Reliability of Ultrasound Duplex for Detection of Hemodynamically Significant Stenosis in Hemodialysis Access

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Objective: This study aims to evaluate the accuracy of AVF and AVG duplex ultrasound (US) compared to angiographic findings in patients with suspected failing dialysis access.

Materials and Methods: From July 2008 to December 2010, US was performed on 35 hemodialysis patients with 51 vascular accesses having clinical feature or dialysis parameter suspicious of access problem. Peak systolic velocity ratio of ≥2 was the criteria for diagnosing stenosis ≥50%. Fistulogram was performed in all these patients. Results of US and fistulogram were compared using Kappa and Receiver Operator Characteristic (ROC) analyses.

Results: In 51 accesses (35 AVF, 16 AVG), US diagnosed significant stenosis in 45 accesses according to the criteria and angiogram confirmed 44 significant stenoses. In AVF lesions, Kappa was 0.533 with 93.3% sensitivity and 60% specificity for US whereas in AVG lesions, Kappa was 0.636 with 100% sensitivity and 50% specificity. Overall Kappa value of 0.56 meant fair to good agreement. ROC demonstrated area under the curve being 0.79 for all cases and was significant (p = 0.016). Using the ≥50% criteria for stenosis diagnosed by US yielded the best sensitivity (95.5%) and specificity (57.1%).

Conclusion: Duplex ultrasound study, using ≥50% criteria, is a sensitive tool for stenosis detection in patients with suspected failing AVF and AVG.

Keywords: ultrasound, angiogram, stenosis, hemodialysis, AVF

Introduction

Chronic kidney disease (CKD) is becoming a significant problem globally, and this is evidenced by the increasing incidence and prevalence in Singapore.1) Hemodialysis is one of methods that many CKD patients choose to use to survive renal failure. A viable vascular access, therefore, is very important for hemodialysis patients. Even though arteriovenous fistula AVF and arteriovenous fistula graft AVG are called permanent hemodialysis access, they are not actually functioning permanently. Stenosis of a part of the fistula or central vein stenosis may cause thrombosis and failure of the access.

Endovascular intervention for failing vascular access could prolong the patency of the access.2) The gold
standard to diagnose stenosis of AVF and AVG is angiogram. However, this procedure is invasive and costly. Duplex ultrasound is a non-invasive investigation, widely used for various vascular conditions. Currently there are no well-defined ultrasonographic criteria for evaluation of AVFs and AVGs. Many centers apply the duplex criteria of arterial stenosis onto AVF and AVG assessment. Validation study is lacking. We would like to assess the accuracy of US assessment of vascular accesses based on arterial stenosis criteria by comparing it to angiographic finding.

This study correlates detection of stenosis in vascular access cases (AVF and AVG) using the colour duplex ultrasound against contrast angiography. Our hypothesis is that the US and angiogram study findings are congruent for vascular access cases, and an US can be used as a sensitive screening tool for guiding decisions on interventions for vascular accesses.

**Materials and Methods**

**Study design**

This is a historical cohort study undertaken at the vascular surgery unit of a tertiary referral center. The study is based on patient data collected over 29 months during the period of July 2008 to December 2010. Patients who were suspected to have a stenosis in their fistula underwent an US study prior to a contrast angiogram. An endovascular intervention, namely angioplasty, was carried out in the same setting of the angiogram if a lesion had been confirmed.

**Case selection**

There were a total of 68 patients over the 29 month period with a clinical suspicion of access failure, of which 33 underwent angiography without duplex US. The remaining 35 patients were selected as they had undergone both US and angiography. All patients had either an AVF or AVG, presenting with one or more of the following clinical features, suspicious of access failure: A) reduced thrill or weak bruit on auscultation by a vascular surgeon, B) documented decreased dialysis flow rate defined by KDOQI guidelines (access flow less than 600 ml/min, or less than 1000 ml/min with a more than 25% decrease over a four month period), C) documented increased venous pressure during dialysis as defined by KDOQI guidelines (venous pressure more than 150 mmHg or a trend of persistent increasing pressure over time), D) difficulty in fistula cannulation, E) persistent bleeding of the fistula. All patients have undergone both an US and angiogram.

**Definitions used**

In our center, the percentage of stenosis was calculated based on the ratio of the peak systolic velocity (PSV) between the suspected area of stenosis and the pre-stenosis. According to guidelines provided by the American Society of Echocardiography (ASE) and the Society for Vascular Medicine and Biology, stenosis in US were reported as <50% when the ratio is <2, and ≥50% for ratios ≥2. The location of stenosis was classified as being at either one of 4 sites: (i) AV anastomotic area (ii) Vein fistula (iii) Vein-graft anastomosis area (iv) Artery graft anastomosis area. The central vein cannot be properly assessed by US; therefore, it was not evaluated in this study.

The percentage stenosis in the angiogram was calculated by measuring the stenotic vessel diameter and comparing it to the average of the pre- and post-stenotic patent vessel diameters. These percentage values were then compared to those obtained by US to check for congruence.

