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ORIGINAL ARTICLE

Direct contrast-enhanced 3D MR venography evaluation of upper extremity deep venous system

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PURPOSE
To investigate the diagnostic value of direct contrast-enhanced three dimensional magnetic resonance (3D MR) venography in mapping the deep venous system of the upper extremities and to plan potential interventional procedures.

MATERIALS AND METHODS
Nineteen cases with the diagnoses of end-stage renal disease with multiple hemodialysis catheter access were examined. Direct contrast-enhanced 3D MR venograms were obtained with 1.5 Tesla device with 3D-FSPGR pulse sequence and using body coil following the manual injection of gadolinium solution prepared by diluting 20 ml of contrast substance in 200 ml saline with a proportion of 1:10 through intravenous access opened symmetrically in antecubital fossa. In the workstation, evaluation was performed on three-dimensional images, two-dimensional multiplanar reformats and maximum-intensity projection method obtained from the source images. Intravenous DSA was performed on all the patients, and two radiologists evaluated MR venograms and conventional angiograms independently from each other. Results of MR venography and conventional angiography were then compared.

RESULTS
In all cases, the MR venograms obtained were capable of supporting the diagnoses. Venous pathologies were found in 16 cases. In three cases central veins were evaluated to be patent. Results of MR venography and conventional angiography were consistent with each other (100% sensitivity and 100% specificity).

CONCLUSION
Direct contrast-enhanced 3D MR venography is a well-tolerated sensitive technique in explaining the cause of the malfunctioning arterio-venous fistulas and in pre-surgical planning before placing new catheters or creating fistulas. It is possible to obtain high-quality images with this technique as an alternative to invasive angiography.

Key words: • contrast media • magnetic resonance angiography • upper extremity • veins

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Thromboocclusive disease of upper extremity deep venous system was first described by Paget in 1875, and by Schroetter in 1884 and it constituted less than 2% of all deep venous thrombosis reported before 1967 (1). Compared with lower extremity deep venous thrombosis, it was thought to be a rare benign entity with a lower incidence of pulmonary embolism. Number of cases has increased significantly with increment of end stage renal disease requiring long-term central venous catheterization. Multiple catheters and venous interventions usually cause upper extremity venous system thromboocclusive disease in patients with end stage renal disease. Also in these patients, fibrin sheath is formed around long term catheters resulting in catheter malfunction.

Upper extremity venous system mapping is important in explaining the etiology of malfunctioning arterio-venous fistulas, in planning probable interventional radiologic and surgical procedures such as creating new fistulas or placing new catheters. Venous imaging is required to diagnose and evaluate the extension of thrombosis. Accurate detection of extension of thrombosis is important in planning the catheter insertion area before placing a new catheter.

Combined methods including color Doppler ultrasonography (CDUS), computed tomography (CT) and intravenous digital substruction angiography (IV-DSA) are used for imaging central veins in the current clinical practice. Each method has advantages and disadvantages according to the location and nature of the disease. CDUS is a useful method for determining upper extremity venous system. Because of adjacent anatomical structures such as bones and lung tissue, sonographic evaluation of brachiocephalic vein and vena cava superior is impossible. Gold standard method, IV-DSA has some limitations such as; nefrotoxicity risk due to iodine contrast agents, allergic reactions, ionized radiation exposure, requirement of bilateral injections and unopacification in juguler veins (2-5).

Magnetic resonance (MR) imaging is not a new technique in venous system evaluation. Two-dimensional (2D), unenhanced time-of-flight (TOF) techniques have been used widely (6-10). Three dimensional (3D) dynamic contrast-enhanced MR angiography (MRA) is widely used for the evaluation of arterial system due to easy application as a minimally invasive method. For venous system imaging MR was first used in 1997 for lower extremity deep venous system evaluation (11). This technique is an indirect method requiring substraction of selective arterial phase from late arterio-venous phase which has been modified for upper extremity venous system in 1999 (12).

