Study objective: To determine the usefulness of high-resolution three-dimensional (3D) gadolinium-enhanced magnetic resonance venography (MRV) in the evaluation of central venous thrombo-occlusive disease of the chest.

Design: Prospective study.

Setting: University hospital.

Patients: Sixteen consecutive patients with clinically suspected thrombosis of the superior vena cava, subclavian, brachiocephalic/innominate, internal jugular, or axillary veins. Thirteen patients had a neoplasm, two patients had a connective tissue disease, and one patient had a history of strenuous exercise. Twelve of 16 patients had prior central venous catheter placement. MRI was correlated with color-coded duplex sonography (CCDS) in 7 of 16 patients, digital subtraction angiography (DSA) in 3 of 16 patients, and CT in 2 of 16 patients.

Intervention: Contrast-enhanced MRV was performed in a total of 20 examinations. A 3D data set (gradient echo; time to repeat, 4.6 ms; time to echo, 1.8 ms; flip angle, 30°; time of acquisition, 23 s; 512 matrix/64 partitions; slice thickness, 1.5 mm) was acquired in the arterial and venous phase. Overall image quality was assessed on a 5-point scale. The presence, site, and extent of thrombus, as well as presence of an intravascular device, were determined.

Measurements and results: Overall image quality was rated very good (1 point) in 7 of 16 cases (44%) and good (2 points) in 9 of 16 cases (56%). Thrombus was detected in 16 of 16 patients, and complete extent of disease could be determined in 15 of 16 patients (94%). MRV did not miss any finding obtained by CCDS, DSA, or CT, and provided additional information in 6 of 16 examinations (38%).

Conclusion: Contrast-enhanced MRV is a fast and reliable noninvasive procedure with excellent results regarding detection and determination of the extent of thrombo-occlusive disease of the chest veins.

Key words: diagnostic techniques, cardiovascular; magnetic resonance angiography; thorax; veins; venous thrombosis

Abbreviations: CCDS = color-coded duplex sonography; 3D = three dimensional; DSA = digital subtraction angiography; FOV = field of view; GRE = gradient recalled echo; MIP = maximum intensity projection; MPR = multiplanar reformation; MRV = magnetic resonance venography; SVC = superior vena cava

Three-Dimensional Gadolinium-Enhanced Magnetic Resonance Venography in Suspected Thrombo-occlusive Disease of the Central Chest Veins*

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Thrombosis of the central chest veins used to be considered an uncommon, innocuous, and self-limiting disease.1–5 However, with the increased use of long-term indwelling central venous catheters for hyperalimentation, chemotherapy, and hemodialysis, it has been recognized that this entity is far more common than previously thought and that it is associated with a significant morbidity.6–9 Complications of thrombo-occlusive disease of central chest veins range from restriction or loss of central venous access, venous gangrene, postthrombotic syndrome, and superior vena cava (SVC) syndrome to pulmonary embolism.10–13 These sequelae can be prevented if prompt diagnosis and adequate therapy are provided to restore patency of the veins.14

The role of imaging is to demonstrate the presence of venous thrombosis, its site and extent, as well as possible causes before therapy is initiated. Digital subtraction angiography (DSA) is considered the standard of reference for the evaluation of the central veins, with ultrasound being the first-line...
imaging modality in cases of suspected thrombosis.\textsuperscript{15} Three-dimensional (3D) gadolinium-enhanced magnetic resonance venography (MRV) has been shown\textsuperscript{16–18} to allow for a comprehensive noninvasive evaluation of the central chest veins. The purpose of this study was to determine the clinical usefulness of high-resolution 3D gadolinium-enhanced MRV in the assessment of suspected central venous thrombo-occlusive disease of the chest.

**Materials and Methods**

**Design and Setting**

The study was performed prospectively at a university hospital.

**Patients**

Sixteen consecutive patients (12 men, 4 women; age range, 21 to 60 years; median, 35 years) with clinical signs of thrombosis of the central chest veins, such as upper-limb swelling, pain, pallor, and/or visible collaterals, underwent a total of 20 examinations by high-resolution breath-holding 3D gadolinium-enhanced MRV. Follow-up examinations performed in four patients within a month were not included in the statistical analysis because these examinations did not represent independent measures. Twelve of 16 patients (75%) had a history of central venous catheter placement for hemodialysis, parenteral nutrition (1 of 16 patients, 6%), or chemotherapy in underlying neoplastic disease (non-Hodgkin’s lymphoma [1 of 16 patients, 6%], leukemia [5 of 16 patients, 31%], gastric carcinoma [3 of 16 patients, 19%], hypophyeal tumor [1 of 16 patients, 6%], rectal carcinoma [1 of 16 patients, 6%]). In 9 of 12 patients, the central venous catheter was present at the time of examination.

