

Variations in vascular access flows in haemodialysis can depend on needle orientation

Schoch, M., Wilson, S and Agar, JWM. (2008). Variations in vascular access flow in haemodialysis can depend on arterial needle orientation *Ren Soc Aust J* 4(2) 45-50

Submitted February 2008 Accepted April 2008

Abstract

Introduction: While using the Transonic Qc™ machine to assess access flow in arteriovenous fistulae (AVF), we observed that when compared to antegrade arterial needle insertion, retrograde arterial needle insertion could regularly produce lower access flow measurements. This study sought to explore this phenomenon.

Method: 23 patients entered and 20 finished the study. Patient selection criteria included: functioning AVF and an adequate AVF length for either retrograde or antegrade arterial needle insertion. After ensuring stable and similar blood pressures, 3 flow measurements were taken during the first 2 hours on the same dialysis day of 3 consecutive weeks using antegrade needle insertion then were repeated on 3 further consecutive weeks using retrograde insertion.

Results: Overall, access flows measured with retrograde insertion were significantly lower by a mean difference of 107.15 ml/min (57-484 ml/min) than the flows measured with antegrade needle placement. In 5/20, 3 recorded minimal difference and 2 had a higher access flows during retrograde insertion. No recirculation was observed during either antegrade or retrograde needle insertion. The paired t-test showed that there was significant difference between the antegrade versus retrograde mean measurements ($p = 0.005$).

Conclusion: Although the sample size is small and the number of measurements limited, we conclude that access flows may be greater with an antegrade arterial orientation compared to flows recorded with a retrograde orientation. The phenomenon behind this conclusion is yet to be investigated. We suggest that when using the Transonic Qc™ access measurement device the arterial needle should always be in the same direction for each measurement for each individual patient.

Key Words

vascular access, transonic, haemodialysis, access flow, cannulation.

Lau, Saunder, Atkins & Kerr, 2006; Vanholder, 2001). When thrombotic events occur intervention is required, either by chemical or mechanical radiological thrombolysis or surgical thrombectomy. The latter in particular, potentially rendering the AVF unusable for weeks (Polkinghorne et al.). In this instance, a central venous catheter is necessary, most commonly inserted into the right, or left, internal jugular vein (Vesely, 2003).

Central venous catheters (CVC) are not ideal as they carry a high risk for thrombosis and infection, especially to the endocardium and valves of the heart, because the location of the tip of the CVC is at the junction of the superior vena cava and right atrium (De Kempnaer, Have & Oskam, 2003; Vesely, 2003). As the presence of a central line immediately increases the mortality rate by 30%, the goal of the dialysis team is to avoid the insertion of a central venous line whenever possible (Clinical Educators Network, 2006; De Kempnaer et al., 2003; Torpey, 2007).

To reduce the insertion rate of central venous lines and to optimise the lifespan of the AVF it is advised that a surveillance program is introduced (Schwab et al., 2001). Most AVF surveillance programs either use hand held ultrasonography,

Introduction

Though the creation of the first arteriovenous fistula (AVF) in 1966 revolutionised haemodialysis (Twardowski, 1995), complications such as thrombosis, stenosis and infection remain common and are a major cause of patient morbidity and mortality in

all dialysis services and in all countries (Schwab, Oliver, Suhocki & McCann, 2001). The two major causes of thrombosis are: (a) damage to the vessel wall and endothelium due to continuous cannulation and (b) stenosis, a narrowing of the vessel wall predominantly caused by intimal hyperplasia (Polkinghorne,

