Transposition of radial artery for reduction of excessive high-flow in autogenous arm accesses for hemodialysis

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Objective: **All surgical methods published to date for the reduction of excessive high-flow in native elbow fistulas for dialysis have limitations. We report a new surgical approach to flow reduction by transposition of the radial artery to the elbow level.**

Methods: **From 1992 to 2008, 47 consecutive patients (22 women) with brachial artery to elbow vein autogenous fistula underwent flow reduction via replacement of brachial artery by transposed distal radial artery inflow. Fistulas were side-to-end either brachial-cephalic (19) or brachial-basilic (28). The indications were hand ischemia (4), cardiac failure (13), concerns about future cardiac dysfunction (23), and chronic venous hypertension resulting in aneurysmal degeneration of the vein (7). Mean patient age was 44 years, 11% were diabetic, 17% were smokers, and mean BMI was 22. Mean fistula age before flow reduction was 2.5 years.**

Results: **Technical success was 91% (43 of 47). The mean flow rate dropped by 66% ± 14%. Clinical success in symptomatic patients was 75% (18 of 24). The fistula eventually had to be ligated in three cases of cardiac failure because of insufficient clinical improvement. All four patients with hand ischemia were cured, with no recurrence during follow-up. Primary patency rates at one and three years were 61% ± 7% and 40% ± 8%. Secondary patency rates at one and three years were 89% ± 5% and 70% ± 8%.**

Conclusion: **Transposition of the radial artery, a safe and effective technique, might now be considered in the surgical armamentarium of flow reduction techniques. (J Vasc Surg 2009;49:424-8.)**

Excessive high-flow is one of the many potential complications of arteriovenous fistulas (AVF) for hemodialysis. It may occur early after fistula construction, especially in upper-arm autogenous fistulas fed by a large brachial artery. Reduction of high-flow can be indicated to prevent or to treat local or systemic complications such as hand ischemia and cardiac insufficiency.[1-5]

The surgical techniques for flow reduction in elbow fistulas reported to date include banding[6,7] and distalization of the anastomosis,[8,9] also called revision using distal inflow (RUDI).[10] Both techniques have limitations and complications. Banding can be too tight resulting in thrombosis of the access, or too loose and therefore ineffective. The distalization technique described to date relies on the interposition of a by-pass with a high risk of secondary stenosis at the venous anastomosis.

This is the reason why we use and now report a new technique of flow reduction in proximal AVF involving transposition of the radial artery from the forearm to the elbow level in order to replace the brachial artery by the distal radial artery inflow. This technique allows for significant flow reduction while preserving the functional and previously matured upper arm vein for dialysis.

It is important to notice that the most popular DRIL procedure[11] and the proximalization of the arterial inflow procedure (PAI)[12] are two surgical techniques that have been established as options only for the treatment of access related ischemia by increasing pressure in the distal arteries and not for the reduction of fistula flow. PAI is even contraindicated when ischemia is associated with flow rates above 800 mL/min.

PATIENTS AND METHODS

This single center retrospective study included 47 patients treated between April 1992 and January 2008. Patient characteristics are summarized in Table I.

Hand ischemia was the indication for fistula flow reduction in four patients and congestive heart failure in 13. In 23 patients, flow reduction was requested by nephrologists in order to prevent potential long term detrimental cardiac effects. A more recent indication (seven cases) was chronic venous hypertension as a result of the combination of brachial artery high-inflow and stenosis of venous outflow. From a clinical point of view, such chronic venous hypertension results in increased compression times after dialysis and in aneurysmal degeneration of the vein. In these patients, surgical flow reduction by radial artery transposition was associated with radiological percutaneous transluminal angioplasty (PTA) of the outflow stenosis.

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Competition of interest: none.

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Table I. Patient characteristics

Characteristic	*Statistics*
Patients	47
Age of patients (years)	44 ± 21 (range, 3-82), (7 < 16 years)
Males/Females	25/22
AVF type	Brachial-cephalic: 19 Brachio-basilic: 28
Age of AVF (years)	2.5 ± 2.1 (range, 8.9-0.1)
Diabetics	5
Smokers	8
Hypertension	24
BSA (m^2)	1.54 ± 0.41 (range, 0.46-2.10)
BMI	22 ± 5 (range, 14-33)
Indications for flow reduction	Ischemia: 4 (finger gangrene: 3, rest pain: 1) Cardiac failure: 13 Regarding cardiac outcome: 23 Venous hypertension: 7

AVF, Arteriovenous fistulas; *BMI,* body mass index; *BSA,* body surface area.

