Diameter measurements of the forearm cephalic vein prior to vascular access creation in end-stage renal disease patients: graduated pressure cuff versus tourniquet vessel dilatation

R. Nils Planken1,2,6, Xavier H. A. Keuter1,6, Arnold P. G. Hoeks3,6, Jeroen P. Kooman4,6, Frank M. van der Sande4,6, Alfons G. H. Kessels5, Tim Leiner2,6 and Jan H. M. Tordoir1,6

1Departments of Vascular Surgery, 2Radiology, 3Biophysics, 4Nephrology, 5Clinical Epidemiology Medical Technology Assessment and 6Cardiovascular Research Institute Maastricht and Maastricht University Hospital, Maastricht, The Netherlands

Abstract

Background. Preoperative assessment of forearm superficial venous diameter may predict early failure of newly created arteriovenous fistulas for haemodialysis access. However, early failure and non-maturation rates remain high (up to 30%) and reported cut-off diameters are inconsistent. We hypothesize that this inconsistency is due to differences in the methods used to achieve venous dilatation prior to diameter measurements and daily variation in superficial venous diameter. We furthermore hypothesize that the use of a cuff will lead to a better inter-observer agreement since the applied pressure can be precisely determined. The purpose of this study was to determine inter-observer agreement of superficial venous diameter measurement under venous congestion by using either a graduated pressure cuff or tourniquet and furthermore, to determine daily variations in superficial venous diameter.

Methods. Diameter measurements were performed by two observers on days 1 and 3, in 21 end-stage renal disease patients using either a cuff (60 mmHg) or tourniquet. Measurements were carried out in random order and observers were blinded for each other’s results. Inter-observer agreement was expressed as interclass correlation coefficients. Variance components analysis was used to determine possible causes of disagreement.

Results. Using a cuff, mean venous diameter was 1.8 mm (range, 0.7–3.3 mm). When a tourniquet was used, the mean diameter was 1.8 mm (range, 0.6–3.2 mm). Interclass correlation coefficients between observers were 0.76 and 0.74 for the use of a cuff and tourniquet, respectively. Diameter measurements were revealed to be observer independent. Variations in venous diameter were determined by the patient and the interaction of patient and day. Repeated assessment of venous diameter on different days revealed a variation coefficient of 26.4% when using a cuff, and 26.5% when using a tourniquet.

Conclusions. Venous diameter assessment is observer and congestion method independent. Daily variations in forearm superficial venous diameters should be taken into account when defining and using cut-off diameters prior to vascular access surgery.

Keywords: arteriovenous fistula; haemodialysis; ultrasonography; vascular access; vascular surgery; vein

Introduction

Superficial forearm venous diameter has been shown to correlate with the risk of non-maturation of newly created autogenous radial-cephalic arteriovenous fistulas (RC-AVF) for haemodialysis [1–3]. Vein diameters smaller than 1.6 to 2.5 mm have been associated with RC-AVF failure [4–10]. However, reported cut-off diameters are inconsistent and the exact cut-off diameter remains a subject of discussion [4–10]. This is underscored by the fact that early failure and non-maturation rates remain up to 30% [1–3].

Because superficial forearm veins are highly compliant, local intravenous pressure is a major determinant of venous diameter [11]. An inflatable pressure cuff or tourniquet at the upper arm are recommended to induce venous dilatation for better appreciation of maximum venous diameter [2].
Preoperative diameter measurements of the cephalic vein

The amount of pressure applied and thus the degree of venous dilatation cannot be determined exactly when using a tourniquet, in contrast to pressure application by a graduated inflatable cuff. We hypothesize that the use of a graduated inflatable pressure cuff will result in a better inter-observer agreement in upper extremity superficial venous diameter measurements compared to the use of a tourniquet. Daily variations in superficial venous diameter might limit the value of preoperative measured diameters to predict AVF early failure and non-maturation.

The purpose of the present study was to compare inter-observer agreement of venous diameter measurements when using either a graduated pressure cuff or a tourniquet. Furthermore, we assessed the variance in superficial forearm venous diameter over time as well as the influence of intrinsic patient factors.

Subjects and methods

Subjects and study design

Twenty-one end-stage renal disease (ESRD) patients (mean age 63, range 28–87 years; mean body mass index 24.4, range 17.7–34.9) participated in the study. Causes of kidney failure were: diabetes type 2 (n=4), hypertension (n=3), nephrosclerosis (n=3), nephrotic syndrome (n=3), nephrolithiasis (n=2), chronic pyelonephritis (n=1), malignancy (n=1) and of unknown origin (n=4). Thirteen patients were treated by peritoneal dialysis (mean creatinine clearance 12.8 ml/min; range 6.0–21.0 ml/min), and eight patients were awaiting vascular access creation for haemodialysis treatment purposes (mean creatinine clearance 14.9 ml/min; range 3.1–25.8 ml/min).

