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Breath-hold Gadolinium-enhanced Three-dimensional MR Thoracic Aortography: Higher Spatial Resolution Imaging with Phased-Array Coil and Three-dimensional Surface Display

Tadashi NAKANISHI, Ryoichiro HATA, Akihisa TAMURA, Minako KOHATA, Kenji MIYASAKA, Toshio KAJIMA, Haruhito FUKUOKA and Katsuhide ITO

Department of Radiology, Hiroshima University, School of Medicine, 1–2–3 Kasumi, Minami-ku, Hiroshima 734–8551, Japan

ABSTRACT

The aim of this study was to examine signal intensities of data sets from MR thoracic aortography and to evaluate three-dimensional surface display (3DSD) for postprocessing. Twenty-five patients were imaged with gadolinium-enhanced 3D fast gradient echo sequence. The intensity at the aortic arch was significantly higher than that at the mediastinal fat ($p<0.0001$). The signal-to-noise ratio was lower at the aortic arch than at the ascending and descending aorta, whereas the contrast-to-noise ratio was fairly high at the aortic arch. Although in one case (4%) the intensity at the arch was smaller than that at the mediastinal fat, 3DSD was successfully performed in all cases. Superiority of 3DSD over maximum intensity projection was obtained in 67% of the cases. 3DSD was evaluated to be superior to maximum intensity projection in all cases of thoracic aortic aneurysm and coarctation of aorta. Higher resolution MR thoracic aortography could be successfully performed with phased-array coil and 3DSD.

Key words: *Magnetic resonance imaging, Magnetic resonance angiography, Three-dimensional surface display, Thoracic aorta*

The value of three-dimensional (3D) gadolinium MR angiography for abdominal and thoracic aortic lesions, including aneurysms, has been demonstrated in several recent studies[1–3,6,7,9,10]. Spatial resolution in magnetic resonance (MR) imaging is apparently lower than that of CT with a matrix of 512 × 512, and intraarterial digital subtraction angiography (DSA) with a matrix of 1,024 × 1,024[4]. Higher resolution is always required, and pursued, if adequate image quality from an MR examination is to be maintained.

Although the phased-array coil provides a higher signal-to-noise ratio (S/N), it has been pointed out that the inhomogeneous intensity in the imaging volume is a disadvantage[8], since maximum intensity projection (MIP) is the standard postprocessing method for MR angiography.

Three-dimensional surface display (3DSD) is another postprocessing method widely available in a commercially available imaging workstation. When the vascular lumen has an adequately high signal intensity over a threshold to eliminate other structures, 3DSD may be another option for 3D MR angiography.

The aim of the present study was (1) to examine signal intensities of data sets obtained from gadolinium-enhanced 3D MR angiography of thoracic aortic disease and (2) to compare three-dimensional surface rendering for postprocessing of these data sets with MIP and DSA.

MATERIALS AND METHODS

Twenty-five patients were examined using gadolinium-enhanced 3D MR angiography. The patients suffered from atherosclerotic thoracic aortic aneurysm (n=15), coarctation of aorta (n=2), aortic dissection without intimal rupture (n=4), and other diseases with negative aortic lesions (n=4). Of the 25 patients, 19 underwent DSA for evaluation of thoracic aortic disease. Aortic dissections with patent false lumen were not included in this study. DSA was performed via a brachial route using a 4-F pigtail catheter, in which anterior and left anterior oblique projections were obtained.

