

Measuring vascular access flow: the accuracy of different methods

Pedro Ponce, Bruno Pinto

Nephrocare, Lumiar. Lisbon, Portugal.

Received for publication: 17/03/2011
Accepted in revised form: 26/04/2011

ABSTRACT

Background: While it is widely accepted that monitoring of vascular access flow (Qa) should be performed, its real benefit has not yet been established. In addition, controversy still reigns over how accurate Qa determinations are, how to react to Qa values and how cost-effective is the preemptive angioplasty of detected significant vascular access stenosis.

Aim: To assess the accuracy of different Qa measurement techniques.

Patients and Methods: Prospective, single-centre, cross-over study. In two midweek dialysis treatments in two consecutive weeks, each one of 63 consenting patients had in the first 90 minutes of their treatments two Qa measurements per dialysis by ultrasound dilution (TS), the gold standard, and ionic dilution (AFM), followed by one measurement by thermodilution (BTM), the standard routine measurement technique of our dialysis unit.

Results: Average Qa measured by TS (the gold standard) was 1354.6 ± 658 ml/min. TS proved to have the higher accuracy and reproducibility (r between measurements > 0.99). AFM results showed higher correlation with TS values in the same patients (0.81) than BTM (0.72). The average Δ Qa between the AFM and TS measurement was 283 ± 237 ml/min. These methods were identical in native AVF or PTFE grafts.

Conclusions: Qa measurements by different methods showed significant variability; therefore their results

cannot be compared among themselves. Ultrasound dilution is the most accurate technique. Threshold Qa values for intervention cannot be universal; they have to be calibrated according to the technique in use.

Key-Words:

Haemodialysis; vascular access flow; vascular access flow measurement.

INTRODUCTION

Vascular access (VA) malfunction and failure is a leading cause of morbidity in chronic haemodialysis patients, responsible for over 25% of annual hospital admissions, and estimated annual vascular access-related costs of USD 1 billion in the US alone¹.

In haemodialysis, VA management, just as in medicine as a whole, an early diagnosis of malfunction and prevention of definite failure is considered the best approach to diminish morbidity and costs. This axiom was strongly suggested in several seminal studies^{2,3} and is expressed in most guidelines of scientific societies in this field.

It is recommended that regular monitoring of VA function should be performed, preferably by measuring VA flow (Qa) and when VA stenosis is present, preemptive intervention should be performed percutaneously without further delay. In support of these level 2 recommendations, we can quote: "All types of pressure measurement should be abandoned in

favour of VA flow measurement”, and “Monitoring plus intervention reduces thrombotic rates, morbidity and costs”^{3,4}.

Consensual recommendations for preemptive intervention in malfunctioning grafts are Qa measurement <600 ml/min for grafts (or <400 ml/min for native fistulas) and a Qa drop higher than 25% over two consecutive measurements⁵. However, recent and quite relevant information has questioned those recommendations, and scanning through recent prospective randomised controlled trials in this field reveals some discordant opinions⁶⁻¹¹.

No matter if we are looking at native fistulas or PTFE grafts, using only Qa measurements, or its association with Doppler studies or dynamic venous pressure as surveillance techniques, it is believed that VA stenosis is now very effectively detected, and responsible for a large increase in percutaneous VA procedures. Surprisingly, however, it has been found that all these diagnostic and therapeutic procedures fail to reduce the thrombosis rate, or prolong VA longevity⁶⁻¹⁴.

Although we are now questioning the reliability of Qa measurement as a predictor of VA longevity and complications^{9,14}, we currently accept its value as an accurate figure. However, those who measure Qa in their routine VA clinical assessment use different validated methods, and then use the same absolute haemodynamic targets as thresholds to decide when to refer the patient for preemptive endovascular or surgical intervention. These standard protocols are probably generating a huge amount of false positive diagnosis of malfunction and extremely expensive futile interventions, without any evidence of benefit.

The aim of our study was to assess the reproducibility of three different Qa measurement methods and to compare their accuracy against the gold standard technique.

PATIENTS AND METHODS

We designed an open, prospective, cross-sectional, single-centre, observational trial, comparing variability and correlations between three methods of Qa measurement.