Table II. Pre- and postoperative mean flow rates

	Preoperative		*Postoperative*	
Flow	*mL/min*	*mL/min per 1.73 m^2*	*mL/min*	*mL/min per 1.73 m^2*
Mean	1681	2012	577	678
SD	499	742	310	416
Max	3000	4554	1900	2569
Min	800*	919	170*	234

SD, Standard deviation.
*Child of 10 kg: preoperative flow = 2993 mL/min per 1.73 m^2.

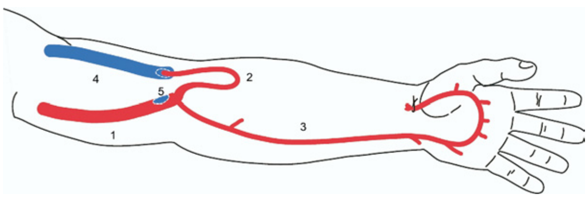

Fig 1. Operating diagram. Number 1: brachial artery; 2: radial artery after transposition; 3: ulnar artery; 4: cephalic or basilic vein; 5: previous arteriovenous anastomosis.

Fig 2. Postoperative view.

Raw flow rates (mL/min) were measured by Color Doppler ultrasonography (CDU), with manipulation and image optimization operated by the same performer (GF) with an ATL HDI 5000 scanner (Phillips Medical Systems, Bothell, Wash). The SonoCT feature and harmonic imaging was used in all cases. A linear probe 7-to-4 MHz was used for deepest arterial segments and a 15-to-7 MHz for more distal and superficial arteries. Flow measurement and Doppler waveform analysis were performed on the brachial artery[13,14] or axillary artery in cases of high bifurcation of the brachial artery. The diameter of the artery was determined by B-mode ultrasonography in a transverse plane from inner edge to inner edge and the accuracy of the measures was controlled by time/movement (TM) mode. The cross-sectional area was automatically calculated. Time averaged velocity (TAV) from Doppler spectra were obtained with large sample volume size insonating the entire luminal vessel in a longitudinal plane with an insonating angle maintained below or equal to 60 degrees. Flow rates were calculated using the formula: volume flow (ml/mm) = TAV (cm/s) × cross section (cm^2).

Flow rates were also calculated in relation to body surface area (BSA) and expressed in mL/min per 1.73 m^2 in order to normalize the volume flow estimates for all types of patients (men, women, children, obese). BSA was calculated according to Mosteller's formula: BSA (m^2) = $\sqrt{}$ [weight (kg) × height (cm)/3600].[15] For example, the lowest preoperative flow rate of operated patients was 800 mL/min in a three-year-old child of 10 kgs and corresponded to 2993 mL/min per 1.73 m^2. Pre- and postoperative flow rates are listed in Table II.

Surgical procedure. The absence of stenosis or occlusion of the forearm arteries and palmar arches, a prerequisite for the intervention, was carefully assessed before intervention by duplex ultrasound or angiography.

Surgery was performed under loco-regional anaesthesia and preventive hemostasis using an inflatable tourniquet,[16] without anticoagulation. The previous arteriovenous anastomosis at the elbow was closed by division and suture of the vein near the artery rather than ligation, which might induce future aneurysmal degeneration of the juxta-arterial segment of the vein. The radial artery was freed from the forearm as a single block with its two concomitant veins, in order to minimize arterial spasm, and then divided at the wrist and turned upwards to reach the vein above the elbow. A surgical microscope was used systematically for creation of the new arteriovenous anastomosis which was either end-to-end with arterial beveling, in order to adjust the differences in diameter between the two vessels, or preferably end-to-side from the artery to the vein. Patency was checked intraoperatively using a sterile Doppler probe. Figs 1 and 2 show a diagram and a postoperative view.

The intervention proved to be feasible even with calcified arteries (n = 6). There was no minimum radial artery diameter required for the procedure, which was even performed in a 30-month child weighing 10 kgs.

