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Technical Note

Flow measurements in dialysis shunts: lack of agreement between conventional Doppler, CVI-Q, and ultrasound dilution

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Abstract

Background. Measuring flow in dialysis shunts is recommended to predict imminent thrombosis. Multiple methods for measuring blood flow are in use. Numerous ultrasound protocols exist which determine volume flow using a conventional Doppler (CD) frequency shift analysis technique. All of these are subject to potentially large errors. Quantitative colour velocity index (CVI-Q) does not make use of the Doppler equation and is more precise *in vitro*. Ultrasound dilution (UD) measures access flow during dialysis in a non-operator-dependent way. The aim of the present study was to compare these three methods of measuring access flow *in vivo* for agreement with each other.

Methods. In 38 accesses flow was measured by CD, CVI-Q, and UD. All measurements were done during dialysis. Agreement was determined by intraclass correlation coefficient (ICC = R_i) and Bland–Altman analysis.

Results. ICC between UD and CVI-Q was $R_i = 0.56$. ICC between UD and CD was $R_i = 0.10$, and ICC between CD and CVI-Q was $R_i = 0.16$. Bland–Altman analysis revealed a bias (mean difference) of −38 ml/min between UD and CVI-Q, a bias of 1129 ml/min between UD and CD, and a bias of 1167 ml/min between CVI-Q and CD.

Conclusions. CD measurements did not agree with UD or CVI-Q: much higher values were recorded with the former than with the latter two techniques. The agreement between UD and CVI-Q measurements is low but reasonable. Caution must be applied in comparing and interpreting values of access flow measured by different techniques.

Keywords: arteriovenous shunt; blood flow velocity; CVI-Q; haemodialysis; ultrasonography; ultrasound dilution

Introduction

Vascular access thrombosis is a major problem for haemodialysis patients. Prospective monitoring for haemodynamically significant stenosis combined with correction can improve patency and decrease the incidence of graft thrombosis [1,2]. Monitoring is usually done by measuring venous pressures or access flow.

A decreased access flow was the most significant predictor for graft failure in the following 6 months in a retrospective study of 2792 polytetrafluoroethylene (PTFE) grafts [3]. In a prospective study of 172 PTFE grafts the access flow was the best predictor of thrombosis in the following 3 months [4]. Monitoring of access flow is now recommended by the National Kidney Foundation Dialysis Outcomes Quality Initiative clinical practice guidelines for vascular access [5].

Access flow can be measured by various methods. Most used are duplex sonography and more recently ultrasound dilution (UD). In duplex scanning measurements of vessel diameter or surface area are combined with Doppler-derived velocity determinations to obtain estimates of volume flow. This technique is, however, not standardized and is subject to potentially large errors [6–8]. Winkler [9] compared measured volume flow of five commercial duplex ultrasound systems in a flow phantom model and found errors between −33.6% and +77.9% in near ideal circumstances. The most accurate in this study was the Phillips CVI system (error −3.1% to +0.5%). This machine does not utilize the Doppler equation, but instead uses a method of pattern recognition in the

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time domain to determine absolute velocity using an algorithm known as quantitative colour velocity imaging (CVI-Q) [10]. No assumptions regarding the flow profile across the vessel are made, which should result in more precise results under different flow conditions. A good correlation between CVI-Q and invasive measurements of volume flow was found in flow models and in canine and human arteries [11–13].

UD is another way of measuring volume flow in dialysis shunts [14]. This is done during dialysis and takes about 15–25 min per patient. It is not operator dependent and can easily be done by a dialysis nurse. This makes it a much more convenient instrument for repeated screening than duplex sonography.

There is no gold standard for determining access flow in dialysis shunts. In our dialysis unit we use a duplex scanner that can measure volume flow both by conventional Doppler (CD) and by CVI-Q. The aim of the present study was to compare these two duplex methods and UD as to assess agreement with each other.