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thermodilution or ultrasound dilution methods. The ultrasound dilution method of surveillance has recently been introduced into Australia by Transonic Systems Inc[®] (Depner & Krivitski, 1995; Polkinghorne et al., 2006). The Transonic Qc machine[®] measures both recirculation (blood pumped back through the dialysis circuit before going through the patients' circulation) and access blood flow through the AVF. The Transonic Qc machine[™] measures recirculation by placing two ultrasound probes on the bloodlines, one on arterial and one on venous. The ultrasound measures at approximately 1560 – 1590 m/sec in blood and is dependent on the blood protein concentration. The operator introduces a bolus of isotonic saline into the bloodstream via the dialysis machine, the blood protein concentration is decreased and ultrasound velocity reduced. This reduced ultrasound velocity is then recorded by the monitor. Therefore, if there is any saline taken back up by the arterial line, then the sensor is able to measure the amount of saline as a percentage of recirculation (Transonic Systems Inc[™], 2003). Access flow measurement is done via the Krivitski method[®] of reversing the bloodlines. The operator again introduces the saline into the bloodlines via the dialysis machine and it enters at the arterial end of the AVF via venous line, travels through the AVF and is detected by the arterial sensor at the venous end of the AVF. This produces 2 measurement curves, one that is the measurement of the dilution at the venous sensor (entering the AVF) and one that is the diluted blood detected at the arterial sensor (leaving the AVF). The calculation is done from the ratio of the area under the venous curve to the area under the arterial curve, given as a measurement of mls/minute (Transonic Systems Inc[™]).

Polkinghorne et al. (2006) state "the measurement of vascular access blood

flow (Qa) is recommended as the preferred method of surveillance for AVF" (p. 2499). This is a view that echoes the recommendations of K/DOQI (National Kidney Foundation [NKF], 2006). The K/DOQI [NKF] guidelines and Krivitski (1995) both recommend strict parameters of acceptable vascular access flow with a Qa of between 500ml/minute and 2000ml/min being ideal. Any measurements that fall outside these parameters require further investigation, such as ultrasound or contrast fistulography to detect problems. Not only is a low access flow an important predictor of access failure but, even more importantly, a significant drop in access blood flow over time, such as a fall of >25% over four months, is a clear indicator of developing access problems as access flow is maintained until a critical stenosis (>70%) is reached. The detection of any significant reduction in flow is of paramount importance as early intervention can then be implemented to save the access (Hakim & Himmelfarb, 1998; Transonic Systems Inc[™], 2003).

The dialysis services at Barwon Health commenced bi-monthly AVF monitoring of all 82 in-centre dialysis patients in February 2006. In our service, all arterial needles are inserted in an antegrade orientation (with the fistula flow, tip towards the heart). The belief is that retrograde needle placement (tip directed away from the heart and into the fistula flow) risks endothelial flap formation at the point of insertion and post-withdrawal extravasation of blood from the lumen into the peri-vascular tissue after needle removal. This microtrauma may, over time promote false aneurysm formation (Twardowski, 1995; Woodson & Shapiro, 1974).

There is disagreement whether needle orientation is or is not associated with recirculation. English (2005) has stated that antegrade cannulation can

result in recirculation of the blood if needle hubs are less than three inches apart. Conversely, Harman (2005) has performed studies with needles inserted in either direction and has found no significant increase in recirculation by cannulating in the direction of flow.

Though we have confirmed these latter findings, we also chanced on what appeared to be an anomaly: when patients had the arterial needle inserted in the antegrade position, the Transonic[™] measured AVF access flows appeared consistently greater than access flows measured in the same patients with the needles inserted retrograde. This dimension of access flow reduction, if >25% or <500ml/min would have, in normal circumstances, prompted a referral for diagnostic intervention.

The chance observation occurred when a flow drop from over 1000ml/min to 340ml/min was noted on several patients on repeated flow measurements over a two-month period. As this was an unusually large drop in flow over a short period of time, the measurements were repeated on two further occasions, the flow remaining at 340ml/min. It was noted, however, that the arterial needle had not been inserted in the usual antegrade position but retrograde. In the next dialysis session, when the arterial needle had been inserted antegrade, the access flow measurements were again performed and flows were recorded at >1000ml/min. This finding, confirmed in several patients, prompted further investigation.