Technical success was defined as immediate postoperative patency of the fistula checked by clinical and Doppler examination and confirmed by immediate availability of the fistula for the next dialysis session.

Technical efficacy was defined as a flow reduction of at least 33% compared with preoperative figures. It was measured at one month follow-up by duplex ultrasound.

Clinical success was defined by regression of ischemia and cardiac insufficiency (clinical and echocardiography data), or normalization of bleeding times at the end of dialysis treatments. Flow rates were then monitored by duplex ultrasound on a yearly basis.

Patency rates after flow reduction by radial artery transposition were calculated according to the Life Table method (Appendix, online only), in agreement with the recommended reporting standards of the Society for Vascular Surgery.[17,18] Primary patency was defined as the interval from the time of radial artery transposition until any intervention designed to maintain or reestablish patency, access thrombosis, or the time of measurement of patency. Secondary patency was the time interval from radial artery transposition until access abandonment, or the time of patency measurement including surgical or endovascular interventions designed to reestablish functionality in stenosed or thrombosed access.

RESULTS

Both technical success (immediate post-operative patency) and efficacy rates (flow reduction > 33%) were 91% ± 4% (same 43 of 47 patients). The mean postoperative flow reduction rate was 66% ± 14% (range, 80% to 33%). The four immediate technical failures were due to major technical difficulties in the creation of the new anastomosis between the small caliber distal radial artery and the large and thick-walled elbow vein. This resulted in immediate acute thrombosis of the access. Thrombosis was neglected in 2 cardiac patients, 2 patients were treated by redo of the previous brachial artery anastomosis with no subsequent ischemic complication despite the distal interruption of the radial artery. No other significant immediate postoperative complications occurred. The lowest postoperative flow rates at 1 month after flow reduction were 420 mL/min (400 mL/min per 1.73 m^2) in adults and 280 mL/min (586 mL/min per 1.73 m^2) in children. Median follow-up as of June 2008 was 20 months (range, 0 to 189 months). No recurrence of high-flow was observed at 48 months (Fig 3).

Clinical success in symptomatic patients was 75% (18 of 24). Three technical failures occurred in this subgroup (two cardiac failure patients and one aneurysm patient). Three patients with congestive heart failure were not sufficiently improved and the fistula had to be ligated. The remaining eight patients with cardiac insufficiency were clearly improved according to clinical and cardiac echography findings. All 4 patients with hand ischemia (mean follow-up, 17 months) were cured within 1 month, with no recurrence of symptoms to date. Six patients with aneurysm met clinical success.

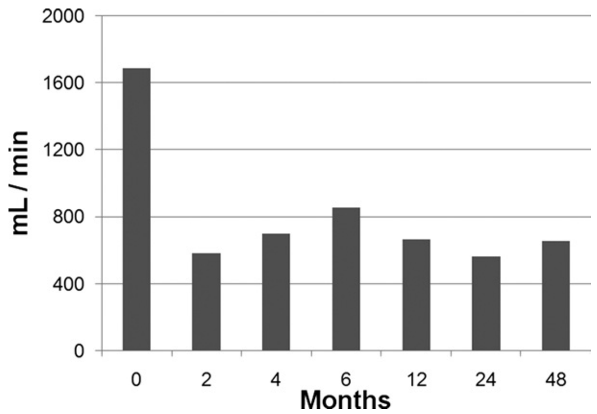

Fig 3. Evolution of mean flow rates in operated patients.

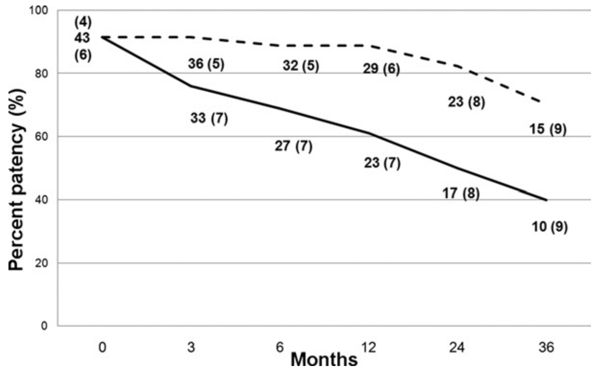

Fig 4. Primary (solid line) and secondary (dashed line) patency rates after radial artery transposition according to the Life Table method and numbers for the patients at risk and standard errors (between brackets) at the start of each interval.