Two patients had a connective tissue disease (mixed connective tissue disease [1 of 16 patients, 6%], systemic lupus erythematous [1 of 16 patients, 6%]). One patient had small cell lung cancer invading the SVC (1 of 16 patients, 6%). One patient reported prolonged carrying of a heavy bag (1 of 16 patients, 6%).

MRI results were correlated with conventional imaging in 12 of 16 patients (75%), which included color-coded duplex sonography (CCDS) in 7 of 16 patients (44%), DSA in 3 of 16 patients (19%), and CT in 2 of 16 patients (12%).

**Imaging Technique**

After informed consent had been obtained and contraindications were excluded, all patients underwent MRI on a 1.5-T unit (Magnetom Vision; Siemens Medical Systems; Erlangen, Germany) using a torso phased-array coil centered over the thoracic inlet. The field of view (FOV) covered the region from the skull base to the diaphragm in craniocaudal extension and the whole chest in axial diameter. Circulation time was determined at the level of the aortic arch (arterial phase) using a two-dimensional spoiled gradient recalled echo (GRE) sequence similar to the method described by Earls et al.\textsuperscript{19} Based on circulation time, 3D gadolinium-enhanced magnetic resonance angiography was performed during end-inspiratory breath-holding in the arterial/late pulmonary-arterial phase as well as in the venous phase of the central chest veins. A fixed delay of 15 s between both acquisitions was set, allowing the patient to breathe in between. Gadolinium-based contrast material (gadopentetate dimeglumine; Magnevist; Schering; Berlin, Germany) was administered as a bolus injection at a weight-adjusted dose (0.2 mmol/kg). All injections were administered with a magnetic resonance power injector (Spectris; Medrad; Pittsburgh, PA) at a flow rate of 2 mL/s followed by a flush of 20 mL of normal saline solution through a 22-gauge injection cannula placed in an antecubital vein. In patients with unilateral upper-limb swelling, the contrast agent was injected in the unaffected arm. 3D data sets were acquired in the coronal plane using a spoiled GRE sequence with the following parameters: time to repeat, 4.6 ms; time to echo, 1.8 ms; flip angle, 30°; adjusted rectangular (6%) FOV (maximum, 500 mm), matrix 200 × 512; 1 excitation; bandwidth, 390 Hz/pixel; 64 partitions reconstructed at a slice thickness of 1.5 mm; maximum slice thickness, 96 mm; time of acquisition, 23 s.

**Analysis**

After image acquisition, maximum intensity projections (MIPs) and multplanar reformations (MPRs) were generated using the standard software of the magnetic resonance unit. Two radiologists (M.T., T.J.K.) experienced in MRI prospectively reviewed the studies by consensus in a random order and without knowledge of the clinical data and the findings of other imaging techniques. In addition to the generated MPR and MIP images, source data (coronial partitions) were reviewed. Source data were assessed on a 3D workstation (EasyVision; Philips Medical Systems; Eindhoven, the Netherlands) that allows for interactive scrolling through the images (cine mode) and distance measurements.

Overall image quality was assessed on a 5-point scale (1 = very good; 2 = good; 3 = moderate; 4 = deficient; 5 = insufficient). Coverage of the central chest veins and major pulmonary artery branches was determined. The presence, site, and extent of thrombotic material and presence of an intravascular device were assessed. MRV results were considered positive for thrombus if thrombotic material could be directly seen as a hypointense structure filling the vessel lumen partially or completely. The length of thrombosis was measured on coronal images of the 3D data sets. MRIs obtained in the arterial/late pulmonary-arterial phase were assessed for pulmonary emboli lodged in major pulmonary artery branches.

**Results**

Overall image quality was rated very good (1 point) in 7 of 16 patients (44%) and good (2 points) in 9 of 16 patients (56%). In all examinations, the FOV covered the central chest veins. Abnormal MRV findings were obtained in 16 of 16 patients (100%) with thrombotic material in 15 patients and a filling defect due to local tumor invasion (confirmed by CT) present in 1 patient. The abnormality was clearly depicted on MRV in all 16 patients.