To determine method agreement for diameter measurements by using a cuff or tourniquet, all subjects were assessed twice, on days 1 and 3, at the same time of day and under standardized conditions. Before each session, subjects were instructed to fast and abstain from exercise, nicotine, caffeine and alcohol in the 12 h preceding the examination. The local medical ethics committee approved the study and all subjects were required to sign informed consent prior to inclusion in the study.

Experimental setup and assessment of venous diameter

B-mode images of the cephalic vein were acquired using an Ultramark ultrasound scanner with a 38 mm linear probe 5–10 MHz (HDI 9, ATL Inc., Bothel, WA). All measurements were performed between 8:15 a.m. and 11:00 a.m. in a temperature-controlled room (range 22–24 °C). Total session time was 35 min for each subject, including 15 min of acclimatization.

To assess venous diameter, subjects were placed in supine position with the left arm placed in a fixation device (foam filled plastic vacuum bag), with the wrist at right atrium height. Special care was taken to avoid compression of the arm by the vacuum bag (Figure 1). After application of a proximal graduated cuff (Iso Stabil 5, Speidel & Keller GmbH, Jungingen, Germany), inflated to 60 mmHg, the cephalic vein was localized and marked 5 cm proximal to the wrist joint. Subsequently, the cuff was deflated and a layer of at least 2 cm of gel was locally applied to optimize the ultrasound image quality. The transducer was fixed in a stand perpendicular to the skin, after optimal positioning for cross-sectional imaging of the vein to enable diameter measurement perpendicular to the skin. Fixation of both the limb and the ultrasound probe avoided extremity or transducer displacement and axial movements. Measurements were started after a 15 min acclimatization period following subject positioning. A proximal cuff (inflated to 60 mmHg) or tourniquet (manually adjusted) was applied at the upper arm. Two minutes after cuff or tourniquet application, the cross-sectional diameter of the cephalic vein was measured using a digital caliper with an accuracy of 0.1 mm on the ultrasonography system monitor.

All measurements were performed by two experienced observers who were blinded for their own and each other’s results. On day 1, both observers measured venous diameter after application of either the cuff or tourniquet in random order. Both cuff and tourniquet were applied by the observers themselves. After 15 min, measurements were repeated with the other method. In a second session 2 days later, both observers measured venous diameter again with both methods. Systolic, diastolic and mean arterial blood pressures were recorded from the contralateral upper extremity prior to acclimatization, directly before and directly after the measurements (Dinamap Vital Signs Monitor 1846, Critikon Inc., Tampa, FL), to determine variability of blood pressures over the course of the imaging sessions.

Statistical analysis

All statistical analyses were performed using SPSS statistical software for Windows (SPSS release 11.0.1, SPSS Inc, Chicago, IL). A paired sample Student’s t-test was used to determine differences in systolic, diastolic and mean blood pressures between sessions. For all comparisons, the level of significance was set to $P < 0.05$. To assess the inter-observer agreement, interclass correlation coefficients were calculated for diameter measurements by the two observers. Variance components analysis was used to determine the effects of subject and observer on the variation in venous diameter measurements. The difference between the
interclass correlation coefficients was tested with a bootstrap technique [12].

Mean differences and the standard deviation (SD) for venous diameters between days, when using a cuff by one observer, were determined for calculation of the coefficient of variation (CV) for repeated diameter measurements at days 1 and 3 (CV% = (SD/\text{Mean}) \times 100\%) [13]. Variation in venous diameter due to the used congestion method or day of measurement were visualized with Bland–Altman plots [14].

Results

All measurements were acquired successfully and there were no significant differences between sessions in contralateral upper arm arterial systolic, diastolic or mean arterial pressures (Table 1). A typical example of a transverse B-mode image of the cephalic vein is shown in Figures 2(A) and (B) before and after cuff application.

Using a graduated pressure cuff, mean venous diameter was 1.8 mm (range 0.7–3.3 mm). When a tourniquet was used, the mean diameter was 1.8 mm (range 0.6–3.2 mm). Interclass correlation coefficients between observers were 0.76 and 0.74 for the use of a cuff and tourniquet, respectively. There were no significant differences between interclass correlation coefficients values of either method (\(P > 0.05\)). Venous diameter measurement on day 1 by observer 1 yielded a mean difference of 0.00 mm (SD = 0.24 mm) between methods (Figure 3). For observer 2, the mean difference was 0.02 (SD = 0.06 mm).