During follow-up, 10 patients underwent renal transplantation, 5 died (2 within 1 year). Nineteen patients with insufficient flow or venous hypertension were treated by PTA for stenoses at the arteriovenous anastomosis (nine) or at the venous outflow (10). Seven of these patients had already been treated by PTA for venous stenosis before flow reduction. Two cases of acute thrombosis occurred and one was successfully treated.

In terms of fistula patency (Fig 4), primary patency rates (including initial failure cases) at 1, 2, and 3 years were 61% ± 7%, 50% ± 7%, and 40% ± 8%. Secondary patency rates at 1, 2, and 3 years were 89% ± 5%, 82% ± 6%, and 70% ± 8%.

DISCUSSION

Banding was the first surgical technique described for reducing excessive high-flow in dialysis fistulas. By contrast, our experience with this technique was not positive, neither in our hands, nor considering the numerous patients referred to us because of the failure of banding performed by other surgeons. The banding proved to be either too tight, resulting in access thrombosis, or too loose and therefore ineffective. These disappointing results were in agreement with the publications of Odland[2] and De Caprio,[3] who reported poor secondary patency rates of 38% and 9% at one year. A more recent publication[19] has reported more favorable short or mid-term results using access flow rate monitoring during banding procedures. However, this single report of better outcomes needs to be confirmed. In our experience, intraoperative flow measurement might not be reliable possibly because of vascular flow modifications related to regional or general anesthesia and to spasm caused by surgical dissection.

Flow rates in our study were calculated using CDU, a reliable method in experienced hands. Although CDU assessment of access flow is performed in the dialysis-free period whereas the ultrasound dilution technique[20] must be performed during hemodialysis sessions, comparative studies[21,22] showed that the results of the two techniques were in agreement (correlation coefficients of 0.83 and 0.79). On the other hand, measurements performed with the ultrasound dilution technique were nevertheless reported to be often lower than those calculated by magnetic resonance.[23] The slight discrepancy might be explained by the temporary reduction of access flow due to an increased dissipation of energy caused by the reversal of needles associated with the ultrasound dilution technique.

The other ways of reducing flow are distalization of the anastomosis - RUDI techniques,[8-10] involving the interposition of a bypass between the radial artery and the elbow vein in order to replace the large brachial artery inflow by the smaller distal radial artery inflow. In addition, this long segment of conduit creates resistance to arterial flow as predicted by Poiseuille's law. In the largest published series of 35 patients,[8] the mean flow reduction rate was 60% ± 18%. Unfortunately, this series also reported that the development of stenoses at the venous anastomosis of the grafts occurred rapidly, especially in children,[24] jeopardizing access patency. The drawbacks of the above-mentioned techniques are the reasons why we have tried to develop this new technique using only native vessels.

Radial artery transposition was done using preventive hemostasis with a tourniquet[16] making extensive exposition and control of the brachial artery unnecessary before section of the vein adjacent to the original arteriovenous anastomosis. Patch-like suture of the vein prevents immediate narowing of the brachial artery and future aneurysmal degeneration of the juxta-artery venous segment that might occur after ligation.

The two major technical difficulties in this surgery of radial artery transposition are spasm and construction of the new anastomosis. Prevention of arterial spasm involved the use of regional anesthesia and a technique of dissection of the radial artery including its satellite veins. With regard to the creation of the new anastomosis, the key problem was the major difference in diameter and wall thickness between the small radial artery and the larger previously arterialized vein. We initially performed end-to-end anastomoses with arterial beveling using non-interrupted sutures but we finally moved to an end-to-side technique with interrupted sutures. Our opinion is that the anastomosis is better performed using a microscope. However, there is a learning curve, as for any surgical technique.

It can be seen from our follow-up data that further stenoses can develop or progress in the vein itself (n = 10) and in the anastomotic area (n = 9). Close monitoring of these fistulas after intervention is therefore mandatory, since acute thrombosis might not be easy to recover.