The purpose of this report is to investigate the sensitivity and specificity of direct contrast-enhanced 3D MR venography in mapping the upper extremity deep venous system as compared to gold standart IV-DSA method.

Material and methods

Nineteen cases (13 female, 6 male), ranging in age between 25 and 71 (mean 50) were examined between January 2002 – March 2004. Indications were hemodialysis catheter problems and preinterventional or presurgical planning in patients with end-stage renal disease. Examinations had optimal quality and there were no technical or patient-related artefacts. IV-DSA was performed with bilateral antecubital intravenous contrast agent injections. For internal juguler vein evaluation, late phase venograms were obtained with selective carotid arterial catheterization if needed.

Bilateral axillary, subclavian, cephalic, brachiocephalic veins were examined with direct contrast enhanced 3D MRV technique and bilateral internal juguler veins were examined with late phase venograms in all 19 cases. Direct MRVs were obtained with 1.5 Tesla Signa Horizon Imaging System (GE, Medical Systems, Milwaukee, USA) with 3D-FSPGR (three dimensional fast spoiled gradient recalled echo) pulse sequence using body coil.

Bilateral intravenous access were opened with symmetrically placed 20 gauge venous canulles at or distal to antecubital fossa. Patients were instructed how to hold their breath. Patients were in supine position and cushions were placed under their arms (Figure 1). Gadolinium solution was prepared by diluting 20 ml of contrast substance (Magnevist®, Schering, Germany) in 200 ml saline with a proportion of 1:10. Body coil was used becuse all examinations were performed bilaterally. Examination area was detected from axial and coronal scout images and slab was placed accordingly. FOV (field of view) was optimized to include the shoulders.

Prepared gadolinium solution injection was performed with fast bolus method using connectors. Scanning was started 8 seconds after injection. Scanning was performed in coronal oblique plane. Imaging parameters were; FOV including shoulders (average 44 cm), TR/TE minimal, slice thickness 4/-2 mm, flip angle 30°, matrix 256x128, fat saturation, NEX 0.5, phase FOV 0.9.

Four serial scans were performed after three to four seconds follwing the end of preceeding scans. Each series consisted of 52 slices with 4 mm slice thickness and 26 images. Average time of each serial scan was 15 seconds. Scanning were performed with breath-hold method during contrast injection periods. Image quality was adequate for diagnostic evaluation unless sudden and wide amplitude breath artifacts occurred.

In the workstation (Advantage Windows 3.1, GE, USA), evaluation was performed by three dimensional images two dimensional multi-planar reformats and maximum intensity projection (MIP) method, obtained from the source images. Venous structures were classified as; patent, narrowed (non-oclussive thrombosis) and occluded. Presence of collaterals was investigated. If filling defect was detected, venous thrombosis was diagnosed. Stenosis was detected based on narrowing ratio of vein calibration. Peripheral small mural thrombosis and wall irregularities were named as chronic venous thrombosis. Two radiologists evaluated MRV and IV-DSAs independently from each other and detected pathologies were recorded. Direct contrast-enhanced 3D MRV and gold standart IV-DSA results were then compared with each other, specificity and sensitivity of methods for examing upper extremity deep venous system pathologies were calculated.

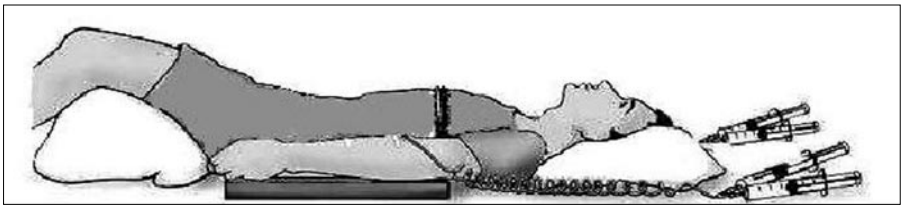


Figure 1. Preperation of the patient.