All the methods studied used the model conceived by Krivitski for calculating Qa by measuring VA recirculation with blood lines in the right position, repeating the procedure with reversed lines, using three different indicators¹⁵.

Method A, Transonic (TS) ultrasound dilution technology (Transonic flow-QC[®] monitor HDo2, Ithaca, NY) relies on a 10cc 0.9% NaCl bolus to be injected into the blood circuit. Saline injected in the venous line dilutes blood protein concentration, reducing ultrasound (US) velocity. US sensors attached on the arterial and venous line measure the US velocity in the blood and the blood volume flow in the arterial line. Specially designed software allows the calculation of Qa¹⁵.

Method B, Automated Flow Measurement (AFM), 5008 therapy system (Fresenius Medical Care, Bad Homburg, Germany) with software version 4.0.2, uses online conductivity monitoring of extracorporeal sodium dialysate gradients and their changes, without injection of any indicator^{16,17}. The AFM data was extracted from a large validation trial still ongoing, conducted by Fresenius Medical Care in the authors' dialysis unit.

Method C, the standard diagnostic tool in our unit, Blood Temperature Module (BTM[®]) (Fresenius Medical Care, Bad Homburg, Germany) uses a thermodilution technique¹⁸ that induces a controlled decrease of dialysate temperature, measuring Qa through the difference of percentage of recirculation with lines in normal and reverse positions.

Sixty-three adult consenting patients on chronic haemodialysis for more than three months, with a mature arteriovenous VA (52 native AV fistulas, 11 PTFE grafts), allowing a Qb >300 ml/min, clinically and haemodynamically stable, were included.

During two midweek dialysis treatments in two consecutive weeks, each patient had in the first 90 minutes two measurements per dialysis with methods A and B and one measurement with method C. All patients underwent online haemodiafiltration with a Fresenius 5008 machine. All measurements were performed by the same operator (BP) or under his supervision.

During measurements, performed in the first 90 minutes of the dialysis treatment, a fixed extracorporeal

blood and dialysate flow of 300 and 500 ml/min respectively were used and ultrafiltration was turned off. Line reversal was obtained by a special rotating device, the Twister® (Fresenius Medical Care North America), without interruption of the blood circuit or the dialysis treatment.

Data collected was analysed to assess the reproducibility between the first and second measurement of each method in each treatment and between consecutive weeks, and correlations of measured Qa of the different methods. All the 63 patients were then prospectively followed-up for four months, registering all VA events and correlating them with baseline average TS Qa measurement and sp Kt/V for that dialysis treatment.

RESULTS

Average Qa in our 63 patients measured by TS, the gold standard technique, was 1354.6 ± 658 ml/min (Table I). To assess reproducibility of each method (TS and AFM) in consecutive measurements, we determined correlation coefficients between consecutive measurements for each technique, in the same treatment, in each week (Table II).

Table I

Average Qa values for each technique, in different VA types

ml/min	TS	AFM	BTM
AVF	1458.4 ± 701	1126.8 ± 672	1277.7 ± 689
PTFE	971.4 ± 351	807.9 ± 389	964.5 ± 401
Global	1354.6 ± 658	1101 ± 664	1112 ± 666

Table II

Correlation coefficients between consecutive measurements for each technique, in the same treatment

	1 st week	2 nd week	P
TS	0.991	0.992	< 0.01
AFM	0.644	0.548	< 0.01

To assess the variability among the different methods, we conducted correlation coefficients among methods (Table III).

Table III

Correlation coefficients among methods

TS vs. AFM	0.810	$p < 0.005$
AFM vs. BTM	0.695	$p < 0.005$
TS vs. BTM	0.727	$p < 0.005$

The average Δ Qa between the AFM vs. TS measurement was 283 ± 237 ml/min, and between BTM vs. TS 361 ± 256 ml/min. All calculation were repeated separately for 52 native AVF and 11 PTFE grafts, and we could not find any difference in these three methods for each type of VA.

As expected, recirculation was 0% in all patients, in all methods.

During the four months of follow-up, six patients had a VA event, or were referred at the discretion of the attending nephrologist for a diagnostic procedure and only four had a real VA problem, again not predicted by the original baseline TS Qa measurement (Table IV).

