the axillary artery, and the medial cutaneous nerve of the forearm which may separate from the medial cord of the brachial plexus above the level of the axilla [7]. Supraclavicular brachial plexus block was chosen in preference to axillary nerve block and this also allowed the routine use of an arterial tourniquet. The use of a tourniquet enabled minimal handling of the artery and vein and, together with the brachial plexus block, virtually eliminated vascular spasm [2, 3]. The analgesic and sympathectomy effect of the block lasted for 10–20 h postoperatively.

The close cooperation with the nephrology team was mutually beneficial in optimizing the timing of fistula construction before dialysis was begun, the timing of initiation of dialysis, the siting of access puncture, and the prolonged maintenance of a useful PAVF. The drawing of a schematic diagram of the PAVF, the determination of vein size by DUS before puncture and the marking of preferred puncture sites were all part of this cooperative effort to optimize results.

Careful follow-up allowed some PAVFs to be treated or revised before occlusion and the same

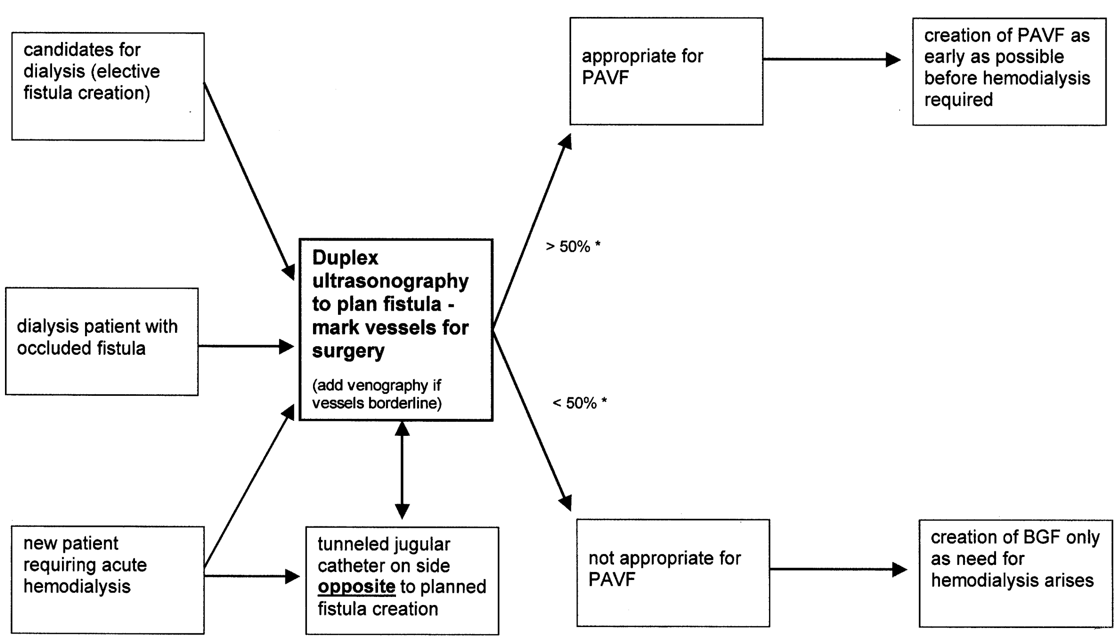

Figure 2 Algorithm for ESRD patient management at presentation

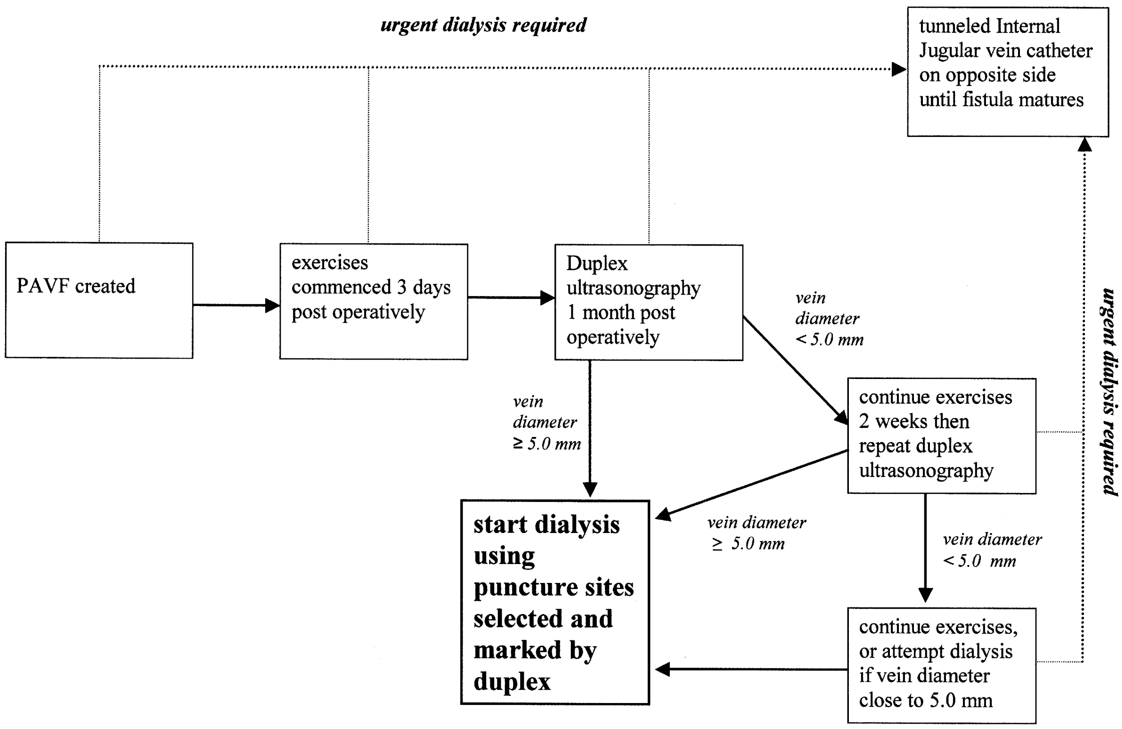

Figure 3 Algorithm for PAVF patient follow-up

access could be used without interruption. When occlusion did occur, the problem was anticipated and the surgical or endovascular solution was known in advance. Thus, after revision, dialysis could be continued using the same PAVF without the need for central venous catheters.

Conclusion

Our study shows that adherence to certain principles can ensure the realization of the DOQI recommendations for a proportion of PAVF/BGF of at least 50%, can maximize the use of the forearm vessels for most PAVFs, and can maintain continued use of the same PAVF for prolonged periods even in the face of the need for revision. In the construction of PAVFs, careful attention should be paid to anesthetic and surgical technique by a dedicated vascular access team, working in close cooperation with the dialysis team. DUS should be used routinely for both planning of the fistula as well as follow-up in order to reduce early failures and maximize secondary patency rates.

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