A torso phased-array coil was used at a field strength of 1.5 Tesla (GE Horizon High-speed, GE Medical Systems; Milwaukee, Wisconsin). Patients were imaged during breath holding using a 3D fast gradient echo sequence (repetition time/echo time/flip angle=11/1.8/15, where fat and water are out of phase). A set of 28 sagittal slices with a thickness of 3 mm each was acquired. A 40 × 30 cm field of view and a 512 × 128 image matrix were employed. Data acquisition began 25 sec after a bolus injection of 0.1 mmol/kg of gadolinium chelate. Timing examination was not performed. MIP and 3DSD were created with a 3D workstation (Advantage Window, GE Medical Systems). Interactive threshold setting and selection of the object with the software of the workstation was performed to render 3D surface. MIP was performed without editing the data sets. To assess the source data sets of 3D MR angiography, the signal intensity in the ascending aorta (As), aortic arch (Ar), and descending aorta (Ds), and fat tissue adjacent to As, Ar, and Ds was measured (Fig. 1). The contrast-to-noise ratio was calculated by C/N ratio=(Signal intensity of the aorta-signal intensity of adjacent fat tissue)/Noise; where SD is standard deviation. S/N was calculated by signal intensity divided by background noise.

3DSD and MIP were compared with regard to visualization of the thoracic aortic lesions, setting DSA as a gold standard. Comparative evaluation of 3DSD and MIP was performed by two experienced radiologists specialized in cardiovascular imaging. For aortic dissection without intimal rupture, a visualization of an ulcer-like projection was evaluated. Disagreement between two radiologists was resolved in a different session. The significance of difference among signal intensities at measured sites was evaluated by Student's t test and established at the $p<0.05$ level.

RESULTS

All patients could hold their breath for 34 sec. Artifacts from pulsation were minimal in each sagittal sectional image. The difference in signal intensity, S/N, and C/N from each site was shown in Table 1. The intensity of fat tissue was lower than that of the 3 aortic sites. The intensity was lowest in the aortic arch although the intensity at the aortic arch was significantly higher than that at fat tissue ($p<0.0001$). Even the measured number of intensity at Ar was 1.4 fold that of fat tissue. S/N and C/N were compared among three sites of the thoracic aorta and fat tissue at anterior mediastinum. At Ar, the S/N was lowest but the C/N was fairly high.

Although in one case (4%) the intensity of the aortic arch was less than that of fat tissue, the vascular component could be exclusively selected using the single threshold value setting in all cases.

The results of comparison of 3DSD and MIP for evaluation of aortic diseases are shown in Table 2. Overall superiority of 3DSD over MIP was obtained in 14 of 21 patients (67%). 3D was evaluated to be superior to MIP in all cases of thoracic aortic aneurysm and coarctation of aorta (Fig. 2, 3), and half of the cases with aortic dissection without intimal rupture. On the other hand, aortic dissection with intimal rupture was better evaluated by MIP in 3 of 4 (Fig. 4). MIP and 3DSD were comparable to conventional angiography, and useful in diagnosis and postoperative evaluation of thoracic aortic diseases.

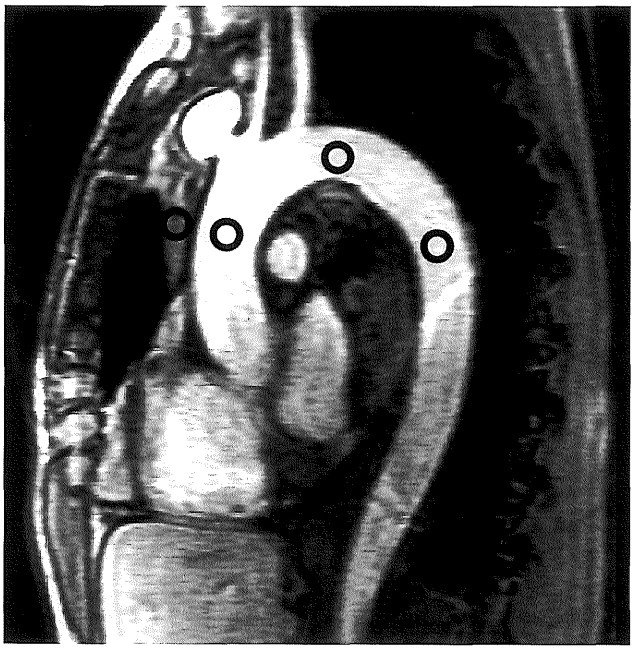

Fig. 1. Sites of intensity measurement. Circles indicate the sites of intensity measurement.