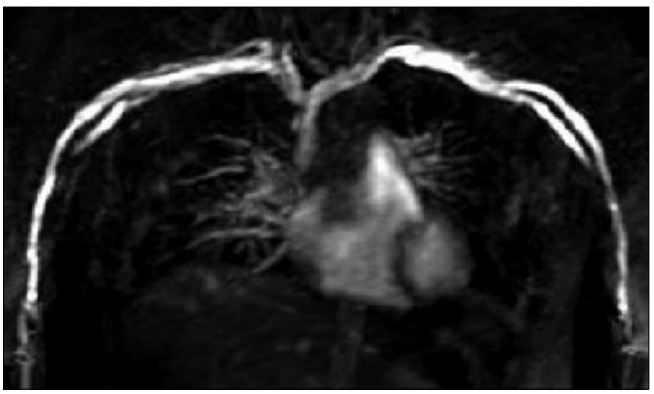


Figure 2. A patient with chronic renal disease with prior history of central venous catheterization underwent planning study for arteriovenous fistula. Coronal MRV-MIP image shows the patency of bilateral subclavian, brachiocephalic veins and superior vena cava.

Results

In all 19 cases, direct contrast-enhanced 3D MRVs were obtained sufficient for supporting the diagnosis. IV-DSA was performed in all of the patients. Central venous system was patent in 3 cases (16%) (Figure 2). Venous pathologies were detected in 16 patients (84%) (Figure 3). Seven patients in this group (37%) had 3 or more venous segmental pathology (Figure 4). Pericatheter fibrin sheath occured in 1 patient (Figure 5). Also 3 cases (15%) had venous anatomic variations with 2 cephalic duplications, 1 internal juguler vein fenestration (Figure 6). Collateral vascular structures were detected with late phase venograms (Figure 7).

False positive or negative results were absent when compared with gold standart IV-DSA. According to these results, specificity and sensitivity of 3D direct contrast-enhanced MRV was found 100% in diagnosing as 'patent, narrow or occluded'. Anatomic details and extension were shown with direct contrast-enhanced 3D MRV.

Discussion

Today, central venous catheterization requirement has increased due to chronic renal disease. Central venous stenosis and occlusion are well-known complications of long-term venous catheterization. Central venous system imaging is important for diagnosing thrombus formation, evaluating central vein patency, pre-surgical planning

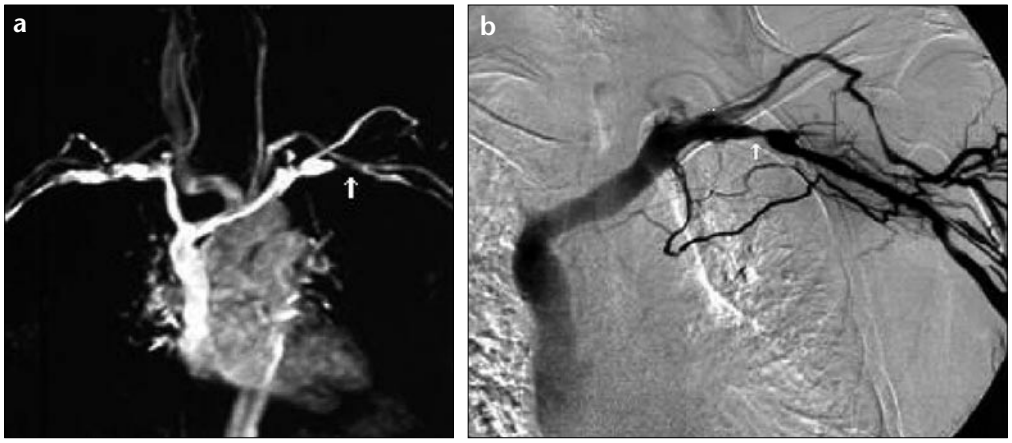


Figure 3. a, b. Coronal MRV-MIP venogram **(a)** and IV-DSA image shows *(arrow)* severe stenosis of the left subclavian vein **(b)**.

