Multi-slice CT angiography versus duplex ultrasound in detection of stenosis of access arteriovenous fistulas and grafts in dysfunctional hemodialysis

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Abstract

Purpose: To assess the accuracy of MS-CTA for the detection and grading of stenosis in AVF and AVG in comparison with colored Duplex.

Patients and methods: Prospective analysis of vascular access related data was obtained from 30 patients (10 Males, 20 Females and age range 18–62 years) referred from hemodialysis unit for CTA and CDUS examination in upper limbs.

Results: There were no statistically significant differences between mean Stenosis%, mean Length of stenosis segment and mean Narrowest part as measured by the two modalities (P-values = 0.115, = 0.271 & = 0.233 respectively).

Results:
- Subclavian vein occlusion: detected in 7 cases (23.3%) by CTA and only 4 out of the 7 cases were detected by Doppler (13.3%).
- SVC occlusion: not detected by Doppler (0.0%) and detected in 4 cases (13.3%) by CTA.
- Chest wall venous collateralization: not detected by Doppler (0.0%) and detected in 10 cases (33.3%) by CTA.

Conclusions: CDUS by an experienced hand is an adequate diagnostic tool except for evaluation of central veins, whereas, the MSCTA plays an important role as a minimally invasive modality for evaluating the AVFs especially the central veins.

1. Introduction

Chronic renal disease (CRD) is currently a well known major public health problem, associated with structural changes of the kidney parenchyma and consequent decline in renal functions that persist over 3 months.

Multiple etiologies had been incriminated in this problem including arteriosclerosis, DM and hypertension with eventual loss of number and functions of the nephrons, and finally the end-stage kidney disease (ESKD) supervene [1].

The cornerstone of hemodialysis in end stage kidney disease (ESKD) is a functioning access. Unfortunately, this vascular access may carry high risk of obstruction by thrombosis due to stenoses that affect patency [2].
Neo-intimal hyperplasia is the most common cause of stenoses that jeopardize the flow, with the stenosis distribution differing e.g. in radio-cephalic arterio-venous fistulas (RCAVF), 55–75% of stenosis were juxta-anastomotic and 25% anywhere along the fistula draining venous pathway while in the brachiocephalic and/or basilic AVFs, stenosis sites (55%) are at the cephalic-subclavian vein junction and at the basilic-axillary vein junction, respectively [3].

In AV grafts 50–70% of the venous stenoses occur within few cms of the vein-to-graft anastomosis. However, feeding artery stenosis more than 2 cm distant to the AVF anastomosis is uncommon, but may be of utmost importance as it may jeopardize the flow in the fistula [4].

Duplex examination has a special value in flow volume measurement and in stenosis detection in mal-functioning AVFs. Moreover, it could share in the treatment plans, as duplex-guided balloon venoplasty of failing or non-maturing AVFs is currently being feasible and could be done safely, even as simple as an office-based procedure [5].

The recently developed MS-CTA technology with improved resolution gives greater anatomic coverage, allowing an expanded evaluation of vascular diseases.

Nevertheless, MS-CTA is clinically feasible for evaluating the complete vascular pathway of failing AVFs and detecting unlikely encountered complications, such as arterial aneurisms, pseudo aneurisms and central vein lesions [6].

The 3D reconstructed images of MS-CTA with free rotation projection angiogram show vascular lesions from the appropriate perspective and the examinations can be accomplished in a quick time (for patient preparation, CT examination and post processing session) all taking about 15 min [7]. The access stenosis evaluations are usually performed in current clinical practice, by duplex examination and/or diagnostic catheter through digital subtraction angiography (DSA), the latter has difficulties in image analysis due to vessel overlap, mainly at the juxta anastomotic level with multiple crossing vessels, so, MS-CTA could be an alternative diagnostic tool for localizing access stenosis, assessing the degree of severity, with an ability to acquire three-dimensional (3D) data, overcoming the problem of vessel overlap and establishing an accurate diagnosis; however, the experience with MS-CTA for imaging of stenotic and malfunctioning access, till now, shows some limitation [8].

