Direct CT Venography in ESRD Patients: Technical Experience and Findings

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ABSTRACT

Objective: The aims of this study were to describe direct computed tomography venography (CTV) for upper limb venous system evaluation and to report on findings in end-stage renal disease (ESRD) patients.

Materials and Methods: Direct CTV was performed using a 64-multidetector computed tomography (MDCT) scanner with simultaneous injection of diluted iodinated contrast (IC); 1:4 at both elbows and 2-phase scanning namely, the direct venous, and the arterial phases. The findings in ESRD patients evaluated between November 2013 and March 2019 were retrospectively reviewed.

Results: Forty CTV examinations (600 venous segments) were performed and the volume of IC used per patient was 38 mL. Number of lesions found in a patient ranged from 1 to 6 and the majority had 1 to 3 lesions (30/38 patients). Stenosis and thrombosis were the two most common findings (112/600) and were equally prevalent. The three most common sites of steno-occlusive complications were the brachiocephalic vein (29 lesions), the internal jugular vein (25 lesions), and the subclavian vein (16 lesions). The most common site of stenosis was the brachiocephalic vein (18 lesions), whereas the most common site of thrombosis was the internal jugular vein (20 lesions). No venous aneurysms or ruptures were found. IC extravasation at the site of injection occurred in one arm in one patient.

Conclusion: Direct CTV has the advantage of requiring lower IC volume while maintaining direct visualization of the venous system similar to conventional venography.

Keywords: Computed tomography venography; contrast material; upper limb,vascular access (Siriraj Med J 2021; 73: 373-379)

INTRODUCTION

Venous steno-occlusive disease after establishment of vascular access is a common complication in end stage renal disease (ESRD) patients. Evaluation of the venous system is important for acquiring information on the lesion, which then facilitates treatment planning. Various non-invasive and invasive imaging techniques can be used to assess the venous system. The color Doppler ultrasound is a non-invasive technique that is easy to perform but its use is limited in some venous segments, especially the central veins.[1] Contrast-enhanced magnetic resonance (MR) imaging is also non-invasive, and does not require iodinated contrast (IC); however, it is not easily accessible and is expensive.[2] Conventional venography (CV) is the gold standard for evaluating the venous system; nevertheless, it is invasive and it requires injection of a

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considerable amount of IC. Multi-detector computed tomography venography (MDCT-V) is fast, easy to perform, provides high spatial resolution, and has high accuracy.[1,3-5] Additionally, three-dimensional images can be acquired by CTV, whereas only two-dimensional images are obtained with CV.

The two types of CTV are direct and indirect CTV, and the indirect CTV technique is considered to be the standard. It is performed by injecting IC at a dose of 2 mL/kg (total 100-200 mL) in a single extremity, usually the unaffected side, and scanning during the arterial phase (second passage) using either a test bolus or bolus tracking.[1,4-5] However, some fresh thrombi may show identical density as contrast-enhanced blood and, thereby, yield false negative results.[6] Moreover, inflow phenomena can mimic an intra-luminal thrombus (Fig 1). Direct CTV of a lower extremity was first reported in 1994 during which diluted IC was injected in a superficial vein and scanning was performed before the IC entered the right atrium (first passage).[6] In contrast to indirect CTV, the advantages of direct CTV are lower IC injection volume and the fact that scanning time is independent of the patient's blood flow velocity.[7] There are a few reports of direct CTV in upper extremities and the techniques used are variable; nevertheless, the direct CTV technique may be considered as a replacement for indirect CTV for evaluating the upper limb venous system.

Therefore, here, we describe our technique and experience in performing direct CTV of the upper extremity, discuss venous complications after vascular access, and investigate findings of venous complications in ESRD patients.

Fig 1. "Inflow phenomenon" Non-opacified blood (arrow) from left brachiocephalic vein draining into opacified blood in superior cava, causing partial hypodensity mimicking thrombus

MATERIALS AND METHODS

We retrospectively reviewed findings from ESRD patients who had undergone CTV of both upper limbs between 1st November 2013 and 31st March 2019. We identified 38 patients (18 males and 20 females) with an average age of 65 years (range 29-85 y). We excluded one patient who underwent upper extremity CTV with only single arm injection. In the cohort, one patient underwent three studies while another required two studies, all at different times. Data from a total of 40 exams were included, and information on the patient's presenting symptoms, and types of vascular accesses were collected. The presence, sites, and number of stenosis and/or occlusion were determined. The clinical data were accessed from medical records while CTV findings were accessed from the PACS database.

The study was approved by the university review board, approval No.282/2019. Informed consent was waived due to the retrospective nature of the study.