The thrombo-occlusive process involved the following vessel segments: SVC (6 of 16 patients, 37%), brachiocephalic or innominate vein (7 of 16 patients, 44%), subclavian vein (8 of 16 patients, 50%), internal jugular vein (7 of 16 patients, 44%), and axillary vein (2 of 16 patients, 13%). In 10 of 16 patients (62.5%), involvement of more than two vessel segments was demonstrated (Fig 1). The full extent of disease could be determined in 15 of 16 patients (94%). In one case, the peripheral extension into the
The brachial vein, as seen on CCDS, was not covered by the FOV. Thrombus length varied from 1 to 25 cm (median, 9 cm). In the majority of patients, the proximal end of the thrombus was within the brachiocephalic or innominate vein. MRV did not miss any thrombus-positive diagnosis made by CCDS, CT, or DSA, and revealed isolated thrombotic material in the subclavian vein and SVC in two examinations while CCDS results were normal. Additionally, MRV determined the central extent of thrombotic material into the brachiocephalic/innominate vein or SVC in 4 patients (brachiocephalic/innominate vein in 2 of 16 patients and SVC in 2 of 16 patients), while CCDS failed to show the full extent of disease (Fig 2). In 6 of 9 patients (67%) with a central venous catheter present at the time of imaging, the device was visualized by MRV (Fig 3). Images obtained in the arterial phase/late pulmonary-arterial phase depicted the major branches of the pulmonary arteries down to the level of second-order vessels. No signs of pulmonary emboli were identified on these images in any examination.

**Discussion**

Thrombo-occlusive disease involving the veins of the shoulder girdle (axillary and subclavian vein) and the central draining veins (brachiocephalic/innominate vein and SVC) are traditionally subsumed under the term *upper-extremity deep-venous thrombosis.* As a descriptive term, however, upper-extremity deep-venous thrombosis is rather imprecise because thrombosis in most cases does not originate in true extremity veins but in the central chest veins, although the symptoms of central thrombosis may become clinically manifest in an upper limb. The spectrum of identifiable causes and presentations has been extended since the first description of classical spontaneous upper-arm thrombosis by Sir James Paget in 1875, and now also includes central venous catheter-related thrombosis, a complication encountered more frequently due to the widespread use of indwelling central catheters. Clinical symptoms of thrombosis are not reliable, and especially patients with catheter-related thrombosis may be asymptomatic. DSA is widely regarded as the standard of reference for evaluation of the chest veins. However, DSA has certain disadvantages in addition to being invasive and involving roentgen...
rays. Venous cannulation at the clinically symptomatic site is often difficult, and contrast dye injection itself may cause thrombophlebitis. Moreover, DSA can only assess one single venous drainage system for each injection, and major draining vessels, such as the internal jugular veins, remain unassessable even if contrast material is injected in both upper limbs. Using DSA, the diagnosis relies on the visualization of filling defects and collateral drainage pathways, whereas MRV depicts thrombotic material directly. Interpretation of DSA images may be impaired by misregistration artifacts due to motion, especially in the region of the SVC. CT and radionuclide venography, while both being capable of providing diagnostic information on vessel patency and collateral vessels, are less well suited for diagnosing thrombo-occlusive disease of the chest veins. The primarily axial approach, the radiation exposure, which is higher than in conventional venography, and misleading flow effects are major drawbacks of CT. The diagnosis of thrombosis with radionuclide venography relies on the visualization of collateral veins and slow flow as important criteria, both of which are prone to errors in interpretation. Furthermore, radionuclide venography is relatively insensitive in determining the central extent of a thrombus.

Most institutions use CCDS as the primary diagnostic procedure in cases of thrombo-occlusive disease. CCDS has certain limitations in the evaluation of the central chest veins in addition to being an operator-dependent modality. Enlarged collateral veins and nonocclusive thrombi may cause false-negative results, and overlying bony structures and lung parenchyma may obscure venous vessel segments. A critical area for CCDS is the SVC, although efforts have been made to overcome this limitation by making use of indirect signs (e.g., the sniff test). Direct visualization of the SVC, brachiocephalic veins, and innominate veins is often impossible as seen in our series (Fig 4) and reported by others.

Thrombo-occlusive disease of the chest veins has been evaluated by MRI using different pulse sequences with emphasis on the noncontrast-enhanced time-of-flight approach. However, the clinical use of unenhanced angiographic techniques has been limited by long examination times and misleading artifacts. With the recent advent of high-performance gradient systems, data-collection times have been reduced sufficiently to acquire a 3D data set within a breath-holding after the IV injection of contrast material. A study by Shinde et al has shown contrast-enhanced 3D MRV to be suitable for evaluating the patency of central veins before surgical intervention, scheduled central venous access, cardiac intervention, and in patients with symptomatic central venous thrombosis. The MRV technique used by these authors differs from our protocol in certain aspects. From magnetic resonance angiographic examinations focusing on arterial disease of the brachiocephalic arteries, we extrapolated the mean time of maximum contrast enhancement of the thoracic veins, which was around 15 s after maximal arterial contrast enhancement. By choosing a time delay of 15 s between acquisition of the arterial and the venous phase, we ensured that patients could breathe before the diagnostic image set was acquired during suspended respiration at end-inspiration in the phase of maximal venous contrast enhancement, obviating multiple acquisitions after contrast administration.