Early referral of chronic kidney disease (CKD) patients to the nephrologist and/or vascular surgeon is crucial to start a policy for appropriate vascular access creation (with preferential order), maturation and access salvage in failing and non maturing AVFs [9], and 200 ml/min is the minimally required flow volume for an adequate hemodialysis session that could be obtained through surgical construction of an arterio-venous fistula/graft [10].

Hemodialysis access placement in preferential order is demonstrated in Table 1. [11]

### 1.1. Aim of the work

The aim of this work was to assess the accuracy of MS-CTA for the detection and grading of stenosis in AVF and AVG in comparison with Colored Duplex Ultrasound and finally an algorithm with the addition of both techniques (MS CTA and CDUS) as complementary studies, and in certain cases will be appropriate.

## 2. Patients and methods

### 2.1. Study design and population

This prospective randomized controlled trial study was conducted in the radiology department.

The patients were referred from Nephrology – Dialysis – Transplantation unit, within a period of 7 months from March 2015 up to September 2015. The study included sample size of thirty patients aged from 18 to 62 years and included both males and females with an upper limb arterio-venous fistula for hemodialysis when their access was considered at risk for thrombosis or suspected malfunction like dialysis needle puncture difficulties, distorted anatomy, enlarging aneurisms, suspected source of infection/abscess, thrombosed access or extremity swelling/edema. For color Doppler ultrasound there were no exclusion criteria but for CTA, the pregnancy was there. We also excluded patients with histories of severe allergy to contrast media in CTA.

### 2.2. Ethics committee approval

Ethics committee approval has been obtained besides patients’ consent after informing the patients with full details of our clinical trial.

#### 2.2.1. Patient assessment

All patients were subjected to the following:

(A) Before examination

(a) Obtained a complete history by interviewing the patient and reviewing the patient’s medical records,
(b) through clinical examination of the dialysis access,
(c) explained the procedure to the patient (including table movements, voice messages, sensation of contrast injection and how to breath hold in case of CTA),
(d) took into consideration the age and mental status of

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Hemodialysis access placement in preferential order[11].</th>
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</thead>
<tbody>
<tr>
<td>Access placement type</td>
<td>Description of access placement</td>
</tr>
<tr>
<td>Forearm AVF</td>
<td>Radial artery to cephalic vein or radial artery to basilic or other suitable forearm vein (transposition)</td>
</tr>
<tr>
<td>Upper arm AVF</td>
<td>Brachial artery to cephalic or brachial artery to basilic or other suitable upper arm vein (transposition)</td>
</tr>
<tr>
<td>Forearm graft</td>
<td>Brachial artery and antecubital vein, a “loop” graft</td>
</tr>
<tr>
<td>Upper arm graft</td>
<td>“straight” graft</td>
</tr>
<tr>
<td>Thigh graft</td>
<td>Common femoral artery to common femoral vein</td>
</tr>
</tbody>
</table>
the patient ensuring that the patient understands the necessity for each aspect of the evaluation and be able to follow instructions.

(B) Patient positioning

(a) Color Doppler examination: patient was most often supine, with arm relaxed and extended out to the side with area to be evaluated closest to the sonographer, or examined in the sitting position. Patient position was optimized so that gravity helped to dilate the veins.

(b) MS-CT angiography: patient was placed supine, with the AVF containing arm placed beside the body leaving a small gap between the arm and the body to avoid vein compression, while an IV catheter was placed in the opposite arm which was raised above the head to reduce artifacts. The reason suggested for the arm being down rather the arm being up in position is that the arm-down position is the neutral one of the upper limb. But when the arm is up, motion artifact is usually observed because the patients (who were usually elderly and have joint motion limitations) were uncomfortable.

The contrast was injected into a peripheral vein in the opposite arm, so as to avoid any damage to the access site.

(C) Color Doppler ultrasound procedure

Linear transducers were usually chosen for superficial vascular imaging (the access itself), and curved transducers were utilized for deeper vascular imaging such as central veins in the neck, or in obese patients. All vessels were examined in both transverse and longitudinal planes. The arm was scanned from proximal to distal both deep veins and the superficial veins were examined for echo free lumen, totally compressible walls, complete color filling with no filling defects, stenoses or obstructed segments and the depth of the fistula draining vein from the skin surface.