**Duplex ultrasound**

Assessment of vascular accesses by US was performed using a 5–10 MHz transducer (Philips IU22) in B-mode, optimized for superficial vessels (1-cm depth), and Doppler velocity range for PSV at 200 cm/s. Stenotic areas were identified by visual observation of narrowing or presence of colour flow bruit. Flow velocity assessment was performed over suspicious areas of stenosis and also at regular locations including arteriovenous anastomosis and venous fistula for AVF, and both graft vessel anastomotic sites, in-graft and outflow vein for AVG.

**Angiogram**

An angiogram of AVF and AVG was performed with the percutaneous method using a non-ionic iodine-based contrast under local anesthesia in the Cardiac Catheterization laboratory. Endovascular intervention in the form of balloon angioplasty was performed in the same setting if a stenosis of 50% or more of the vessel diameter was detected on angiography, using either a simple Wanda balloon (Boston Scientific, Natick, Massachusetts, USA) or Peripheral cutting balloon (Boston Scientific, Natick, Massachusetts, USA). Cutting balloons were utilized for high grade stenosis (≥90% stenosis) or
lesions non-responsive to a simple balloon angioplasty. Completion angiogram was performed immediately after the angioplasty for determining the success of the procedure. All patients were observed in the day surgical ward for at least two hours and discharged if no acute complication (bleeding or thrombosis) was detected.

**Statistical methods**

Statistical analyses were done by SPSS v18, setting the significance level of \( p \) value at 0.05. Chi square test or Fisher’s exact test were employed to describe baseline characteristics. Kappa value, sensitivity and specificity of US were calculated assuming the angiogram as the gold standard. Arbitrary guidelines characterized kappa values over 0.75 as excellent agreement, 0.40 to 0.75 as fair to good, and below 0.40 as poor.\(^7\) Comparison of the two tests was done in all patients (AVF and AVG) and subsequently in AVF only and AVG only subgroup analysis. A Receiver Operating Characteristic (ROC) curve was also performed, plotting PSV ratios recorded by US under the assumption of angiogram as the gold standard diagnosis method. The estimate of the area under the ROC curve was computed to evaluate the performance of US. Sensitivity and specificity values were also obtained to define a cut-off point of diagnosis for the most specific and sensitive PSV ratio for this set of data. As seen in Figs. 1 and 2, the sensitivity and specificity of US changes as the PSV ratio increases.

**RESULTS**

Over the study period, 35 renal failure patients with a total of 51 vascular accesses undergoing both US and angiograms were studied. The mean age of patients was 60.5 (±11.45, range 28 to 82) with a majority of male patients (62.9%). Causes of renal failure varied, but the major cause was diabetic nephropathy comprising 70.6%, followed by hypertension, which comprised 14.7%. The time between the US and angiogram assessment varied with a mean of 41 days and median of 28 days. In total, 9 main types of fistulae were recorded in this study. Under the AVF category, there are the radiocephalic, brachiocephalic, brachiobasilic and femorosaphenous fistulae. Under the AVG category, there are the forearm brachiocephalic and brachiobasilic, arm brachiopheliac and brachiobasilic, brachioaxillary and femorosaphenous graft fistulae. Radiocephalic and brachiocephalic AVFs were the major types of vascular accesses, with 34.3% for each. Among the 51 fistulae, 35 were AVF, and 16 were AVG. There were eight arteriovenous anastomotic area stenoses, 34 vein fistula stenoses, seven vein graft anastomotic area stenoses and two artery graft anastomotic site stenoses. Fifty-one pairs of tests were done of which the US diagnosed 45 stenoses, and the angiogram con-
firmed 44 stenoses (1 false positive). For the remaining 6 cases, in which the US did not detect any significant stenoses, the angiogram detected ≥50% stenoses in 4 cases (false negatives) and agreed with US findings for 2 cases. The observed agreement, being the sum of true positive and true negative test findings were 46 out of 51 fistulae.

Among AVFs, Kappa was 0.533 with a sensitivity of 93.3% and specificity of 60% for the US, whereas, among AVGs, Kappa was 0.636 with a sensitivity of 100% and specificity of 50%. Congruence of the two imaging modalities was the highest in AVG cases at 93.8%, and the kappa value was 0.636, as shown in Table 1. In the analysis of all cases, kappa was 0.560, which meant a fair to good agreement between the two tests. A high level of agreement was observed between the US and angiogram: 90.2% for all cases, 88.6% for AVF only, and 93.8% for AVG only cases. Each point on the ROC curve (Fig. 1) represents specificity and sensitivity values when different PSV ratios are used as the cut-off criteria for diagnosing stenosis, with the angiogram being used as the gold standard. The area under the curve was 0.786, and this was statistically significant as $p = 0.016$, meaning that using the US was definitely better than guessing.