A protocol was established to test the hypothesis that retrograde arterial needle placement is associated with a lower arteriovenous flow measurement when assessed by the ultrasound dilutional access flow method. If access flows <500ml/min were encountered with retrograde arterial needle placement, flow

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measurements should be repeated with antegrade placement. If, with a change in needle orientation, adequate flows were re-established, unnecessary and expensive diagnostic tests might thus be averted and patient discomfort and interventional expense avoided. This requires further investigation.

Method

Though suffering from the disadvantage of being a quasi-experimental design, this study aimed to test the following chance observation: that Transonic Qc™ ultrasound dilutional AVF access flow measurements taken with the dialysis lines reversed are associated with an apparent decrease in access flow when the arterial needle was placed in the retrograde position. The measurements were undertaken over a six-week time period in an outpatient dialysis unit (South Geelong Renal Dialysis Unit).

After Research and Ethics Committee approval, 23 patients were enrolled. The inclusion criteria were: satellite facility-based patients with a functioning AVF who had previously known vascular access flows >500ml/min with the needle placed antegrade and who were able to give informed consent. The exclusion criteria were: patients who were unable to give informed consent or with an AVF with known access flows < 500ml/min with the arterial needle antegrade. AVF that cannot accommodate retrograde arterial needle placement, AVF less than three months old, patients on single-needle, graft (as there is only one graft in the unit), or catheter accessed dialysis and those AVF where the buttonhole technique had already been established.

Measurements were performed over 6 dialysis sessions in each patient, three with the arterial needle placed antegrade and three with the arterial needle placed

retrograde. Three tests were performed on each day on each patient, the recorded measurement for that day being the mean of the three measurements. These tests were then averaged to find the mean and compared using the paired t-test. The three tests with the arterial needle in antegrade position were conducted in the first 3 weeks, and retrograde arterial needle placement in the following 3 weeks. There was no random assignment as we were trying to reduce confusion with the staff cannulating the AVF's. The AVF's were not cannulated by the same staff member each session, therefore this could be a contributing factor to differences in measurements due to needle placement and distance between the needles. The flow measurements were all performed during the maximal haemodynamic stability of the first 2 hours of dialysis (BP >100/60). Operator discrepancy and internal validity were strengthened by ensuring a single operator for the Transonic HDO2 Haemodialysis Monitor™, (Transonic Systems Inc.™, 2003). The Transonic Qc monitor™ has been described and validated in previous studies (Krivitski, 1995). The dialysis machine pump speeds were set at 300ml/min for all tests. The operator was not blinded to the study.

The data was automatically recorded onto a laptop formatted to the Transonic Qc machine™. The statistical analysis was calculated using GraphPad InStat 3 (Graphpad, 2007).

Results

Of the 23 patients who fulfilled the inclusion criteria, 9 were female and 14 were male, 17 patients had a radiocephalic AVF, 1 a brachio basilic AVF, and 5 a brachiocephalic AVF. The age of patients ranged from 42 - 86 years with a mean of 64.9 years (SD = 11.59). 20 of the 23 patients completed the 6-week study. Table 1 provides the antegrade

and retrograde mean readings and the difference between these means for all 20 patients.

The mean access flow calculated for each patient under each needle placement was: antegrade mean = 1144.5ml/min (SD ± 659.36); retrograde mean = 1037.35 / min (SD ± 603.21). This was statistically significant at p = 0.005. Means were compared by the dependent sample paired t-test. The mean difference was 107.15 ml/min and the 95% confidence interval of the difference was 35.88ml/min - 178.42 ml/min (GraphPad, 2007).

Discussion

Clinical data on the effect, if any, of arterial needle orientation on ultrasound dilutional vascular access flow measurements is minimal with only a few studies briefly referring to this matter. As we believe needle orientation may be an important factor in longer-term fistula integrity, we routinely insert all arterial needles, fistula anatomy permitting, with an antegrade and not retrograde orientation.