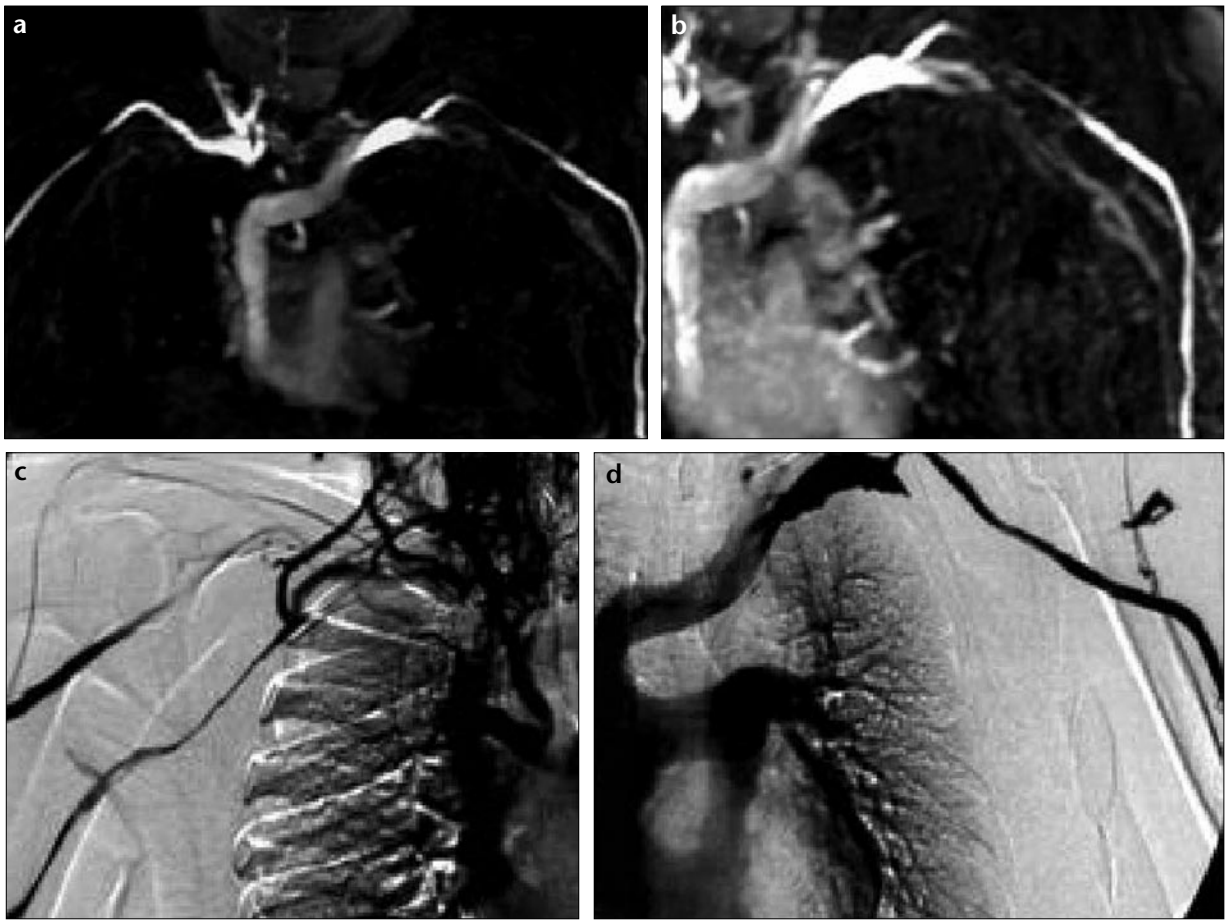


Figure 4. a-d. First **(a)** and third **(b)** phases of MRV-MIP images and right **(c)**, left **(d)** IV-DSA images show occlusion of right axillary, brachiocephalic and left subclavian and axillary vein.

before creating arterio-venous fistulas for hemodialysis.