This technique in addition enabled us to use a single venous image set obtained with a high-resolution (512) matrix instead of acquiring multiple image sets at the expense of resolution. Contrary to Shinde et al, we did not subtract images obtained in the venous phase from images obtained in the arterial phase, a technique previously described by Lebowitz et al. In our experience, contrast enhancement of arterial vessel segments did not cause any difficulties in detecting thrombotic material in the thoracic veins. As mentioned in the studies by Shinde et al and Lebowitz et al, subtraction data sets yield visually appealing MIPs while the diagnosis relies on

Figure 3. A 43-year-old patient with gastric carcinoma after resolution of catheter-associated thrombosis. The central venous catheter is readily seen by MRV (targeted MIP) as a hypointense line (arrows).
interpretation of source images (coronal partitions) and MPRs. In fact, MIPs may not only mimic abnormalities, as demonstrated by a case in the study of Shinde et al., but also underestimate or even obscure abnormalities as shown in one of our examinations (Fig 5). Our results are backed up by the experience reported by Thornton and colleagues, who concluded that arteriovenous overlap does not seriously affect image interpretation, especially when individual images of a sequence are compared. In conclusion, we regard subtraction images as well as MIP generated from subtracted data sets or unsubtracted data sets as unnecessary and even potentially misleading when used alone. The 3D nature of the magnetic resonance angiographic data set can be best exploited when using a viewing station that allows for interactive viewing and MPRs of the source data. Therefore, we recommend establishing the diagnosis solely from source images and MPR. Targeted MIP may be printed out on hardcopy only for documentation of the relevant findings.

In contrast to Thornton et al., who obtained breath-holding 3D spoiled GRE images during first pass as well as in the delayed arteriovenous phase after manual IV gadolinium bolus injection, we did not perform imaging during the venous first pass of the contrast material for the following reasons: (1) first-pass imaging requires a venous access site in the clinically symptomatic limb, while a venous access anywhere else is preferable and possible using the imaging technique described in our study, which relies on second-pass of the contrast material through the vessel territory of interest. Therefore, we did not encounter artifacts related to inflow of unenhanced blood as reported by Thornton et al. (2) First-pass imaging does not allow for a complete evaluation of the chest veins, even with bilateral injection, because of unenhanced blood flow in the internal jugular veins, which may also lead to flow-related artifacts.

Concerning the analysis of the 3D angiographic data sets, consensus reading as performed in this study may enhance accuracy compared to independent single observers, thus leading to a maximum advantage of the technique studied. MRV yielded diagnostic images in all examinations performed. Minor limitations resulting from the FOV chosen existed in demonstrating thrombosis extending into the brachial veins. Since the central chest veins are of major therapeutic concern, this is not regarded as a disadvantage of our technique. The overall diagnostic quality was rated only moderate in one follow-up examination (not included in the statistics) because motion artifacts degraded image quality. These artifacts were related to the inability of the patient to hold his or her breath during the acquisition of the second data set (venous phase). We did not skip image acquisition in the foregoing arterial/late pulmonary arterial phase for the sake of better patient compliance because evaluation of the pulmo...
nary arteries would have been impossible. Artifacts related to implanted devices such as stents, as seen in one of our examinations, are disadvantageous, especially in follow-up examinations, but they are rarely encountered.

Major limitations of this study were the number and selection of patients enrolled and the lack of correlation with DSA as the “gold standard.” Patient referral was based on clinical suspicion of thrombosis. In the setting of a university hospital, most cases of central chest vein thrombosis are related to central venous catheter placement, which is reflected by our study population. Surprisingly, we had two patients with connective tissue disease in our study group who presented with signs of central thrombosis. Thrombosis in these two patients was presumably due to an underlying thrombophilic state associated with this disease entity. We had one case of local tumor invasion and thrombus formation in the SVC from small cell lung cancer, one case of intracardiac lymphoma manifestation, and one case of true effort thrombosis in a young woman who had no other underlying disease. Correlation was available in 75% of patients, in the majority of cases with CCDS performed as part of the initial evaluation. Since MRV answered virtually all relevant questions, DSA was performed as an additional procedure in only three cases. Regarding the detection of pulmonary emboli, our technique was limited by the thickness of the slab that could be used for coverage of the thoracic veins and pulmonary arterial tree without loss of high spatial and temporal resolution, a drawback that may be overcome by technical advances in sequence design and gradient systems.

In conclusion, high-resolution 3D gadolinium-enhanced MRV was diagnostic in all examinations performed, and clearly depicted the site and extension of thrombotic material in clinically relevant venous vessel segments. MRV provides a fast, noninvasive, and comprehensive evaluation of the central chest veins in patients with suspected thrombo-occlusive disease.

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