The encircled point on Fig. 1 and points of PSV in Fig. 2 show that the cut-off criterion of the PSV ratio of $\geq 1.96$ yielded the highest combined sensitivity (95.5%) and specificity (1-0.429 = 57.1%). In this study, the PSV data point after 1.96 is 2.055; therefore, this result is concordant to the current cut-off value of PSV $\geq 2$, which is used to define an US stenosis of $\geq 50%$.

**DISCUSSION**

There are several publications that demonstrate the use of US in detecting dysfunctional vascular access cases. However, US criteria for evaluating AVF and AVG have been adopted from arterial studies. In AVF and AVG, the vein or graft usually join to the artery in an angle. Compliance of the vein and graft also differs significantly from that of the artery. Whether US arterial criteria will suit the evaluation of AVG and AVG remains uncertain. There is a lack of validation studies for AVF and AVG, and our current study aims to fill this gap. Angulation between the vein to artery or graft to vessel in hemodialysis accesses also added a challenge to the US evaluation. Vascular technologists in the current study adopted a protocol of interrogating the anastomosis both using grey scale imaging at different angles, color Doppler imaging, and PSV assessment. The result of the current study shows that adopting the US criteria of arterial stenosis reliably identifies stenosis in AVF and AVG.

There are two methods for reporting stenosis in an US examination. One adopts a diameter-based approach when reporting stenosis in an US, whereas, the other defines AVF stenosis as a $>50%$ luminal reduction compared with the adjacent vein in the fistula. In reality, the diameter of the fistula vein may vary significantly along its length, due to the presence of aneurysmal changes, temperature of the environment, as well as the type, location and age of the fistula, therefore, making the diameter-based approach difficult. Our study has adopted a PSV ratio measurement when reporting stenosis in an US. It shows good agreement when compared to the gold standard of the angiogram. Our data demonstrate that the use of PSV ratios can accurately predict stenosis in clinically suspected dysfunctional AVFs and AVGs. Nonetheless, PSV ratio assessment over the anastomotic regions is a challenging task requiring vascular technicians to meticulously measure the PSV at various points—proximal and very close to the anastomosis, at the anastomosis and distal to the anastomosis. It is the practice of authors (Canlas, Seah, Serrano) to assess the B mode image of the anastomosis at various angles to look for morphological stenosis, in addition to the PSV measurement, to avoid false PSV elevation due to particular angulation.

This study had limitations, the first being the small dataset of 51 vascular accesses. The time lag between the US and angiogram was variable, with a mean of 41 days and a median of 28 days. The condition of the vascular

<table>
<thead>
<tr>
<th>Type of access</th>
<th>No. of paired tests</th>
<th>Congruence between US and Angiogram</th>
<th>Congruence (%)</th>
<th>Kappa value</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall AVF/AVG</td>
<td>51</td>
<td>46</td>
<td>90.2</td>
<td>0.560</td>
<td>95.5</td>
<td>57.1</td>
<td>93.3</td>
<td>66.7</td>
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<tr>
<td>AVFs only</td>
<td>35</td>
<td>31</td>
<td>88.6</td>
<td>0.533</td>
<td>93.3</td>
<td>60.0</td>
<td>93.3</td>
<td>60.0</td>
</tr>
<tr>
<td>AVGs only</td>
<td>16</td>
<td>15</td>
<td>93.8</td>
<td>0.636</td>
<td>100</td>
<td>50.0</td>
<td>93.3</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1 Agreement between Duplex US and Angiogram regarding stenosis.
access might have changed during the period between the two tests. Although we take the angiogram as the gold standard, the 2-dimensional visualization of stenosis in an angiographic analysis may not accurately reflect the actual luminal loss.

When clinical features or dialysis parameters are highly suspicious of a dialysis access stenosis, an US study is not necessary and may delay the definitive treatment. An angiogram should be arranged as a diagnostic investigation as well as a form of treatment. We believe US will be most useful to detect hemodynamically significant stenosis, in cases of equivocal clinical findings or non-conclusive dialysis parameter changes. Additionally, US can be used as a surveillance tool in precious accesses to detect stenosis in an early phase for a prompt salvage procedure. The validation of applying US criteria for dialysis access is also important for clinicians to apply US for guidance of dialysis access angioplasty without fluoroscopic imaging.12)

As our results show high reliability of the ASE arterial stenosis criteria for clinically suspected dysfunctional vascular accesses, further prospective studies can be carried out using the same criteria in a surveillance setting. The duplex ultrasound is a non-invasive and relatively less costly study than the angiogram. It can be used as a screening tool for hemodialysis patients. Only those with US finding of stenosis were required to undergo more expensive and invasive contrast angiography and angioplasty.

CONCLUSION

The current study showed high agreement between duplex ultrasound findings of stenosis in vascular access, based on ASE arterial stenosis criteria, when compared to the gold standard of contrast angiography.

DISCLOSURE STATEMENT

The authors have no financial or related disclosures and have no conflict of interest.