Criado and et al. reported 14 (11.5%) subclavian vein obstruction in one year period of 122 cases requiring long-term central venous catheterization (13). Haire and et al. examined 225 cases undergoing chemotherapy or bone marrow transplantation and found the ratio as 10% for central venous thrombosis in first three months after the placement of Hickman catheters (14). Stenosis or occlusion of subclavian vein may be asymptommatic and can casue arteriovenous fistula malfunction. Subclavian vein patency should be examined in patients with prior central venous catheterization history and for planning arteriovenous fistulas. Also imaging is important for planning central canulation.

Alternative methods for evaluating central venous system are CDUS and contrast enhanced CT. CDUS is a cheap, easy and non-invasive method and can be performed in unstable and uncooperable patients. This method is

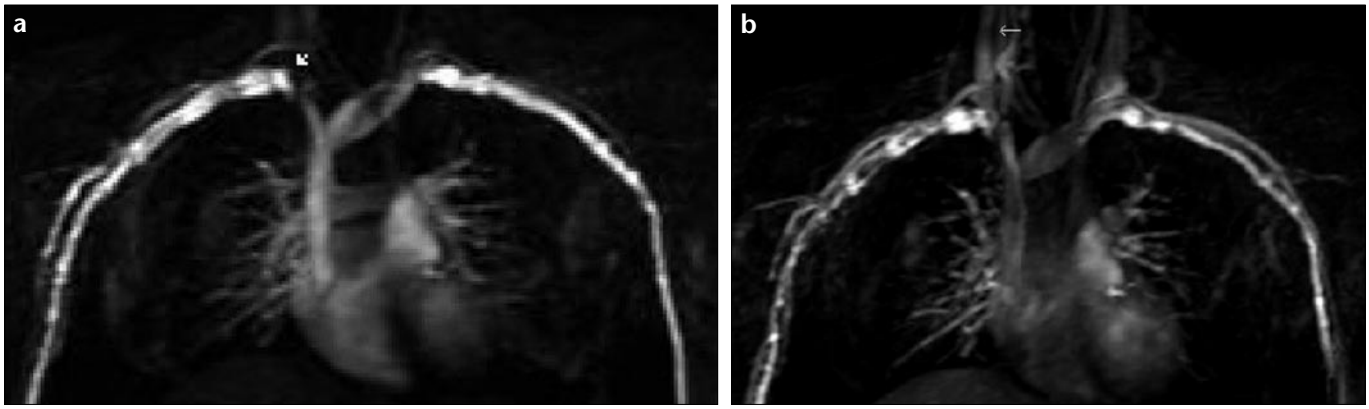
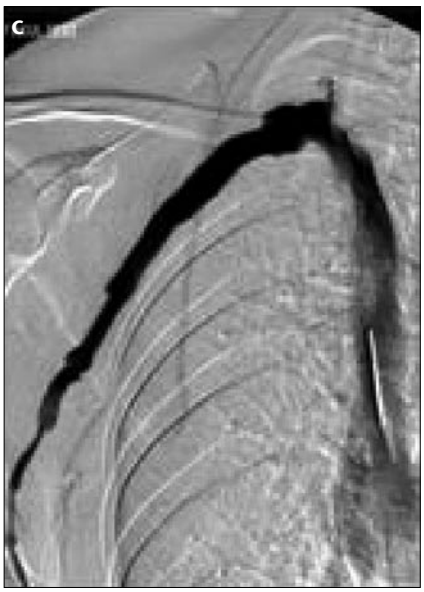


Figure 5. a-c. A patient with a history of non-functioning hemodialysis catheter placed 4 months before. First **(a)** and third **(b)** phase venograms show dilatation of right distal internal juguler vein around the catheter (*long arrow,* **b**) and bulbous appearance (*short arrow,* **a**). Right IV-DSA **(c)** image shows filling defect and reflux of contrast agent at the same level. Also MR venograms demonstrate non-occlusive thrombus of the left brachiocephalic vein.