Woodson and Shapiro (1974) have shown that when a dialysis needle is inserted, an endothelial flap pouts into the lumen behind the needle that, upon removal of the needle, is 'pressed shut' by flow forces in antegrade needling but which sheer forces 'hold open' in retrograde needling and thereby allow extravasation of blood into the perivascular tissue. It was our antegrade arterial needling orientation protocol that led to the chance observation that flow measurements were different in antegrade compared to retrograde insertion techniques and that prompted our interest in investigating further.

In a study to evaluate intra- and inter-session AVF access flow variability with the Transonic Qc™, Huisman

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Table 1 Antegrade and retrograde means for each patient

Patient	Antegrade Mean Week 1 - 4	Retrograde mean Week 5 - 8	Difference in means	
1	508	327	181	↓36%
2	648	498	150	↓24%
3	2023	1539	484	↓24%
4	1066	966	100	↓9%
5	1358	1091	267	↓20%
6	2028	1863	165	↓9%
7	795	892	97	↑11%
8	934	930	4	↑0.5%
9	487	362	125	↓26%
10	1382	1182	200	↓14.5%
11	404	288	116	↓29%
12	685	592	93	↓14%
13	2465	2158	307	↓13%
14	1454	1454	0	0
15	1285	1383	98	↑7%
16	2277	2145	132	↓6%
17	614	557	57	↓9%
18	1575	1558	17	↓1%
19	550	409	141	↓26%
20	352	553	201	↑37%
Total mean	1144.5	1037.35	107.15	↓9%

et al. (2005) documented the needle orientation at each measurement and found flow variability depending upon needle orientation. Huisman et al. concluded that changes in access flow measurements between dialysis sessions were “critically dependent on similar needle orientation” but did not specify which needle orientation (p.2846). They recommended that to obtain inter-session measurement reliability, the needles ought to be placed in the same direction, whether antegrade or retrograde. Lastly Huisman et al. suggested that “best mixing occurs with

the arterial needle facing towards the shunt flow” (i.e. retrograde) (p.2845).

In our study, however, the higher mean access flow of 1144.5ml/min was obtained with the arterial needle antegrade compared to a mean flow of 1037.35ml/min with the arterial needle retrograde in AVF without other obvious inadequacies and with unaltered and appropriate dialysis adequacy. A previous study presented by Wiggins, Agar and Somerville (2003) showed that there was no change at all to dialysis adequacy when the arterial needle was in the antegrade or retrograde position, so this

testing was not replicated in the current study. There were no recorded readings of recirculation during this study, with the needle in either orientation. Although the mean results for each of the groups is only a 9 % difference in flow rates, the results (see table 1) reveals that individually the access flow rates with the arterial needle in retrograde position are considerably lower for 6 out of the 20 patients (24% or greater). For these 6 patients these results would be significant if we were considering investigation, and the possibility of sending these patients for unnecessary and invasive investigations. The only way to prove that this is a phenomenon related to the direction of needle placement and not an abnormality within the vessel would be to have all 20 patients undergo imaging (ultrasound or fistulagram) to rule out any stenoses or other abnormalities. This is an avenue for further investigation in future studies.

A disappointing result from the study was the inability to replicate the original drop that prompted the study of 1000ml/min down to 340ml/min. Some theories of why this occurred is the possibility of larger space between the arterial and venous needle (distance between needle tips), or the loss of a percentage of saline through collateral vessels linked to the AVF, possible differences in blood pressure and/or cardiac output. It would require a much larger investigation to rule out these other extraneous variables.

There have been other studies that have looked at the usefulness of the Transonic Qc machine™ as an indicator of early stenosis formation. However, none of these studies have looked at arterial needle direction as a possible variable in access flow measurement results. Tonelli et al. (2001) in a prospective observational cohort study compared bi-monthly measurements of recirculation

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and blood flow (Qa) to detect whether the ultrasound dilution method was an adequate tool in early detection of significant (>50%) stenosis. Although Tonelli et al. did not document needle orientation; they did comment that “a positive study led to a change of needle placement in one patient (with subsequent studies with the needle position optimised showed greatly improved Qa” (p.1730). In addition, Tonelli et al. did not comment whether needle orientation or simple in-vein placement was at issue.

