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Proximal Radial Artery Ligation (PRAL) for Reduction of Flow in Autogenous Radial Cephalic Accesses for Haemodialysis

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Abstract *Objective:* Juxta-anastomosis proximal radial artery ligation (PRAL) is a new surgical technique for reduction of excessive blood flow of radial cephalic fistulas (RCFs).
Patients and methods: This prospective study included 37 consecutive patients (eight children and 29 adults) who underwent PRAL of high-flow RCFs causing ischaemia ($n = 2$), aneurysmal degeneration of the vein ($n = 14$), and cardiac insufficiency ($n = 7$) or for prevention of cardiac overload ($n = 14$). Mean fistula age was 2.6 years for children and 7.4 years for adults. None had diabetes. Anatomical prerequisites (side-to-end anastomosis fistula and retrograde flow in the distal radial artery) were checked by ultrasound or angiography. Division and ligation of the juxta-anastomosis proximal radial artery were performed under regional anaesthesia. Patency following ligation was estimated according to the life table method.
Results: The success rate was 92% (34/37). The three failures included one excessive and two insufficient reductions of flow (<33%). Mean flow reduction rates were 50% in children and 53% in adults.

Primary patency rates at 1 and 2 years were 88% ± 6% and 74% ± 9%, respectively. Secondary patency rates were 88% ± 6% and 78% ± 8%, respectively.
Conclusion: PRAL is a simple, safe, and effective technique for reduction of flow in RCFs.

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Excessive flow is one of the many potential complications of arteriovenous fistulas (AVFs) for haemodialysis. It may occur early after construction of an elbow fistula fed by the large brachial artery or later in wrist fistulas fed by the smaller radial artery. Reduction of AVF flow can be indicated to prevent or to treat local or systemic complications such as aneurysmal vein dilatation, hand ischaemia and cardiac overload.

Few publications have addressed the problem of reduction of flow in forearm fistulas, and they were concerned only with the problem of cardiac failure resulting from hyper-flow. Banding is the only surgical technique reported to date in this location. Anderson was the first (in 1975) to report successful banding in three distal AVFs with intraoperative monitoring of the flow rates.[1] Individual cases were subsequently published and Zanow recently published 10 cases of successful banding in distal AVFs.[2] However, our earlier personal experience with banding was frustrating because of frequent postoperative persistence of high flow or occurrence of thrombosis.[3]

In 1977, Anderson studied the local flow characteristics of side-to-end radial cephalic fistulas (RCFs) at the time of fistula construction.[4] Approximately one-third of the total fistula flow was derived from retrograde flow in the distal part of the radial artery. We similarly observed that a distal AVF could remain patent with sufficient flow for haemodialysis after spontaneous occlusion of the proximal artery. From these observational results, we hypothesised that ligation of the juxta-anastomosis proximal radial artery might result in a significant reduction in fistula flow and that this technique might be worth using for treatment of excessive flow in RCFs. We had been using this technique with favourable results for more than 20 years when we realised that there was no report in the literature validating this approach. We therefore initiated a prospective study and report here our experience in the reduction of flow of RCFs by juxta-anastomosis proximal radial artery ligation (PRAL).

Patients and Methods

Patients

This single-centre prospective study included 37 consecutive patients treated by PRAL for reduction of flow in RCFs between March 2005 and May 2009. No institutional review board (IRB) approval was required but all patients signed an informed consent form in agreement with the declaration of Helsinki. The consent of an ethics committee is not necessary for such a non-randomised study in our country.

The intervention was possible only if the anastomosis was side to end and if the distal radial artery was clearly patent, with retrograde flow originating from non-stenosed ulnar artery and palmar arches. All these prerequisites were assessed by duplex ultrasound or angiography before intervention.

Patient characteristics, co-morbidities and indications for reduction of hyper-flow are summarised in Table 1. The blood pressure of the 21 patients treated for hypertension had normalised at the time of intervention. It should be remembered that aneurysmal degeneration of the vein results from the chronic collision of excessive flow with recurring stenosis of the venous outflow.[5–7] From a clinical point of view, such chronic venous hypertension usually results in increased compression times after dialysis, and PRAL was associated with surgical or percutaneous treatment of the outflow stenosis.