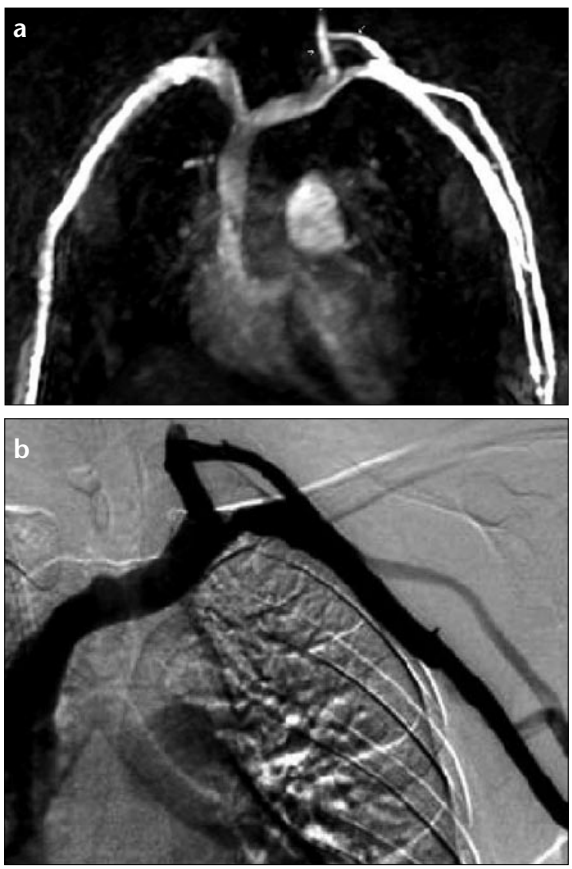


Figure 6. a, b. Coronal MRV-MIP image **(a)** and IV-DSA image **(b)** show fenestration of left distal juguler vein *(arrows,* **a***)*. At the same level focal minimal stenosis of the left subclavian vein is seen.

usually performed as the initial method which is useful for upper extremity venous system. But brachiocephalic vein and superior vena cava can not be evaluated due to bones and lung and central extension of venous thrombus or abnormalities may not be demonstrated (14, 15). Also proximal portion of subclavian vein examination is limited. Haire and et al. has reported that CDUS can not demonstrate 45% of short segment occlusions at the medial aspect of subclavian vein and 43% of non-occlusive subclavian venous thrombosis. CT demonstrates mediastinal soft tissue details perfectly and contrast-enhanced images may be used for evaluation of central veins. But iodine contrast agents have some disadvantages such as contrast agent artifacts (16, 17). CT with minimal artifacts and increased diagnostic accuracy requires bilateral venous contrast agent injections.

Although conventional venography is the standart reference method for evaluating central veins, it has some limitations (2). Direct contrast agent injection is required for detecting unilateral venous thrombosis, but for evaluating central veins, especially superior vena cava, bilateral contrast agent injection is required. Also, juguler veins are usually not opacified. Despite bilateral contrast agent injection, venous artifacts can occur due to venous system convergancy preventing diagnosis. Unopacified juguler vein flow may prevent the evaluation of brachiocephalic vein and superior vena cava. Also contrast agent is nephrotoxic and thrombogenic and there is radiation exposure. Complication rates associated with contrast agent is reported in 2-4% of patients.