It is understandable that colleagues might be reluctant to suppress the radial artery inflow to the hand, especially in the sub-group of patients with hand ischemia. However, we emphasize that this technique of radial artery transposition was performed only in cases of excessive high-flow originating from the brachial artery, and only when the ulnar artery and palmar arches were clearly patent. In contrast to the DRIL procedure which includes the ligation of the brachial artery, it is the radial artery and not the brachial artery that is ligated.

As preoperative AVF flow rates before DRIL are usually not mentioned in the literature, the real incidence of high-flow fistula and therefore the indications for flow reduction in the treatment of ischemia might have been underestimated up today.

The detrimental effects of arteriovenous fistulas on the heart are extremely difficult to assess and this is a subject of controversy. Our experience shows that eight out of 13 patients with cardiac insufficiency were clearly improved after fistula flow reduction. However, it is at present impossible to draw straightforward conclusions for the 23 asymptomatic patients referred by nephrologists for prevention of potential long-term deleterious effects of high-flow on cardiac function. Some publications[25] have reported a reduction of the left ventricular mass (LVM) after fistula ligation in transplanted patients, and such LVM reduction is correlated with decreased cardiovascular risk. A similar benefit might be expected from fistula flow reduction but nothing has been proven to date for asymptomatic patients. Two recent publications have conflicting results. The findings of the North American series[26] do not suggest an increased risk of death at higher levels of access blood flow whereas the European study[27] might be the first to have shown a high predictive value for high-output cardiac failure occurrence of flow values above two L/minute. Anyway, the current debate will not be solved by surgeons. The goal of this article is to report a new technique of fistula flow reduction that might help surgeons to face a potential increasing request from nephrologists. In our experience, it was difficult not to favorably answer to the clinical requirement of nephrologists that had in mind several cases of acute pulmonary edema inaugurating cardiac failure in patients with a delayed diagnosis of high-flow fistulas.

Chronic venous hypertension is an emerging new indication (n = 7). It is well known that brachial-cephalic fistulas frequently develop stenosis in the final arch of the cephalic vein or in the upper part of the transposition of the basilic vein. Fistula high-flow chronically collides with these venous outflow obstructions, which causes permanent venous hypertension resulting in aneurysmal degeneration of the vein, especially in cannulation areas. Nurses often meet prolonged bleeding times at needle removal and skin vulnerability with risk of focal necrosis. Most surgeons or interventionists are reluctant to reopen fully (by dilatation) these outflow vein stenoses in view of the risks of subsequent excessive high flow which might increase considerably, for example to above three L/minute, or cause hand ischemia. We experienced such complications in the past. The best treatment might be concomitant stenosis treatment and flow reduction surgery, using our method of radial artery transposition whenever technically feasible.

CONCLUSION

Whatever the indication (hand ischemia, cardiac failure, aneurysmal degeneration of the vein, concerns regarding cardiac outcome), transposition of the radial artery to reduce the flow of an elbow fistula is a safe and effective technique which might be now considered in the surgical armamentarium.

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AUTHOR CONTRIBUTIONS

Conception and design: PB, JG, LT-R
Analysis and interpretation: PB, JG, LT-R
Data collection: PB, JG, GF, OV-L, AR
Writing the article: PB, JG, LT-R, GF
Critical revision of the article: PB, JG, LT-R
Final approval of the article: PB, JG, LT-R, GF, OV-L, AR
Statistical analysis: PB, LT-R
Obtained funding: PB
Overall responsibility: PB, JG, LT-R

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Appendix, online only. Life tables

Interval (mo)	*N° at risk at beginning of interval*	*N° failed during interval*	*Withdrawn during interval*	*Interval failure rate*	*Cumulative patency rate*	*Standard error*
Primary patency life table						
0	47	4	0	0.085	91%	4%
3	43	7	3	0.169	76%	6%
6	33	3	3	0.095	69%	7%
12	27	3	1	0.113	61%	7%
24	23	4	2	0.182	50%	7%
36	17	3	4	0.200	40%	8%
48	10	1	3	0.118	35%	9%
Secondary patency life table						
0	47	4	0	0.085	91%	4%
3	43	0	7	0.000	91%	4%
6	36	1	3	0.029	89%	5%
12	32	0	3	0.000	89%	5%
24	29	2	4	0.074	82%	6%
36	23	3	5	0.146	70%	8%
48	15	4	3	0.296	49%	9%