CTV technique

Images were obtained with patients in the supine position with their heads directed toward the gantry. Hands were placed in the head-holder, superior to the head, and immobilized with tape to limit motion. A tourniquet was not used, as recommended by Mavili et al.[8]

CTV was performed using a 64-MDCT scanner (Toshiba Aquillion one, Tokyo, Japan) with tube potential set at 100 kV, and current at 300 mA. The parameters for CTV were beam collimation 0.5 mm, pitch 0.641, slice thickness 1.0 mm, and reconstruction interval 0.8 mm.

The scanning protocol progressed in the cranio-caudal direction from the elbow to the superior vena cava. To explore image quality and its usefulness, the scanning phases were initially set, as follows-non-contrast scan and three post-contrast phases. The first post-contrast phase was scanned after a delay of 7 seconds from contrast injection (first passage). The second phase was repeated at the same scan length immediately after the first phase for arterial opacification (second passage), and the third phase was repeated immediately after the second phase at the same scan length. We observed that no additional information was acquired from the third phase. Moreover, if the patient experienced an arterio-venous fistula development, the opacified blood was rapidly washed out from vascular system and no vascular enhancement was observed during the third phase. Therefore, the third post-contrast phase was omitted. However, the second phase was retained because the internal jugular veins were better opacified in the second phase than in the first phase. This is because, in the absence of central vein obstruction, the internal jugular veins are usually not opacified in the first phase.

IC fluids, with concentrations of 320, 350 and 370 mgI/mL (Visipaque, Omnipaque, and Ultravist, respectively) were simultaneously administered through a 20-22 gauge IV catheter into the subcutaneous superficial veins of both forearms just below the elbows using an automated injector. Initially, the rate of injection was 2 mL/s for each extremity but based on our observations, it was increased to 3 mL/s. Next, IC concentrations were optimized as follows. Initially, IC was diluted at a ratio of 1:2 in saline which led to very high IC concentration in the veins and artifacts. Therefore, we titrated IC dilution to 1:4. The volume of diluted IC injected was 75 mL for each extremity, and thus, a total of 38 mL IC was used for each patient.

Image analysis and interpretation

Acquired data were transferred to a workstation (Vitrea 5.2.512.6014), which allowed processing of multiplanar reconstructions, including maximum intensity projection (MIP), multiplanar reformations (MPR), and volume rendering (VR). The images were then sent to a PACS (Infinite Healthcare, Seoul, South Korea). All CTV examinations were arranged such that they were performed before the patients' hemodialysis session.

Conventional transverse images, reformatted sagittal, and coronal reconstructions, MIP, and VR 3D images were used for interpretation. All images were analyzed by radiologists on duty. A total of 8 general radiologists with variable experience, ranging from 1 to 26 years, interpreted the images.

Statistical analyses

Data were analyzed using R software, version 3.5.1 and SPSS statistical software ver. 22 (SPSS, Chicago, Illinois). Residuals were examined for assumption of normality and heteroscedasticity. Continuous variables are expressed as mean ± standard deviation. Categorized variables are presented as numbers with percentages. Association between patient's gender and occurrence of either stenosis or thrombosis was analyzed using the Chi-squared test of Independence. Lastly, the effect of a patient's age on occurrence of both stenosis and thrombosis was analyzed using binary logistic regression. P values less than 0.05 were considered as significantly different.

RESULTS

Of the 40 patients in the study, two had normal findings; thus the incidence rate was 95%.

Table 1 illustrates patient demographics. Almost all patients had prior vascular access either temporary or permanent, and only one patient had no prior vascular access. About 50% of patients had indwelling catheters while undergoing CTV. Patients' presenting symptoms are listed in Table 2. Most of the patients (27/40; 67.5%) presented with upper limb swelling.

Superficial and deep veins in both arms, and the central veins and internal jugular veins were evaluated and categorized into segments; as basilic vein, cephalic vein, brachial vein, axillary vein, subclavian vein, brachiocephalic vein, internal jugular vein, and SVC, representing a total of 15 segments per study. This study analyzed data from 600 venous segments. The number of lesions found in one patient ranged from 1-6, but a majority of patients had 1-3 lesions (30/38; 78.9%) (Fig 2). Data on sites and types of lesions are provided in Table 3. Stenosis (Fig 3) and thrombosis (Fig 4) were the two most common findings, were equally prevalent, and were seen in 112 of the 600 segments (18.7%). The three most common sites of steno-occlusive complications were the brachiocephalic vein (29 lesions), the internal jugular vein (25 lesions), and the subclavian vein (16 lesions). The most common site of stenosis was the brachiocephalic vein (18 lesions) whereas the most common site of thrombosis was the internal jugular vein (20 lesions). We did not encounter any venous aneurysms or ruptures. Extravasation of IC at the injection site occurred only once and in one arm of one patient.