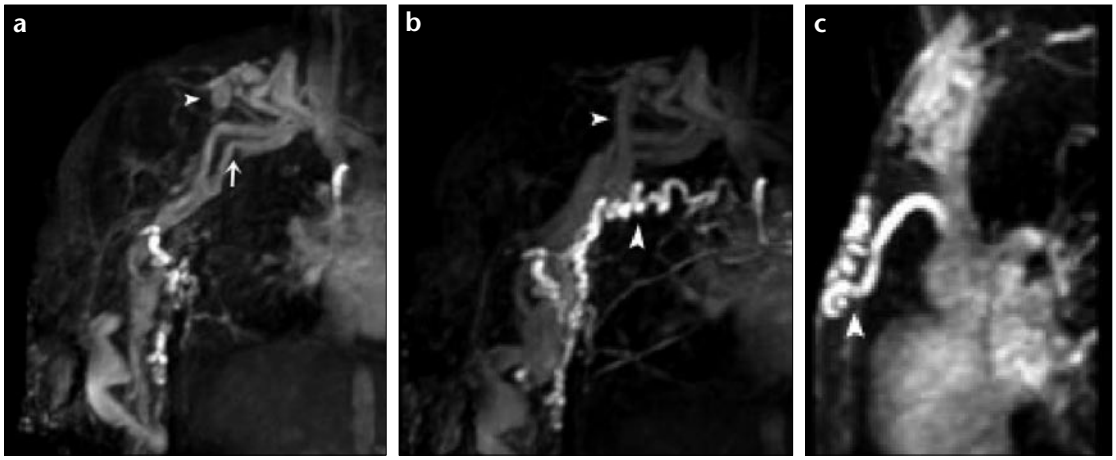


Figure 7. a-c. A patient with a history of right brachiocephalic arteriovenous fistula creation ten months ago presented with problems due to fistula. First **(a)** and third **(b)** phases of coronal and third phase sagittal **(c)** images show central thrombus of the right subclavian vein *(arrow,* **a** *and arrowheads,* **b***)*. Extensive collaterals are also seen significantly over right shoulder and thoracic wall on late phase images that are running into the brachiocephalic vein, internal mammarian vein and superior vena cava.

Some authors advocate MR imaging as an alternative to conventional venography for evaluating central venous system (6, 11). MRV is not a new technique and is a suitable method for evaluating central veins. 2D-TOF method is used in most of the studies (6-10). Finn and et al. examined 30 cases with probable thoracic venous occlusion with 2D-TOF MRV and compared with conventional venography. In 19 of 22 cases (86%) MR imaging results were correct in 11 cases and MR imaging allowed successful venous intervention (6). Hartnell et al. reported similar findings (7). Some artifacts may prevent diagnosis in 2D TOF MRV. Finn et al. noticed focal decreased signals causing false positive thrombus formation in venous confluens and in vessels extending for a long distance. They pointed out the importance of examining all source images and slices together in order to make correct diagnosis (6).

TOF imaging technique is sensitive for pulsation, plan saturation effects and 'spin dephasing' in disorder of laminar flow, which limit intravascular signal uniformity and cause suboptimal MIPs. If saturation bands are used for selective vein imaging, venous signals of collateral intensities may be saturated. Collapsed veins, having low flow or no flow may not be demonstrated by 2D TOF technique. Also complex venous anatomy of central veins should be kept in mind. These may cause high interobserver variability and to overcome this problem acquisition of images in different scanning plans is required at the cost of increased examination time (8). But orthogonal imaging method is disfavoured due to increased examination time and incidence of breath and movement artifacts. Therefore contrast enhanced MRV has been developed.

Paramagnetic contrast agents, having short T1 relaxation time and causing contrast difference between blood and surrounding tissue, are used intravenously for contrast enhanced 3D MRA method (3, 4). In contrast to 2D TOF technique, flow artifacts and saturation effects are minimal. Multiplanar reformats may demonstrate complex and tortuose vascular anatomy (3, 4, 18, 19).

Contrast enhanced 3D MRA is generally used for evaluating arterial system. It was first used in 1997 by Lebowitz for lower extremity venous system evaluation using substraction procedure (11). This method is faster than axial TOF technique and has more uniform signal intensity. Shinde et al. has reported similar results and they evaluated central venous system using substraction method (12). In this method, after the contrast agent enjection, early arterial and late phases are obtained, then early arterial phase images were substracted from late phase images. And venous system was evaluated after detecting peak time for arterial and venous opacification with test dose. Only 3 cases were correlated with gold standard conventional venography which is a major limitattion of this study. Thornton et al. examined 37 cases with central venous thrombosis with MRV and they reported 100% sensitivity and 100% specificity (3).