DISCUSSION

3D MR angiography with gadolinium injection has recently become one of the most acceptable non-invasive imaging modalities for thoracic aortic lesions[2,5]. There are two different strategies

Table 1. Comparison of Mean S/N and C/N for the 3 Aortic Sites and Fat Tissue Adjacent to the Ascending Aorta

Location	As	Ar	Ds	Fat
Intensity	74.4 ± 17.6	57.9 ± 14.7	74.6 ± 18.1	40.4 ± 10.9
S/N	98.6 ± 25.6	76.9 ± 22.1	99.6 ± 30.8	
C/N	45.3 ± 18.4	46.6 ± 19.3	62.2 ± 24.6	

Note. — Data represent mean ± standard deviation
S/N: signal-to-noise ratio C/N:contrast-to-noise ratio
As: Ascending aorta Ar: Aortic arch
Ds: Descending aorta

Table 2. Comparison of 3DSD and MIP for Evaluating Aortic Disease

	3DSD>MIP	3DSD=MIP	3DSD<MIP
TAA	13	2	0
CoA	1	1	0
DAA	0	2	2

TAA: atherosclerotic thoracic aortic aneurysm
Coa: coarctation of aorta
DAA: aortic dissection without intimal rupture
3DSD: three-dimensional surface display
MIP: maximum intensity projection

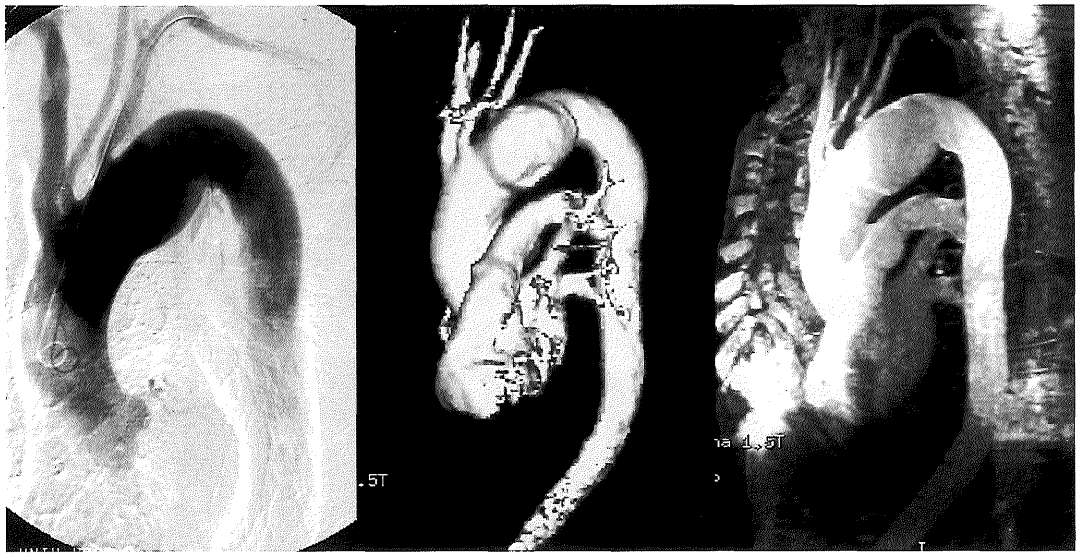

Fig. 2. Thoracic aortic aneurysm (a) An angiogram of thoracic aorta in left anterior oblique view. The left subclavian artery was involved in the aortic arch aneurysm. (b) Three-dimensional surface display demonstrated not only the aneurysm itself but also the relationship of cervical branches to the aneurysm. (c) In maximum intensity projection, the aortogram is inhomogeneous according to the distance from the coils.