Table 1 Patient characteristics, comorbidities and indications for flow reduction.

	Children	Adults
Patient characteristics:		
N° of patients	8	29
Sex ratio: m/f	04/04	17/12
Patient age [years], mean (range)	11 (5–15)	45 (16–82)
Age of AVF [years], mean (range)	2.6 (0.4–4.7)	7.43 (0.3–29)
Weight [kg], mean (range)	27 (15–35)	62 (16–106)
BSA, mean ± SD (range)	0.99 ± 0.22 (0.66–1.50)	1.68 ± 0.29 (0.67–2.20)
BMI, mean ± SD (range)	15.9 ± 1 (14–17)	22 ± 5.6 (15–39)
Comorbidities:		
Hypertension	3	18
Diabetes	0	0
Coronary disease	0	0
Lower limb arteritis	0	0
Smoker	0	5
Indications for flow reduction:		
High flow only	5	9
Overall aneurysmal degeneration of the vein	2	12
Cardiac failure	1	6
Ischaemia	0	2

Raw flow rates (ml/min) were measured by colour Doppler ultrasonography (CDU), performed by the same operator (GF) with an ATL HDI 5000 scanner (Phillips Medical Systems, Bothell, WA, USA). The SonoCT feature and harmonic imaging were used in all cases. A linear probe of 7–4 MHz was used for the deepest arterial segments and a 15–7-MHz probe for more distal and superficial arteries. Flow measurement and Doppler waveform analysis were performed on the brachial artery, or on the axillary artery in cases of high bifurcation of the brachial artery. The diameter of the arteries was determined by B-mode ultrasonography in the transverse plane and the accuracy of the measurements was monitored by time/movement (TM) mode.[8] The cross-sectional area was calculated automatically. Time averaged velocity (TAV) from Doppler spectra was obtained with large sample volume size insonating the entire luminal vessel in the longitudinal plane with an insonating angle below or equal to 60°. Flow rates were calculated using the formula: volume flow (ml/min) = TAV (cm/sec) × cross section (cm^2).[9]

Flow rates measured in ml/min were also calculated in relation to body surface area (BSA) and expressed in ml/min per 1.73 m^2 (i.e., 'normal' adult BSA) as usually calculated for glomerular filtration rate (GFR) and cardiac

index reports.[10,11] This allows comparison of the flow volume estimates between different types of patients (adults, children and obese). BSA was calculated according to Mosteller's formula: BSA (m^2) = $\sqrt{}$ [weight (kg) × height (cm)/3600].[12] For example, the highest preoperative flow rate in operated children was 2300 ml/min in a 15-year-old child and corresponded to 3936 ml/min per 1.73 m^2. It is noteworthy that 4/5 children and 3/9 adults treated for prevention of cardiac failure had a flow rate above 2 l /min per 1.73 m^2. Pre- and postoperative flow rates are listed in Table 2. Unfortunately, digital pressure measurements were not available for the two cases of ischaemia.[13]

Angiography was performed in cases of hand ischaemia and in cases of aneurysmal degeneration of the vein concomitantly with percutaneous transluminal angioplasty (PTA) of the outflow stenosis.

Surgical Procedure

Surgery was carried out in all patients under regional anaesthesia and preventive haemostasis using an inflatable tourniquet, without anticoagulation. A short longitudinal incision was performed immediately above the previous scar. The juxta-anastomosis proximal radial artery was freed and divided (Fig. 1).

In six cases, a new anastomosis was constructed prior to the PRAL phase in order to resect a venous aneurysm that had developed near to the former anastomosis. In two cases, a side branch of the vein showing retrograde flow to the dorsal aspect of the hand was ligated.

Follow-up and statistical analysis

Success was defined by a flow reduction of at least 33%, immediate availability of the fistula for the next dialysis session with a flow rate of at least 300 ml/min and regression of symptoms in the two cases of ischaemia. This 33% threshold for technical success was based on our initial experience with this technique. Postoperative flow rates were measured within 1 month by Duplex examination. Follow-up was based on clinical surveillance by nephrologists in dialysis units, yearly Doppler ultrasonography (DU) examination with flow measurement and consultation with the surgeon. The results are reported on an intent-to-treat basis.