Oxtoby et al. used an easier method in 2001 without calculating injection delay time and without performing substraction (4). They increased the time between injection and beginning of scan (average 20 seconds) and they used circulation hemodynamic method. In this method, contrast agent runs into the circulation before scanning, lower extremity circulation time is longer than upper extremity circulation, and subclavian veins have longer opacification time than juguler veins. Authors reported that calculating scanning time is less important than arterial MRA, but late phase images are necessary (4).

All these modifications allowed shorter scanning times giving the chance to patients who are unable to perform breathholding and to uncooperative patients such as with end stage renal disease as in our study.

These multiphase contrast-enhanced studies require recirculation of contrast agent into venous system and substraction procedure. Substraction causes problems for central venous system evaluation because of respiratory movements. Oxtoby et al. evaluated venous system without obtaining substraction which resulted superimposed arterial and venous structures. But they supported that source images were adequate for image analysis. This retrospective study with 24 cases had disadvantages as cases were evaluated according to clinical information and results were not correlated with IV-DSA.

Ruehm et al. and Li et al. reported evaluation of venous system with low dose contrast agent injection consist-

ing of case reports in 2001 (18,19). Direct infusion technique, used in our study prevents long examination time of TOF and susceptibility to slow blood flow. All vessels with contrast agent can be visualized due to T1 shortening effect which is insensitive to blood flow effects. Saturation and spin dephasing effects are eliminated. Also scanning time is significantly shortened. Examination time is completed in about 15 minutes including patient's preparation. Workstation procedures and image analysis can be completed in minutes with increased experience.

Insufficiency of evaluation from only reformatted images and importance of evaluating source images should be emphasized. Source images are important for demonstrating collaterals and multiple thrombosis. Duplication of brachiocephalic vein was suggested in 1 case on MIP images but it was evident from source images that this appearance was caused by central thrombus formation and false negative evaluation was prevented. Although the number of cases are limited (n=19) in our study, 100% sensitivity and 100% specificity is found for evaluation of upper extremity deep venous system thromboocclusive disease after comparing 3D contrast enhanced MR venography with gold standart IV-DSA results.

Respiratory artifacts causing limitations are not seen in our study. Patients tolerated short-time breathholding (average 15 seconds) easily. Examination was performed in two cases having poor clinical status with instruction of superficial breathing. If not deep and sudden, breath movement did not prevent imaging quality in these cases.

Direct contrast enhanced MRV technique permits evaluation of venous system completely with good quality. This method has advantages for demonstrating complex venous anatomy, varicosity and superficial venous collaterals. Clinicians may easily get oriented with the images obtained with MIP technique. Concominant arterial opacification may occur on late phase images because of long injection period. Direct injection technique allows distinction of veins having high signal intensity from arterial structures. Also multiplanar workstation methods allows differantiation of veins from arteries easily.

Contrast enhanced multiphase 3D MRV technique including recirculation of contrast agent to venous system that require substraction of selective arterial phase images from late phase images, has some technical problems: Selective arterial imaging without venous back flow is difficult for peripheral vascular structures. Extracellular capillary passage of contrast agent during arterial phase causes decreased venous back flow and venous signal and requires use of high dose contrast agent. In direct contrast enhanced MRV technique, diluted contrast agent is used and only venous system is demonstrated. Gadolinium dilution is necessary to prevent decreased signal from vascular structures due to T2 shortening effect of high doses of contrast agent. Gadolinium can be used in patients with renal disease safely and when compared with iodine contrast agents, it has significantly less risk of nephrotoxicity (20, 21).

Direct contrast enhanced MRV has some limitations. It has same contraindications with MR imaging. It requires venous access in all patients so that it is minimal invasive. It does not give information about the way of flow, it only demonstrates all vessels containing contrast agent.

As a result, direct contrast enhanced three dimensionel MRV is a well-tolerated highly sensitive technique for obtaining high-quality and fast images. Also it is ideal for central venous mapping in pre-interventional planning which can be an alternative to invasive angiography.

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