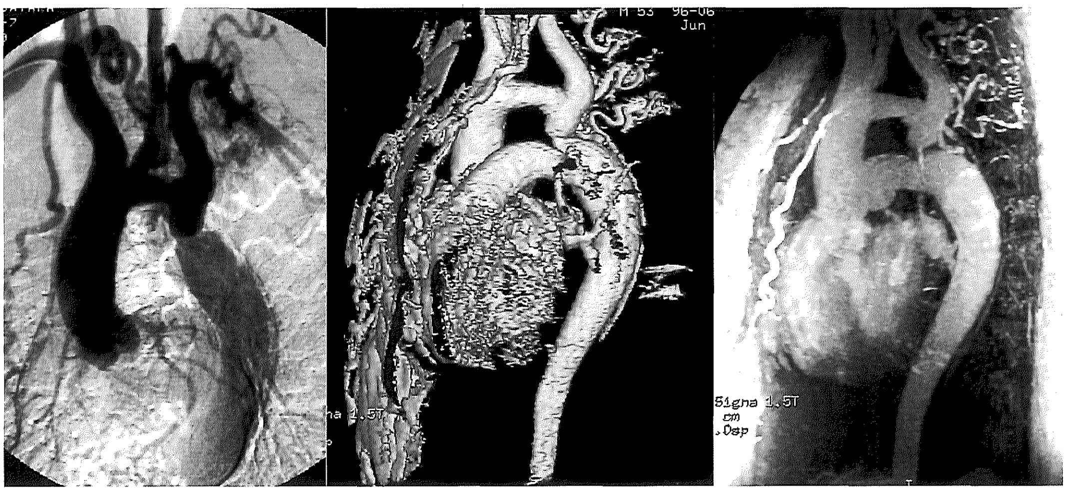

Fig. 3. Coarctation of aorta (a) An angiogram demonstrated well the ascending aorta and arch including cervical vessels, the opacification of the descending aorta distal to the coarctation is poor. (b) Three-dimensional surface display provided a homogeneous aortogram including the stenotic site and distal descending aorta. (c) Maximum intensity projection well demonstrated small collateral vessels as well as the aortogram.

towards breath holding in gadolinium-enhanced 3D MR angiography. Breath holding can contribute to a reduction in motion artifacts from breathing and efficacious use of limited amounts of gadolinium chelates. Whether breath holding is possible or not depends on the acquisition time determined by repetition time, the number of phase encoding steps, and the number of slices acquired in the sequence. In general, breath-holding acquisition is recommended and is a practical choice if the acquisition time is tolerable for the patients.

A higher performance gradient system has recently enabled shorter repetition time and echo time sequences, which leads to shorter acquisition time and a greater number of partitions. However, lower contrast results and larger amounts of gadolinium chelates may be required in order to achieve contrast of the aorta in lower performance systems. Timing examination or automatic detection of arrival of contrast medium has been proposed for better contrast with smaller amounts of gadolinium chelates.

A sequence of a matrix of 512 has not been used for body imaging without the use of a phased-array coil. Many reports have documented the advantages of the phased-array coil, which include sufficient diagnostic image quality in high resolution images[9]. MIP and three-dimensional surface rendering provides projection images similar to those of conventional angiography, which has no extra information other than vascular component,

Fig. 4. Aortic dissection without intimal rupture: A small pouch at the aortic arch indicating an ulcer-like projection was well demonstrated with sagittal source image (left). The lesion was better visualized in maximum intensity projection (right) than in three-dimensional surface display (middle).

such as mural thrombus in aortic aneurysm. Consequently, multiplanar reformation or inspection of axial images is referred to during the evaluation, while topographic information attributable to projection images is required for surgery.

As shown in the present study, 3DSD provided more information than MIP when applied with a phased-array coil. This does not negate the need for axial images or multiplanar reconstruction. For aortic dissection with patent false lumen, sectional images allow visualization of both the thin intimal flap and entry sites better than projection images like MIP or 3D surface rendering.