Patency rates after flow reduction by radial artery ligation were calculated according to the life table method, in agreement with the recommended reporting standards of the Society for Vascular Surgery.[14,15] All statistical analyses were performed using SPSS Statistics 18.0 (SPSS Inc., Chicago, IL, USA). Primary patency was defined as the interval from the time of PRAL until any intervention designed to maintain or re-establish patency, access thrombosis or the time of measurement of patency. Secondary patency was the time interval from PRAL until access abandonment, or the time of patency measurement including surgical or endovascular interventions designed to re-establish function in stenosed or thrombosed accesses.

Table 2 Flow measurements and reduction rates.

	Children	Adults
Preoperative flow		
Mean (ml/min)	1316	1739
SD	428	526
Range	880—2300	1000—3000
Mean (ml/min per 1.73 m^2)	2451	1883
SD	1103	770
Range	1132—3936	1013—4239
Postoperative flow at 1 month		
Mean (ml/min)	606	773
SD	119	307
Range	450—800	350—1600
Mean (ml/min per 1.73 m^2)	1146	773
SD	380	307
Range	803—1656	317—1438
Reduction rates		
Mean (%)	50	53
SD	11	16
Range	33—63	8—77

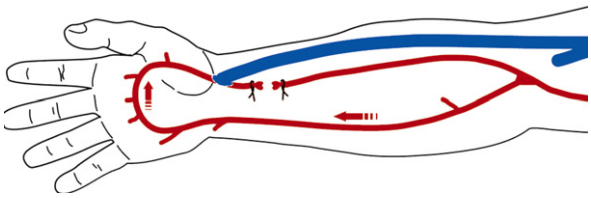

Figure 1 Operating diagram.

Results

Success was achieved in 34/37 patients: fistula flow decreased (Table 2) by at least 33% in 35/37 and the two cases of ischaemia were cured. The mean flow rate was reduced by 50% in children and 53% in adults. Median follow-up as of May 2009 was 20 months (range: 0—89 months). No recurrence of high flow had occurred at 48 months.

The failures included two cases of insufficient and one of excessive reduction of flow. The first failure occurred in a 45-year-old patient whose fistula flow decreased from 1700 to only 1600 ml/min (the reduction rate was 8%). The explanation was that large collaterals originating from the interosseous artery re-entered the small stump of patent proximal radial artery left between the ligation and the anastomosis. This part of the radial artery was resected 1 month later and fistula flow eventually fell to 1000 ml/min, resulting in transient secondary success. Unfortunately, the ulnar and interosseous arteries then developed so much that the flow rate increased to 1900 ml/min 1 year later. For this patient, we are now considering ligation of the distal radial artery a few centimetres from the anastomosis to stop direct retrograde flow coming from the ulnar artery via the palmar arches and to allow only flow of the collaterals coming from the ulnar and interosseous arteries. The second failure occurred in an 18-year-old patient. He had developed aneurysmal degeneration of the forearm cephalic vein caused by occlusion of the proximal cephalic and basilic veins in the upper arm as a result of previous

accesses at the elbow. Flow reduction by PRAL was performed to limit further vein dilatation, although at 1250 ml/min the flow was not very high. Unfortunately, the flow reduction was limited to 23% and remained unchanged 2 years later, with major dilatation of the upper limb cephalic and collateral veins. The third failure occurred in a 64-year-old patient. Fistula flow fell from 1500 to 350 ml/min and this sharp reduction in flow resulted in partial thrombosis of aneurysms. We were obliged to reconstruct an anastomosis to the proximal radial artery and the aneurysms were excluded.

During the follow-up period, one patient was lost to follow-up after 2 months, four fistulas were ligated after renal transplantation, two stenoses were cured by open surgery and one acute thrombosis was successfully treated by percutaneous thrombo-aspiration and concomitant PTA.[16] Primary patency rates at 1 and 2 years were 88% ± 6% and 74% ± 9%, respectively. Secondary patency rates were 88% ± 6% and 78% ± 8%, respectively (Fig. 2).