Assessment of the central veins was done either by direct evaluation of the traceable portions from the subclavian, innominate and the internal jugular veins by gray scale and color Doppler or by indirect assessment through spectral waveform analysis that should show respiratory phasicity and transmitted right atrial pulsatility (Fig. 1). Volume of blood flow at the site of the anastomosis was measured either by auto trace measurement or manually using the machine software.

(D) CT angiography protocol

The examination was done with sixty-four multi-detector CT scanner (TOSHIBA Medical Systems, Aquilion). The acquisition range extended from thoracic outlet to the end of fingers in a dynamic phase in which both the AVF arterial inflow and venous outflow tract up to the right atrium, are well opacified with contrast. The bolus-tracking technique was employed, with a region of interest (ROI) placed at ascending aorta. A post-threshold delay of about 10 s and a flow rate of 3 ml/s were used to obtain proper enhancement. When CT attenuation exceeded 120 HU in the ROI, scanning started in a cranio-caudal direction. Injection of 90 ml contrast medium is followed by 40 ml saline chase.

We tried to minimize patient exposure to contrast medium by scheduling CTA immediately before a dialysis session. None of the 30 patients included in the study experienced an allergic reaction or extravasations of contrast material.

2.2.2. CTA image interpretation and post-processing

Two-dimensional (2D) image reconstructions, such as maximum intensity projection (MIP), multi-planar reformation (MPR), curved multi-planar reformation (cMPR), as well as 3D volume rendering (VR) techniques, were used interchangeably.

3. Statistical methods

Data were coded and entered using the statistical package SPSS version 23. Data were summarized using mean, standard deviation, median and minimum for quantitative variables and frequencies (number of cases) and relative frequencies (percentages) for categorical (qualitative) variables.

Comparisons between values measured by CDUS and values measured by MSCTA were done using paired t test. Agreement between the two modalities was done using Cronbach’s alpha reliability coefficient. P-values less than 0.05 were considered as statistically significant.

4. Results

4.1. Fistula type

Four patients (13.3%) had brachioaxillary fistula, 6 patients (20.0%) had brachiobaselic fistula, 4 patients (13.3%) had radio-cephalic fistula while 16 patients (53.3%) had brachiocephalic fistula (see Table 2).

4.2. Stenosis %

Descriptive statistics of Stenosis % measured by the two modalities are presented in Table 3. There was no statistically significant difference between mean Stenosis % as measured by the two modalities (P-value = 0.115) (Fig. 2). There was very good agreement between the two modalities (Cronbach’s alpha coefficient = 0.978).

4.3. Length of stenosis segment

Descriptive statistics of length of stenosis segment as measured by the two modalities are presented in Table 4. There was no statistically significant difference between mean Length of stenosis segment as measured by the two modalities (P-value = 0.271) (Fig. 2). There was very good agreement between the two modalities (Cronbach’s alpha coefficient = 0.921).
4.4. Narrowest part

Descriptive statistics of narrowest part as measured by the two modalities are presented in Table 5. There was no statistically significant difference between mean Narrowest part as measured by the two modalities ($P$-value = 0.233). There was very good agreement between the two modalities (Cronbach’s alpha coefficient = 0.858).

4.4.1. Subclavian vein occlusion

Subclavian vein occlusion was detected in 7 cases (23.3%) by CTA and only 4 out of the 7 cases were detected by Doppler (13.3%) (Fig. 3).

4.4.2. Superior vena cava (SVC) occlusion

SVC occlusion was not detected by Doppler (0.0%) while it was detected in 4 cases (13.3%) by CTA (Fig. 3).

4.4.3. Chest wall venous collateralization

Chest wall venous collateralization was not detected by Doppler (0.0%) while it was detected in 10 cases (33.3%) by CTA (Fig. 3).

4.4.4. Innominate vein occlusion

Innominate vein occlusion was not detected by Doppler (0.0%) while it was detected in 2 cases (6.7%) by CTA.