A further randomised controlled trial conducted by Tessitori et al. (2004) measured whether AVF surveillance by ultrasound dilution detected stenosis early enough to implement subsequent pre-emptive surgical correction and whether this early intervention prolonged the life of the AVF. These authors found that “Qa surveillance and pre-emptive correction of subclinical stenosis reduce failure rates and prolonged the useful life of a native, mature forearm AVF” (p. 2331). Although confirming the value of AVF surveillance by the ultrasound dilutional method, the effect on access flow and outcome of variables such as variations in needle placement were not studied.

Lok et al. (2003) explored the best surveillance methods in the early detection of stenosis and the avoidance of thrombotic events but also did not consider the effect of arterial needle orientation on access flow measurement. Though some patients in their study had poor AVF flows yet no angiography-confirmed stenosis, there was no consideration that needle orientation may have been an important issue in these cases.

Why, then, might the insertional orientation produce a significant difference in flow measurement?

It is likely that our finding relates to the saline bolus ‘travel distance’ and ‘travel time’ between the ultrasound probe sensors on the venous and arterial lines. If the arterial needle is inserted retrograde, the needle tips are likely to be more separated than when both needles are inserted antegrade. Antegrade/antegrade insertion will shorten bolus travel distance and time and thus ‘appear’ as a faster access flow. In addition, a mixing and flow-related delay may result as a saline bolus, entering the AVF from the distal needle, is initially moving towards the arteriovenous anastomosis. After mixing, bolus flow reversal will occur as the access blood flow washes the bolus away from the anastomosis towards the sensor in the more proximal line. This may add a further dimension to tip separation as an explanation for the finding.

This latter explanation concurs with Huisman et al. (2005) who remarked on the technological problems of sensing when mixing an indicator solution with blood. However, in making this observation they referenced a 1970 paper and, as technological advances in methods to distinguish between saline and blood have advanced significantly since that time, it is likely that mixing errors are less of a sensing issue now.

Our study is limited by small numbers, by the inability to blind the operator and the difficulty in providing a control versus treatment group – also the result of the small study population and the inability to have the same cannulator each session. Nevertheless, our data suggests that needle orientation may be an important factor in ultrasound dilutional studies and requires further assessment and confirmation. At the least, it cautions that when performing ultrasound dilution method AVF surveillance, the orientation of the arterial needle must be consistent in serial measurements for any one

patient. Which orientation may not be so crucial though it seems likely that if antegrade/antegrade needling orientation is used, the flow parameters set for access flow may be different from the limits stated in the literature.

Conclusion

We believe this study suggests that when using the Transonic Qc™ access measurement device, the arterial needle should always be inserted in the same direction for each measurement in an individual patient. In addition, access flows may be greater with an antegrade arterial orientation compared to flows recorded with a retrograde orientation, potentially changing the flow parameters that accompany the Transonic™ manual.

As a result, if lower flow measurements are found when using the ultrasound dilutional method and the arterial needle orientation is retrograde in direction, it is important to ensure that previous measurements had not been taken with an antegrade arterial needle orientation. Do this before concluding that a fall in access flow and initiating a referral for further potentially invasive, complex and expensive investigation.

It must be noted that when using the Transonic Qc machine™ for AVF and AVG surveillance, it is important to factor in the other clinical indicators of issues with AVF/AVG flows. These clinical indicators include venous and arterial pressures, physical assessment of thrill and bruit, cannulation difficulty, and poor dialysis adequacy. When used in this capacity the Transonic Qc machine™ is a useful adjunct to AVF/AVG assessment in the haemodialysis setting.

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