Patient gender was not significantly related to the occurrence of either stenosis (χ^2 (1) = 0.003, p = 1.00) or thrombosis (χ^2 (1) = 2.308, p = 0.170). Further, patient age did not significantly predict the likelihood of stenosis (Binary logistic regression, χ^2 (27) = 15.984, p = 0.9533) or thrombosis (Binary logistic regression, χ^2 (27) = 32.763, p = 0.205)

DISCUSSION

CTV is a highly accurate, minimally invasive method for diagnosing steno-occlusive disease of the upper extremity veins.[3,10] However, as false positives for occlusion can occur upon external compression of the patient's body, the patient's position on the table is critical during the scan.[4] Additionally, indirect or direct CTV technique, and single site or double site injections have been used. The indirect CT technique uses 100-150 mL of undiluted IC injected at the unaffected arm at a flow rate of

TABLE 1. Patient demographics.

	No. (%)
Gender	
Female	20 (52.6)
Male	18 (47.4)
Types of prior vascular access	
Arteriovenous fistula	17 (42.5)
Arteriovenous graft	13 (32.5)
Temporary vascular access	9 (22.5)
None	1 (2.5)
Presence of indwelling catheter while undergoing CT scan	21 (52.5)

TABLE 2. Patients' presenting symptoms.

Presenting symptoms	No. (%)
Upper limb swelling	27 (67.5)
Failed cannulation	5 (12.5)
High venous pressure*	3 (7.5)
Clot derived from catheter	2 (5)
Decreased fistula flow**	1 (2.5)
Asymptomatic: follow up	2 (5)

* High venous pressure = A venous segment static pressure greater than 0.5 in grafts or fistulae[9]

* Decreased fistula flow = An access flow < 600mL/min in grafts and < 500 mL/min in fistulae[9]

Fig 2. A 85 year-old female with failed left radiocephalic arteriovenous fistula, and indwelling catheter at right internal jugular vein, presents with right upper limb and face swelling. Direct computed tomography venography with maximum intensity projection reconstruction, coronal view reveals stenosis at right subclavian vein (top-arrow), and thrombosis in right internal jugular vein (bottom-arrowhead), and thrombosis in superior vena cava (bottom-arrow)

TABLE 3. Sites and types of lesions.

Site	Stenosis (No.)	Thrombosis (No.)	Total
Superior vena cava	3	4	7
Internal jugular vein	5	20	25
Brachiocephalic vein	18	11	29
Subclavian vein	9	7	16
Axillary vein	5	4	9
Brachial vein	3	2	5
Cephalic vein	10	5	15
Basilic vein	3	3	6
Total	56	56	112

Fig 3. Direct computed tomography 3D volume rendered image of a 81 year-old female shows right axillary vein stenosis (arrow), measured 1.9 mm. in diameter, compared with 9.9 mm. of normal diameter, about 1.0 cm. long. Much collateral veins are noted at left upper limb.

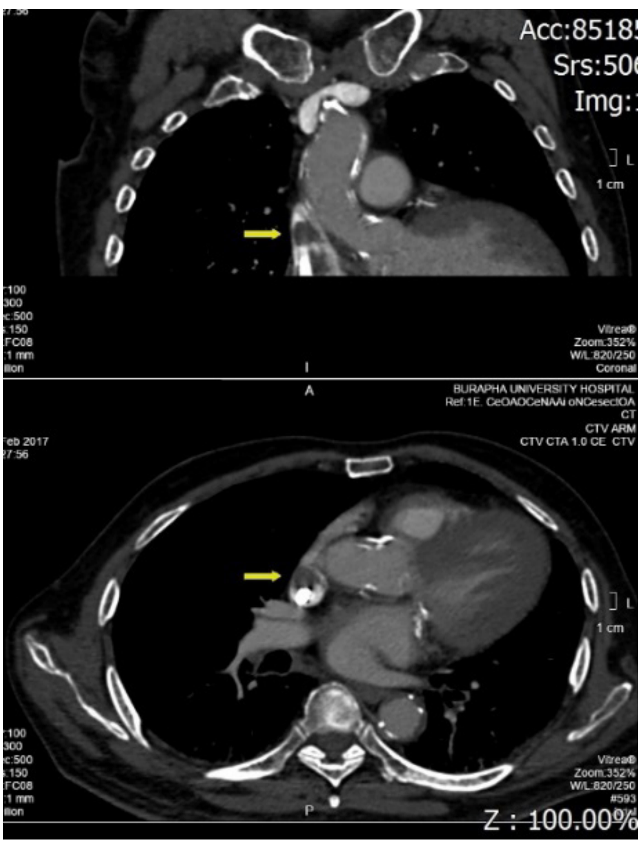

Fig 4. A 82 year-old male presents with failed cannulation at right internal jugular vein. Direct computed tomography venography with multiplanar reconstruction longitudinal view (top) and axial view (bottom) demonstrate thrombus in the superior vena cava (arrows).