5. Discussion

Chronic renal disease (CRD) nowadays has an increased worldwide distribution [12]. It has multiple etiologies including arteriosclerosis, DM, and hypertension, leading to end-stage kidney disease (ESKD). The main etiology of ESKD observed in our study was diabetic or hypertensive nephropathy. Two patients (6.7%) had history of diabetes, 16 patients (53.3%) had history of hypertension while 12 patients (40.0%) had both diseases, which is almost the same with that observed by Shemesh et al.[13] who found that 55% of the patients had ESKD secondary to the same of both etiological factors.

Hemodialysis is often used as renal replacement therapy for patients with ESKD, and the brachiocephalic arterio-venous fistula and the radio-cephalic arterio-venous fistula (RCAVF) are the primary and secondary access options giving an opportunity for a long-term hemodialysis access.

This access becomes challenging, in certain circumstances especially in elderly ESKD patients, where, associated vascular co-morbidities such as arterial atherosclerotic and calcific changes could exist[14]. The brachiobasilic arterio-venous fistula is the tertiary option, when the above options are not possible or had failed.

In our study we found that number of female patients exceeded that of males being 10 male patients and 20
female patients representing 33.3% and 66.7% of all patients respectively.

In this study, we have found that most common AV fistulas were brachiocephalic (53.3%), followed by brachiobasilic (20.0%), radio-cephalic and brachioaxillary synthetic graft (13.3% for each of them), which is not similar to those found by Ahmed et al. with their fistulas that were radio-cephalic and brachiocephalic in 80% and 20% of cases respectively [15].

Access imaging is to be performed as soon as possible, for access salvage when a hemodynamically significant stenosis is suspected [2]. Duplex ultrasonography (DUS) is suggested to be the initial study of malfunctioning fistulas [16], being an available, cheap, and simple method, and moreover could be portable with no ionizing radiation and a non invasive technique, so it has acceptance. However, still operator dependent [17] with inter and intra observer variability.

Table 4
Descriptive statistics, results of Wilcoxon signed-rank test for comparison between length of stenosis segment as measured by CT and CDUS and results of Cronbach’s alpha reliability coefficient for agreement between the two modalities.

<table>
<thead>
<tr>
<th>Length of stenosis segment (mm)</th>
<th>CT</th>
<th>CDUS</th>
<th>P-value</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>21.2 ± 12.0</td>
<td>22.6 ± 10.8</td>
<td>0.271</td>
<td>0.921</td>
</tr>
<tr>
<td>Median</td>
<td>20.0</td>
<td>22.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>5.0–40.0</td>
<td>7.0–40.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at P ≤ 0.05

Table 5
Descriptive statistics, results of paired t-test for comparison between narrowest part as measured by CT and CDUS and results of Cronbach’s alpha reliability coefficient for agreement between the two modalities.

<table>
<thead>
<tr>
<th>Narrowest part (mm)</th>
<th>CT</th>
<th>CDUS</th>
<th>P-value</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>3.0 ± 0.9</td>
<td>2.9 ± 0.7</td>
<td>0.233</td>
<td>0.858</td>
</tr>
<tr>
<td>Median</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>2.0–4.5</td>
<td>1.5–4.0</td>
<td></td>
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</tr>
</tbody>
</table>

*Significant at P ≤ 0.05.
MS-CTA is a relative minimally invasive technique for stenosis detection in hemodialysis access. It offers an ability to acquire 3D data sets, with no time consumption, as MS-CTA scans can be performed in 10 min or less. However there is some limitation for this technique as an imaging modality in stenoses evaluation for the dialysis access [6].

Since hemodialysis AVF shows structural and course changes of the vessels sharing in the fistula in the form of dilatation, tortuosity and displacement of the sharing vessels, it is difficult to realize its structure basing solely on axial images, although they are useful in evaluating the relationship with extra-vascular structures. Thus post-processing workstation was used for interpretation.

In our study, 10 (33.3%) were male and 20 (66.7%) were female with the ratio of 1:2, regarding the stenosis percentage. There was no statistically significant difference between mean Stenosis % as measured by the two modalities (P-value = 0.115). There was very good agreement between the two modalities.