Subjects and methods

Measurements were made in 38 adult stable chronic dialysis patients, involving 21 distal arteriovenous fistulae and 17 PTFE loop grafts. Access flow was measured sequentially by CD, CVI-Q and UD (Table 1). All measurements were made during the same dialysis session immediately after each other with the dialysis lines in the same (reversed) position and the blood pump at the same speed. Duplex measurements (CD and CVI-Q) were taken on the same marked location on the access. A Phillips P700 (Santa Ana, CA) ultrasound machine was used with a 7.5 MHz grey-scale linear array, 5.0 MHz spectral Doppler and colour flow imaging transducer. The beam was positioned to keep the angle of insonation at 60° or lower. The location of measurement was predetermined by using the Doppler spectrum and colour to select an area in the access graft with the least turbulence (Figure 1).

Conventional Doppler

The cross-sectional area of the lumen was measured using a point ellipse trace with the vessel in B-mode transverse plane. Doppler flow information was collected during a sweep of 4 s. The machinery does not provide mean velocity (MV) in cm/s. It was calculated from peak systolic velocity (PSV), end-diastolic velocity (EDV) and pulsatility index (PI). The PI is defined as the difference in velocity per cycle divided by the MV. Mean velocity can thus be derived using the formula [15]:

$$MV = \frac{PSV - EDV}{PI}$$

The product of the cross-sectional area (cm^2) and the MV (cm/s)$\times$60 was used to define volume flow in ml/min.

CVI-Q

CVI-Q information was acquired in the M-mode during a sweep of 9 s with optimal colour gain. A velocity profile is displayed. The effective diameter of the vessel was derived from the distance between two points where the velocity profile equals zero. Assuming a circularly symmetrical velocity profile an estimate of volume flow can be made by integrating the velocity profile over the diameter. Both velocity profile and diameter vary during the cardiac cycle. Calculations were done over a time span of at least four cardiac cycles. The implemented software did these calculations. The calculated volume flow in ml/min was displayed.

Table 1. Access flow and CV measured by UD, CVI-Q, and CD

Method	Access flow (ml/min)		CV (%)
	Range	Mean	Mean ± SD
UD	87–1333	752	11.4 ± 8.0
CVI-Q	205–1154	753	12.6 ± 9.7
CD	515–5999	1958	10.5 ± 7.6

Ultrasound dilution

The Transonic HD01 Hemodialysis Monitor (Transonic Systems Inc. Ithaca, NY) was used. To measure access flow the dialyser lines were temporarily reversed. The blood pump speed was set as close to 300 ml/min as possible and ultrafiltration was left on. Isotonic saline was infused by opening the saline infusion line for 4–5 s without clamping off the arterial line. Arterial and venous dilution curves were derived from calibrated clamp-on sensors on the bloodlines. Access flow was computer calculated. The average of three consecutive flow determinations was taken.

Statistical analysis

Means ± standard deviations (SD) are given where indicated. Intraclass correlation coefficient (ICC) was derived from two-way analysis of variance (ANOVA) and determined as:

$$R_i = \frac{P - E}{(P + E) + 2/n(O - E)}$$

In which P is the between-subjects mean square, O is the between-raters mean square, E is the error mean square and n is the number of pairs of subjects (n subjects measured by two raters) [16].

Bland–Altman analysis was done by graphically plotting differences against means and calculating the bias (mean difference) and limits of agreement (LA) (bias ± 2SD) [17].

Results

The range of values of access flow measured by UD was 87–1333 ml/min (average 752 ml/min).

ICC between UD and CVI-Q was $R_i = 0.56$. ICC between UD and CD was $R_i = 0.10$. ICC between CD and CVI-Q was $R_i = 0.16$. Pearson R was higher for all comparisons (Table 2).