Analysis of variance revealed that the patient was the main factor determining the variation in venous diameter measurements (variance = 0.303 mm\(^2\)). Diameter measurements were almost observer independent (variance = 0.014 mm\(^2\)). The factor day alone had a negligible contribution to total diameter variance (variance = 0.005 mm\(^2\)). However, the diameter measurement was revealed to be dependent on the interaction of subject and day (variance = 0.080 mm\(^2\)). Repeated measurements of venous diameters on days 1 and 3 by one observer yielded a mean variation of 0.12 (SD = 0.48 mm) (Figure 4). Repeated assessment of venous diameter on different days revealed a variation coefficient of 26.4% when using a cuff, and 26.5% when using a tourniquet.

Discussion

In the current study, we found reliability of forearm superficial venous diameter assessment to be independent of observer and congestion method used. The hypothesis that the use of a cuff will result in more accurate and precise superficial venous diameter measurements compared to the use of a tourniquet was not supported by our results. An additional source of variation might be inconsistency of tourniquet application. This is reflected by the difference between observers in the SD of the mean difference between the congestion methods used. Furthermore, our results indicate that forearm superficial venous diameters vary substantially between subjects and between days.

The comprehensive vascular evaluation prior to vascular access placement should also include evaluation of the arterial as well as the venous vasculature [15]. However, a reproducible measurement of superficial forearm venous diameter is crucial when choosing the type of access based on vessel diameters. Venous diameter measurement under congestion prior to vascular access surgery is

Table 1. Mean systolic, diastolic and mean blood pressure (BP) and pulse rate for day 1 and day 3. There is no significant difference between both sessions

<table>
<thead>
<tr>
<th>Blood pressure and pulse rate for different sessions – mean (SD)</th>
<th>Day 1</th>
<th>Day 3</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP mean</td>
<td>138.3 (20.2)</td>
<td>139.6 (20.4)</td>
<td>0.616</td>
</tr>
<tr>
<td>Diastolic BP mean</td>
<td>75.45 (11.2)</td>
<td>77.5 (11.6)</td>
<td>0.306</td>
</tr>
<tr>
<td>Mean BP mean</td>
<td>101.5 (15.9)</td>
<td>101.6 (14.7)</td>
<td>0.968</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>69.7 (14.0)</td>
<td>67.2 (11.2)</td>
<td>0.167</td>
</tr>
</tbody>
</table>

Fig. 2. (A) Cross-sectional B-mode image of a cephalic vein prior to cuff inflation. (B) the same location in the same vein is shown 2 min after the graduated pressure cuff has been inflated to 60 mmHg. The location of the cross-sectional depiction was identical for both images, about 5 cm proximal to the wrist joint. Note venous dilatation after application of pressure cuff.
recommended by the National Kidney Foundation (NKF DOQI guidelines) and the Vascular Access Society (Good Nephrological Practice guidelines) guideline on vascular access [1,2]. In these guidelines no preferred method has been specified.

Variance components estimation revealed that the factors subject and day determined variations in venous diameter measurements. There was, however, no systematic difference between the mean diameters measured on days 1 and 3 on group level. In contrast, variations at patient level were substantial, as evidenced by the variation coefficients of 26.4% and 26.5%.

Repeated measurements of venous diameters using a cuff yielded a SD of 0.5 mm, which seems to be clinically inadequate, taking into account the fact that the clinically used cut-off diameters range from >1.6 to >2.5 mm [4–10]. Furthermore, the variation of venous diameter over the course of time in this study might even be an underestimation of the true venous diameter variation because a potential recall bias cannot be excluded.

Day-to-day variations in venous diameter might have been due to differences in venous dilatation due to alterations in vascular tone. However, disturbing factors modifying the sympathetic nervous tone and venous diameter (temperature, physical activity, mental state, alcohol, nicotine, caffeine etc.), were controlled. Sympathetic tone itself, however, was not controlled and this might have affected day-to-day variation on patient level. Furthermore, a venous diameter is a static parameter which is used for the characterization of dynamic tissue (e.g. the cephalic vein). A dynamic measure might be more suitable for this purpose, as has been demonstrated by Malovrh [8], who found that cephalic vein compliance (i.e. rate of increase of venous diameter at different congestion pressures) rather than diameter is correlated with RC-AVF non-maturation [10]. In the subgroup of patients in whom the RC-AVF failed, a 48% lower diameter increase due to venous congestion was found when compared to the group in whom the RC-AVF was functioning well [10].

In conclusion, venous diameter assessment is observer and congestion method independent in this study setup. Daily variations in forearm superficial venous diameters should be taken into account when defining and using cut-off diameters prior to vascular access surgery.

Conflict of interest statement. None declared.

References


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