Table IV

Correlates between baseline Qa, Kt/V and vascular access events during follow-up

Patients	Qa ml/min	spKt/V	Events
JDR – AVF	755	1.51	Angioplasty (at 61 days)
MLQ – PTFE	895	1.9	VA infection
VLQ – PTFE	840	1.85	Thrombosis (at 93 days)
DAF – FAV	1635	1.99	Diagnostic Angio – no disease
MAS – FAV	1165	1.9	Thrombosis (at 66 days)
MRD – PTFE	515	1.7	Angioplasty (at 110 days)

DISCUSSION

All presently approved clinical guidelines recommend monitoring VA quality and performance, aiming at early detection of VA stenosis, which induced a global trend towards implementation of Qa-based monitoring programmes in many dialysis units.

The clinical utility of such an approach has been challenged by the reported results of several randomised clinical trials that have not demonstrated clinical benefit with Qa monitoring approaches⁶⁻¹⁴, fuelling an ongoing controversy regarding its beneficial

effects, both in terms of overall VA survival and associated costs.

The recommended Qa thresholds for angiography referral are based on its putative predictive power of VA malfunction and/or failure. However, even before the final decision on the clinical relevance of periodic Qa determination, the quality and accuracy of the Qa measurements methods must be questioned.

In our series, the performance of the transonic ultrasound dilution technology was highly reproducible, provided higher values of Qa than the other two techniques, and performed as well as the gold standard technique.

The correlation of the AFM and BTM techniques with TS were identical, with a coefficient around 0.8, usually considered quite acceptable, but still corresponding to average differences in Qa of about 280ml/min (20% variance). This can have a dramatic clinical and financial impact on our present decision process of referral for endovascular intervention.

Although other groups have found a better correlation (above 0.9) between the transonic technique and ionic dilution^{17,19}, others reported the same limitations of our study with variation coefficients up to 14%²⁰⁻²², or 260ml/min, usually greater at higher levels of Qa. This raises the indication for angiography from 7% of all patients tested using TS to 40% when the same patients were tested using other methods²³.

Other sources of variation were also demonstrated *in vivo*. Differences in needle placement, at what time during dialysis session measurements were performed, or differences in systemic haemodynamics in the same patient over different treatments can cause a large variability in Qa measurements²⁴.

Lateral to the aim of this study, in our series, baseline Qa determination was not predictive of the four VA events occurring in the subsequent four months of follow-up. It is, therefore, imperative to consider device-specific Qa thresholds for angiography, or alternatively standardisation of Qa results between manufacturers. Clinicians should be aware that Qa results cannot be compared directly between

different devices, and VA monitoring should be performed using a single technique in any given patient, with target and alarm values validated for that specific technique.

We are now in a position where we feel that we must perform some form of VA monitoring, but do not know exactly which. Qa, although not perfect, with results that are hard to interpret and need specific calibration to fine-tune appropriate alarm thresholds for each measurement technique, is probably the best haemodynamic parameter to follow.

In our unit we evaluate monthly Qa, together with a trend analysis of other equally not perfect parameters, such as physical examination²⁵, Kt/V in all dialysis treatments, recirculation and maximum obtainable Qb, with circuit arterial pressure above minus 250mmHg and then decide empirically, as physicians always do, while awaiting further evidence.

Conflict of interest statement. Both authors work with Fresenius Medical Care, but they did not receive any grant or fees for the design or execution of this study protocol.