Bland–Altman analysis gave the following results: a bias of −38 ml/min between UD and CVI-Q, LA −585 ml/min to +508 ml/min, a bias of 1129 ml/min between UD and CD (CD mean is larger than UD

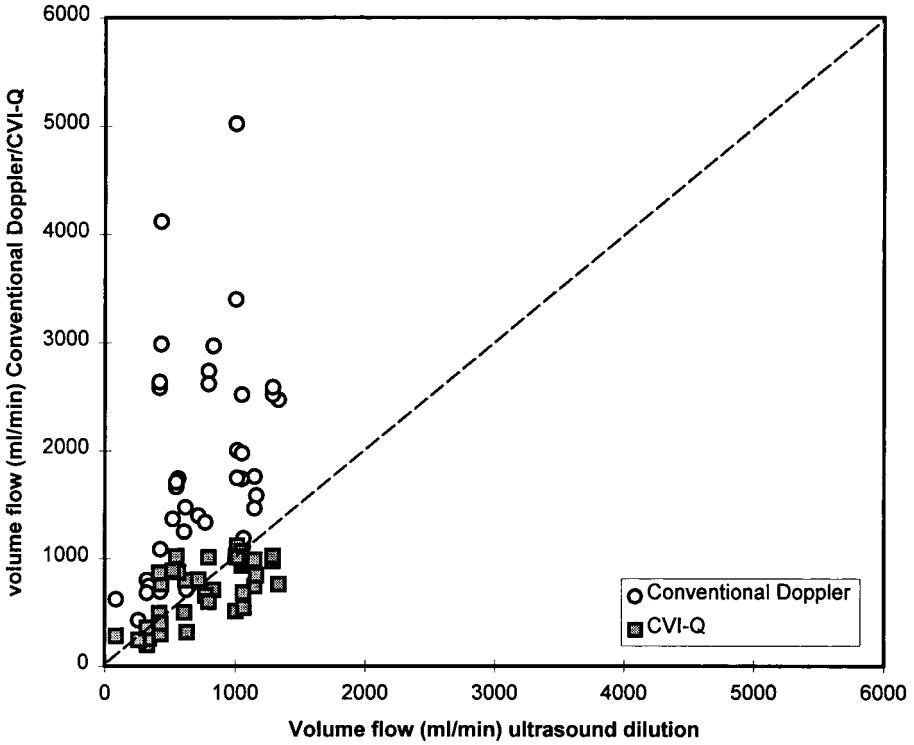

Fig. 1. Comparison of volume flow in 38 dialysis shunts determined by three methods. A plot is made between UD (values on x axis) and two sets of matched y values (CVI-Q and CD). The dotted line is the line of identity. UD, ultrasound dilution; CVI-Q, colour velocity index—quantitative; CD, conventional Doppler.

Table 2. Correlation coefficient (R) and intraclass correlation coefficient (ICC) of comparison of volume flow in 38 dialysis shunts determined by three methods

Methods compared	R	ICC
UD *vs* CD	0.35	0.10
UD *vs* CVI-Q	0.62	0.56
CD *vs* CVI-Q	0.43	0.16

mean), LA −757 ml/min to +3013 ml/min and a bias of 1167 ml/min with LA of −674 ml/min to +3007 ml/min between CD and CVI-Q. A graphical plot of differences against mean values is shown in Figure 2.

Discussion

Few comparisons of UD and duplex are made. A good correlation between duplex and UD was found in three studies. Deppner compared only seven measurements and found a correlation coefficient of $R=0.69$ [18]. Sands compared CVI-Q during dialysis with UD in 19 patients (66 measurements) and found a correlation coefficient of $R=0.83$ [19]. May compared colour Doppler (Acuson) with UD in 87 PTFE grafts and found a correlation coefficient of $R=0.79$ [4].

All previous studies used the Pearson R for comparison. This is not an appropriate measure for agreement. The ICC $=R_i$ and Bland–Altman analysis are better statistics for assessing agreement or consistency between two methods [16,17,20].

Over a wide range of access flow measurements we found a lower but reasonable agreement between UD and CVI-Q access flow measurements than in the cited studies. Although the results for both measurements are reasonably similar on the whole, any given value obtained in one of these methods does not allow a correct estimate of the value to be seen with the other methods because the LA are too large to be clinically acceptable. We found a very poor agreement between CD and either UD or CVI-Q. Conventional Doppler measurements were much higher. The difference increased with higher flows. A possible explanation is the higher susceptibility of CD for disturbed flow. CVI-Q is theoretically less influenced by turbulent flow and UD is even more precise with turbulent flow, because a better mixing of the saline indicator fluid with the blood is achieved.