The length of stenosis segment in this study was measured by the two modalities and there was no statistically significant difference between mean Length of stenosis segment as measured by the two modalities (P-value = 0.271). There was very good agreement between the two modalities.

Regarding the narrowest part as measured by the two modalities, there was no statistically significant difference between mean narrowest part as measured by the two modalities (P-value = 0.233). There was very good agreement between the two modalities.

In our study and Cansu et al. study [18] it had been shown the complete agreement between CDUS and multi-detector CTA in detection of stenosis at the anastomotic site and at the venous side of the fistula. While Chandra et al. study was concerned with CDUS only, they demonstrated that CDUS is very accurate in identifying the location of AVF stenosis especially in anastomosis and in the draining vein pathway [19].

Cansu et al. study had shown that color Doppler ultrasound had detected just 1 case out of 5 (i.e. 20%) cases having central venous lesions, while the MS-CTA had detected all the 5 (100%) lesions [18]. In our study the color Doppler ultrasound could not detect any case of Superior vena cava (SVC) (4 cases) or innominate vein (2 cases) occlusions.

Also, subclavian vein occlusions (4 cases) all were detected by CTA while color Doppler ultrasound detected only 2 out of the 4 cases, which is similar to the study of
Doleman et al. where CDUS was unable to identify more than one-third of subclavian vein lesions [16].

MSCTA may have false negatives and positives related to the examined arm positioning. Heye et al. did extension of the arm with AVF over head in one half of their cases and they extended it over or to the side of the body in the other half. In an overhead extension of the arm with AVF, proximal veins compression, particularly the central veins had occurred at the thoracic outlet [20]. In our study the arm with AVF was pulled toward the contralateral side with the patient’s body inside the gantry and a normal anatomical position established. We left a space between the arm with AVF and the body and so artifacts that might form from the body were prevented.

MS-CTA technique has limitations, as the large coverage of the region of interest may be on the expense of resolution of the vascular imaging. Therefore, we have focused on the region of interest at the AVF and adjacent arterial inflow and venous outflow vessels during scanning to obtain better image quality. With this technique, stenosis outside the imaging field may be missed.

Our study has shown that color Doppler flow imaging is accurate for detecting, localizing and characterizing the vascular complications at hemodialysis access sites. Considering the non-invasive nature and high sensitivity and specificity of this modality, some authors consider it the modality of choice for access surveillance. However, it has a limited role in central venous pathology evaluation [18].

MSCT angiography clearly depicts native vessel diseases such as stenosis, thrombosis, aneurisms, pseudo aneurisms, calcifications, intimal thickening as well as in the deployed stents like stent neo intimal ingrowths, in addition to the peri-vascular complications such as seroma and other collections [18].

In our experience, a good knowledge of the vascular anatomy in the concerned dialysis access and the built up experience with image interpretation and pathology detection obtained by MSCTA goes hand in hand with hemodynamic study obtained by CDUS for safe passage to accurate diagnosis overcoming the falsies that could be encountered by each technique, whenever done solely; thus, combined use of both techniques will significantly raise the success rate in detection of all AVF lesions.

6. Conclusion

The obtained results document the Color Doppler US in addition to be known as readily available, inexpensive, and noninvasive method, with no radiation exposure or use of contrast material. It also, allows assessment of both anatomy and hemodynamics of an AVF. However CDUS is still operator dependent and inaccurate in detection of central venous obstruction; moreover, there is absence of an angiographic map, which may be required for surgical planning.

Multi-slice CT angiography is a minimally invasive procedure that is clinically feasible for evaluating the complete vascular tree of failing AVFs and in showing central vein lesions. In addition, the 3D capability of CT angiography can offer freely rotated projection angiograms to show vascular lesion from the appropriate perspective.

In patients with AVF dysfunction, vascular mapping with MDCT angiography should be performed, and if there is a doubtful diagnosis, we think that an algorithm with the addition of CDUS will be appropriate from the hemodynamic aspect of view.

Conflict of interest

The authors declared that there are no conflict of interests.

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