3-5 mL/min, along with scanning in the arterial phase using a timing bolus test or bolus tracking.[4-5] There have been few reports of direct CTV for upper extremities and the techniques used are variable. A prospective study of 22 patients used a 1:2 dilution of IC that was injected simultaneously in both arms, along with scanning using bolus tracking.[10] The total volume of IC used per patient in that study was 75 mL. Svensson and colleagues used 45 mL of 1:10 diluted IC, and scanning at 12 seconds; thus, less than 5 mL of IC was used in their study.[11] We used 1:4 diluted IC, which is similar to that used by Kuo et al. who injected IC into both femoral veins.[12] Total volume of of IC used in our patients was 38 mL, and we simultaneously injected IC into both arms to avoid inflow phenomenon at the superior vena cava (SVC), which is a common problem with single arm injection. Our protocol yielded good quality images of bilateral upper extremity veins that were also suitable for mapping. In cases of chronic occlusion, collateral veins were also easily visible (Fig 5). Tanju et al. have used direct contrast-enhanced 3D magnetic resonance venography (MRV) with bilateral injections, and have reported 100% sensitivity and specificity. However, there were only 19 patients in that study.[2]

Multiple contrast agents can be used for venography other than IC such as carbon monoxide[11,13] or gadoterate meglumine[12,14] which provide high quality images but are not feasible for use because of their availability. Non-contrast enhanced MRV has been proposed in patients who want cannot endure risk from either the contrast agent or radiation[13,15], even though contrast-enhanced MRV has a higher diagnostic odds ratio than non-contrast techniques.[14,16]

The incidence of steno-occlusive complications in our cohort was 95%, which is higher than that reported by previous studies.[15-19] This may be because almost all our patients were symptomatic and had undergone prior subclavian catheterization or placement of peripherally inserted long-term catheters for hemodialysis before fistula formation. Prior catheter use is associated with primary patency loss in patients with a fistula or a graft, and this is the strongest independent predictor of upper extremity venous thrombosis.[18-21] Moreover, most of our patients had an indwelling catheter, which is also the strongest independent predictor of upper extremity deep venous thrombosis.[20,22] Additionally, average patient age in the current study was more than 65 years, and available literature suggests that age more than 50 years is a significant risk factor for AVF thrombosis.[21,23]

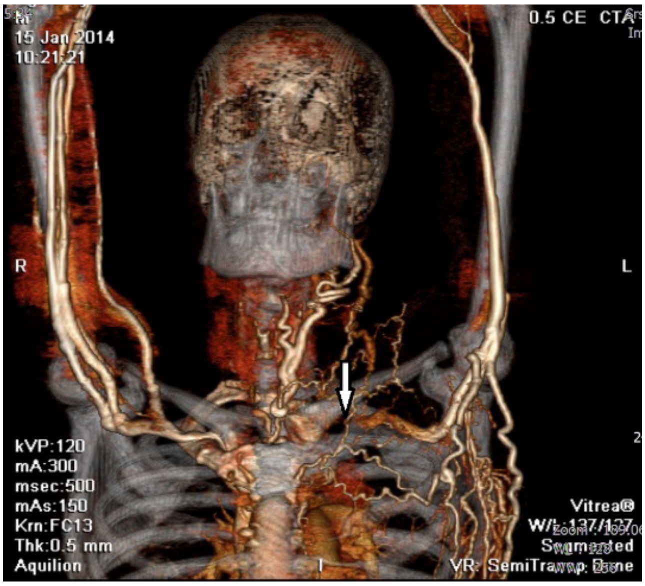

Fig 5. Direct computed tomography venography 3D Volume Rendered image of a 52 year-old male demonstrates left brachiocephalic vein thrombosis (arrow). Much collateral veins are noted at left hemithorax.

Limitations

The limitations of this study are a selection bias due to the lack of a control group, because it is not possible to perform CTV in a healthy individual. Therefore, all participants were symptomatic, which led to a high incidence rate. Further, information on several vascular access characteristics such as anatomic location, and time-to complication development was not available. Another limitation was the potential for variability in image interpretation because of the variation in radiologists' experience. Lastly, the study did not investigate the effects of radiation dose which is a topic of concern. However, as the conversion factor in this region is small, radiation exposure is expected to be minimal[3,24], and radiation hazard in this cohort would be less of a concern given the higher mean age of the patients.[25]

CONCLUSION

We describe a direct CTV technique used in our facility, which involved simultaneous injection of diluted contrast medium in both upper extremities. This technique not only has the benefit of requiring a lower volume of contrast medium while maintaining direct visualization of the venous system similar to conventional venography, but also avoids inflow phenomenon at the SVC. Additionally, mapping for venous reconstruction of both arms was possible based on data acquired. The notable findings in this study are beneficial for future study. Further comparative cross-sectional study or RCT in a larger population to demonstrate the benefit of this novel technique over the conventional method is required.

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