We found very different values for blood flow in dialysis shunts using two different techniques available in a single machine. It must be stressed that our conclusions apply only to this machine and these methods. Flow measurement with CD is not standardized. Different methods are in use to determine cross-sectional area and MV. In the Phillips P700 scanner that we used the cross-sectional area is calculated from

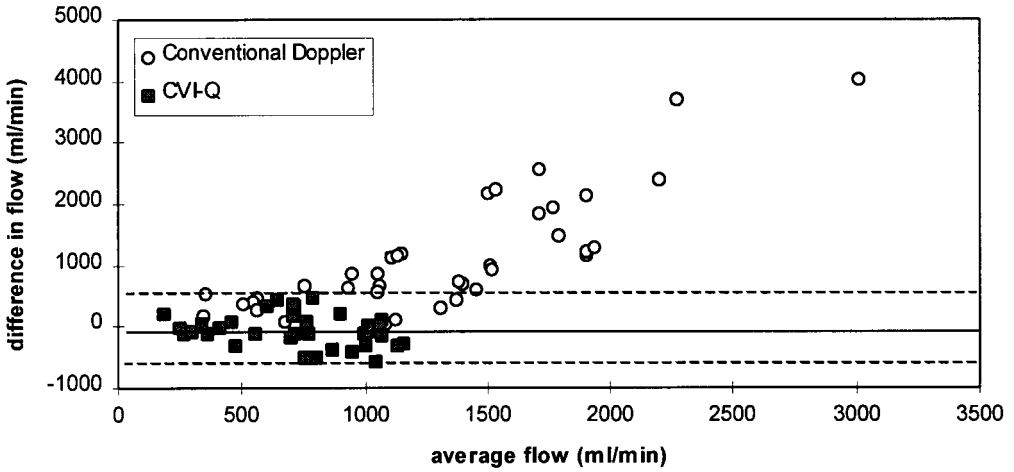

Fig. 2. Plot of differences against averages comparing conventional Doppler (CD) and CVI-Q with ultrasound dilution. The solid line is the bias (mean difference) and the dotted lines are the LA for CVI-Q *vs* UD measurements.

a point ellipse trace. In many other scanners the cross-sectional area is derived from measurement of the transverse diameter, assuming a circular vessel. Mean velocity is not given by the Phillips P700 scanner. We derived it from PSV, EDV, and the PI. Other methods of calculating or approximating the MV are in use. In many other machines the MV is calculated by implemented software of which the algorithm is not always clear.

It is important to take into account the possibly large differences within and between ultrasound machines when comparing data of blood flow cited in the literature.

Only a single apparatus for UD is currently available. Together with the operator independence and the convenience of taking quick measurements during dialysis, this makes UD a more suitable method for standardization and comparison of blood flow in dialysis shunts than CD or CVI-Q.

Duplex measurements give, however, more information besides flow. The location and haemodynamic relevance of stenoses can be detected. Duplex examination can be done prior to percutaneous transluminal angioplasty (PTA) in shunts with a low flow screened by UD. PTA is facilitated when the location of the stenosis is known because positioning and direction of needle placement can be optimized. UD is not possible in single-needle dialysis, which for some patients is the only possibility. Duplex measurements will therefore remain an important non-invasive examination tool in dialysis shunts.

The application of the UD method is limited to dialysis shunts. For flow measurements in other vessels in the human body, duplex scanning is extensively used. According to our results, CVI-Q measurements may be more reliable than CD for flow measurements in these vessels.

In conclusion, we found a very poor agreement of access flow as measured by CD with CVI-Q or UD in *in vivo* measurements in dialysis patients. In studies of access flow in dialysis patients, the method and machine employed should be described. Duplex measurements are not standardized and may give very different results not only because of operator dependency. The UD technique is a promising technique for international comparisons of access flow because only a single apparatus is currently in use, the technique is standardized and not operator dependent.

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