Discussion

Excessive flow is a much less frequent and clearly more delayed complication in forearm fistulas compared to upper arm fistulas. However, once matured, forearm fistulas have much longer survival rates and thus, an increased probability of developing high flow with time. For example, Rodriguez reported median secondary patency rates of 7.2 years for radial cephalic fistulas compared to only 3.6 years for brachial cephalic fistulas; and it should be emphasised that our adult patients were relatively young (mean age 45 years) and that none of the 37 patients had diabetes.[17]

From a technical point of view, some issues need to be emphasised. The proximal radial artery must be ligated close to the anastomosis and not at the level of its brachial artery ostium. The first reason for this is that side branches leaving the proximal radial artery between the ostium and the level of the ligation permit residual flow, which usually prevents thrombosis of the entire artery. This complication, which is not severe but transiently painful, nevertheless occurred twice (2/37, 6%). The second reason is that, in the case of ligation of the artery far from the anastomosis, several artery-to-artery collaterals might develop from the interosseous or ulnar arteries, with potential for recurrence of high flow. However, access to the proximal radial artery is not performed exactly at the site but just above the initial anastomosis because the local fibrosis resulting from the former intervention would make it more difficult to perform safe dissection. The third reason is that a new anastomosis between the proximal radial artery and the vein can be reconstructed at the mid-forearm in cases of over-reduction of flow after PRAL. Another technical point is that the artery should not only be ligated but also divided. From our initial experience, we know that simple ligation can allow persistent residual flow and eventually be ineffective. Finally, we used a tourniquet to facilitate minimal dissection of the artery.

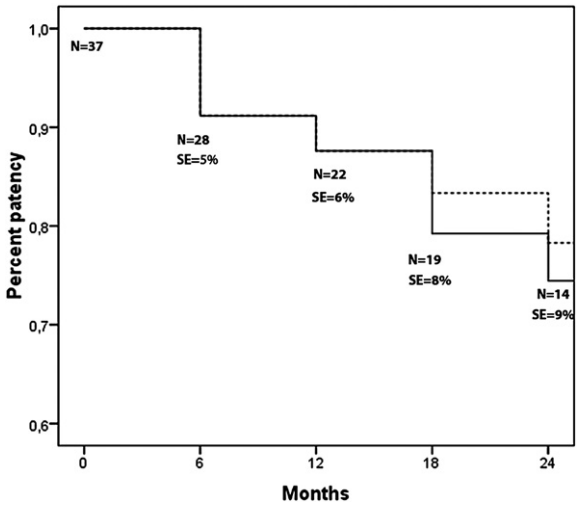

Figure 2 Primary (solid line) and secondary (dashed line) patency rates after juxta-anastomosis proximal radial artery ligation (PRAL) according to the Life Table method, and numbers of patients at risk (N) and standard errors (SE) at the start of each period.

The three failures (one excessive and two insufficient flow reductions) illustrate that selection of patients is not easy. The results of DUS and angiography might show evidence of borderline palmar arches and a distal radial artery that might be able to provide sufficient flow to the fistula after PRAL — or might not. We can simply state that the intervention can be attempted only if there is retrograde flow in the distal radial artery with concomitant patent ulnar artery and palmar arch. Similarly, it is difficult to decide when moderate aneurysms should be corrected concomitantly with PRAL to avoid the development of mural thrombus following flow reduction. However, one of the great advantages of PRAL is that it is an easily reversible intervention, since in the majority of cases a new anastomosis can be performed with the proximal radial artery if necessary, slightly more proximal compared with the initial anastomosis.

Banding with intra-operative flowmetry was the first surgical technique described for reducing excessive high flow in dialysis fistulas.[1] Zanow reported favourable results with banding in a series of radial-cephalic fistulas.[2] Unfortunately, our experience with this technique was not positive, neither in our own hands, nor considering the numerous patients referred to us because of the failure of banding previously performed by other surgeons. Banding frequently proved to be either too tight, resulting in access thrombosis, or too loose and therefore ineffective. Compared to banding, ligation of the juxta-anastomosis proximal artery appears to be a simpler, faster and cheaper technique that is also reversible and which can be performed by any surgeon, without any intra-operative flow measurement, giving high success and primary patency rates.