References

1. Feldman HI, Kohn S, Wasserstein A. Hemodialysis vascular access morbidity. *J Am Soc Nephrol* 1996;7:523-535
2. Tessitore N, Bedogna V, Gammaro L, *et al*. Diagnostic accuracy of ultrasound dilution access blood flow measurement in detecting stenosis and predicting thrombosis in native forearm arteriovenous fistulae for hemodialysis. *Am J Kidney Dis* 2003;42:331-341
3. McCarley P, Wingard R, Shyr Y, *et al*. Vascular access blood flow monitoring reduces access morbidity and costs. *Kidney Int* 2001;60:1164-1172
4. Tonelli M, Jindal K, Hirsch D, *et al*. Screening for subclinical stenosis in native vessel arteriovenous fistulae. *J Am Soc Nephrol* 2001;12:1729-1733
5. Tessitore N, Mansueto G, Bedogna V, *et al*. A prospective controlled trial on effect of percutaneous transluminal angioplasty on functioning arteriovenous fistulae survival. *J Am Soc Nephrol* 2003;14:1623-1627
6. Lumsden AB, MacDonald MJ, Kikeri D, *et al*. Prophylactic balloon angioplasty fails to prolong the patency of expanded PTFE arteriovenous grafts. *J Vasc Surg* 1997;26:382-392
7. Moist LM, Churchill DN, House AA, *et al*. Regular monitoring of access flow compared with monitoring of venous pressure fails to improve graft survival. *J Am Soc Nephrol* 2003;14:2645-2653
8. Dember L, Holmberg E, Kaufman J. Randomized controlled trial of prophylactic repair of hemodialysis arteriovenous graft stenosis. *Kidney Int* 2004;66:390-398
9. Ikizler T, Himmelfarb J. Trials and trade-offs in hemodialysis vascular access monitoring. *Nephrol Dial Transplant* 2006;21:3362-3363
10. Shahin H, Reddy G, Sharafuddin M, *et al*. Monthly access flow monitoring with increased prophylactic angioplasty did not improve fistula patency. *Kidney Int* 2005;68:2352-2361

11. Robbin ML, Oser RF, Lee JY, *et al.* Randomized comparison of ultrasound surveillance and clinical monitoring on arteriovenous graft outcomes. *Kidney Int* 2006;69:730-735
12. Lok CE, Bholra C, Croxford R, *et al.* Reducing vascular access morbidity: a comparative trial of two vascular access monitoring strategies. *Nephrol Dial Transplant* 2003;18:1174-1180
13. Ram SJ, Work J, Caldito GC, *et al.* A randomized controlled trial of blood flow and stenosis surveillance of haemodialysis grafts. *Kidney Int* 2003;64:272-280
14. Ponce P, Mateus A, Santos L. Anatomical correlation of a well-functioning access graft for haemodialysis. *Nephrol Dial Transplant* 2009;24:535-538
15. Krivitski N. Theory and validation of access flow measurement by dilution technique during hemodialysis. *Kidney Int* 1995;48:244-250
16. Mercadal L, Hamani A, Bene B, Petclerc T. Determination of access flow from ionic dialysance. Theory and validation. *Kidney Int* 1999;56:1560-1565
17. Lindsay R, Huang S, Sternby J, Hertz T. The measurement of hemodialysis access blood flow by a conductivity step method. *Clin J Am Soc Nephrol* 2010;5:1602-1606
18. Schneditz D, Wang E, Levin N. Validation of haemodialysis recirculation and access blood flow measured by thermodilution. *Nephrol Dial Transplant* 1999;14:376-383
19. Lacson E Jr, Lazarus J, Panlilio R, Gotch F. Comparisons of hemodialysis blood access flow rates using online measurement of conductivity dialysance and ultrasound dilution. *Am J Kidney Dis* 2008;51:99-106
20. Lopot F, Nejedly B, Sulkova S, Blaha J. Comparison of different techniques of haemodialysis vascular access flow evaluation. *J Vasc Access* 2004;5:25-32
21. Fontseré N, Blasco M, Maduell F, *et al.* Practical utility of online clearance and blood temperature monitors as non-invasive techniques to measure hemodialysis blood access flow. *Blood Purif* 2011;31:1-8
22. Bosman P, Boereboom F, Bakker C, *et al.* Access flow measurement in hemodialysis patients. *J Am Soc Nephrol* 1996;7:966-969
23. Tonelli M, Klarenbach S, Jindal K, *et al.* Access flow in arteriovenous accesses by optodilutional and ultrasound dilution methods. *Am J Kidney Dis* 2005;46:933-937
24. Huisman R, Dijk M, Bruin C, *et al.* Within session and between-session variability of haemodialysis shunt flow measurements. *Nephrol Dial Transplant* 2005;20:2842-2847
25. Asif A, Leon C, Vargas L, *et al.* Accuracy of physical examination in the detection of arteriovenous fistula stenosis. *Clin J Am Soc Nephrol* 2007;2:1191-1194

Correspondence to:

Dr Pedro Ponce

FMC

Rua Prof. Salazar de Sousa, Lote 12

1750-233 Lisbon, Portugal

pedro.ponce@fmc-ag.com