In cases of hand ischaemia caused by RCFs, the usual treatment is ligation of the distal (not the proximal) radial artery to suppress the steal related to the retrograde flow.[18,19] However, the problem of concomitant high flow has never been discussed in publications referring to distal radial artery ligation.[20] We favoured reduction of the high flow in two ischaemic patients and this suppression of the proximal radial artery antegrade steal to the brachial artery by PRAL also meant disappearance of the clinical steal to the hand. However, any definitive recommendations based upon the good results of the two patients included in this study would be premature.

The value of fistula flow reduction in patients with cardiac insufficiency has not been questioned.[1–4] In contrast, flow reduction for prevention of potential cardiac overload is a much more controversial issue since the detrimental effects of AVFs on the heart are extremely difficult to assess. Some publications have reported a reduction in left ventricular mass (LVM) after fistula ligation in transplanted patients, and such LVM reduction was correlated with decreased cardiovascular risk.[21,22] A similar benefit might be expected from fistula flow reduction but this has not been proven to date for asymptomatic patients. Two recent publications have reported conflicting results. The findings of the North American series do not suggest an increased risk of death at higher levels of access blood flow, whereas the European study might be the first to show a high predictive value of flow values above 2 l/min for the occurrence of high-output cardiac failure.[23,24] The aim of this article is to report a new technique for fistula flow reduction that might help surgeons to meet a potentially increasing demand from nephrologists. It was difficult, in our experience, not to respond positively to the clinical requirements of nephrologists facing several cases of acute pulmonary oedema inaugurating cardiac failure in patients with delayed diagnosis of high-flow fistulas. As an illustration, Smith and Calder recently reported a clear improvement in the cardiac status of a 32-year-old patient after ligation of the proximal radial artery in a brachial cephalic fistula whose high flow was insufficiently reduced after distalisation of the anastomosis to the upper radial artery by interposition of a piece of graft (450 ml/min after vs. 3 l/min before PRAL).[25]

Aneurysmal degeneration with or without chronic venous hypertension is an emerging new indication. The majority of RCFs develop aneurysmal degeneration with time for several reasons: hyper-flow is almost the rule when no stenosis develops, repeated cannulations weaken the vein wall and outflow stenoses develop at the elbow or upper arm level. In the latter case, fistula flow chronically collides with these venous outflow obstructions that are not severe, but this results in permanent venous hypertension associated with prolonged bleeding times and skin vulnerability, with risk of focal necrosis at puncture sites.[5] In addition, such aneurysmal degeneration is resented by many patients for aesthetic reasons. Two possible treatments have been reported to date: interposition of a long prosthetic graft (with all the well-known problems of subsequent stenosis at the venous anastomosis) or creation of a more proximal anastomosis at the elbow with a high risk of hyper-flow or hand ischaemia. Using both techniques, Georgiadis reported a 57% 1-year primary patency rate whereas we report 88% with PRAL.[5] Stabilisation of such aneurysmal degeneration by flow reduction therefore appears to be a valid technique. The key question is to determine when to consider fistula flow reduction by PRAL with only the objective of preventing such aneurysmal complications: the 1 l/min threshold might be an indication in the average adult patient. Our experience indicates that such fistulas running at 400—500 ml/min after PRAL are at low risk of thrombosis in the absence of vein stenosis.

However, we do not suggest that all forearm fistulas running at more than 1 l/min should undergo flow reduction, especially if they are well tolerated from a cardiac point of view and if they do not show overall aneurysmal degeneration.

Conclusion

Whatever the indications, whether hand ischaemia, cardiac failure or other cardiac issues or aneurysmal degeneration of the vein, PRAL is a simple, safe, effective and reversible intervention for reduction of flow in RCF. Unfortunately, in view of the anatomical prerequisites, that is, a side-to-end anastomosis fistula with retrograde flow in the distal radial artery and no ulnar artery and palmar arch stenosis, not all patients are candidates for this intervention.

Conflict of Interest

None.

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