The view angle in the observation of the thoracic aorta in 3DSD is not restricted by subcutaneous fat tissue adjacent to the phased-array coil or pulmonary arteries. Another advantage of 3DSD over MIP is homogeneous visualization of the aortogram. The intensity of aortic lumen in MIP is affected by the distance from the phased-array coil.

The signal intensity at each site should be measured to evaluate whether single value threshold setting is possible. In the present study, an adequate C/N was obtained in most cases for 3D surface rendering, in that a high C/N may lead to better selection of vascular components in surface rendering. These values were higher than that of a previous report[5], in which a body coil and a larger amount of gadolinium chelate was used for MR angiography of thoracic aortic disease.

Elimination of fat tissue by threshold setting and/or exclusion of blocks including fat tissue is essential if additional fat suppression pulse is unavailable or if introduction of fat suppression increases the acquisition time.

In the current study, the imaging matrix was low in the phase encoding direction, with 128 being the maximum tolerable condition for patients' breath holding.

DSA is an invasive method but superior to MR angiography in spatial resolution. The resulting spatial resolution of DSA ranges between 0.4–0.9 mm at a 16 inch field of view, since DSA is usually performed in a 512 × 512–1,024 × 1,024 matrix. In most previous reports, MR aortography has been performed in a matrix of 256 × 128–256[3,5,6,9,10]. Although spatial resolution is not the only factor in determining the clinical efficacy of the images, higher resolution is needed if MR aortography is to replace DSA. Recently, sophisticated phased-array technology has enabled an increase in S/N without an increase in acquisition time with good results. On the other hand, usage of phased-array coil can lead to inhomogeneity in signal intensity. When MIP is applied to MR aortography using a phased-array coil, inhomogeneity in signal intensity is disadvantageous in image display. In the present study, 3DSD, which was available with an independent workstation, was able to provide an homogeneous volume in signal intensity.

Large amounts of gadolinium chelate have been used to produce adequate enhancement of the blood pool especially in combination with body coils and MIP for MR angiography.

The contrast of vessels in 3D MR angiography after administration of gadolinium is achieved by T1 shortening rather than by time of flight. Breath-hold imaging with relatively small amounts of gadolinium is an important factor in vascular imaging. With shortening of repetition time and echo time, in conjunction with a high performance gradient system, breath holding has become an ideal and practical policy. Moreover, the amount of gadolinium chelates is not proportional to the increase in signal intensity. From the standpoint of postprocessing technique, vascular components are more easily chosen in MR data sets obtained from gadolinium enhanced 3D MR angiography than in CT data sets, which show a very wide range of signal intensity (attenuation). We demonstrated that an adequate rise in signal intensity could be obtained using a three-dimensional MR angiography sequence for excellent thoracic aortic images. 3DSD plays a major role in the assessment of aortic lesions, especially when a targeted organ is anatomically complex as when the thoracic aorta runs in the thorax in a three-dimensional curve when elongation or tortuosity has been created by an atherosclerotic change. Another possible advantage of 3DSD is the relatively small amount of fat tissue around the thoracic aorta, since fat tissue is the only obstacle to choosing vascular component exclusively.

A fat-suppression technique with less acquisition time and 3D time of flight with shorter repetition time has been recently developed. This may contribute to better image quality and ease of creation of 3D surface rendering. The new sequence is promising but further study is required to verify its feasibility for diagnosis of thoracic aortic diseases. As long as high spatial resolution is pursued, a decrease in the S/N will be inherent in MR imaging. High resolution MR angiography of thoracic aortic diseases with gadolinium enhancement could be preferably performed in combination with a phased-array coil and 3DSD technique. High resolution gadolinium-enhanced MRA of the thoracic aorta can be achieved using phased-array surface coil. 3DSD postprocessing of the data helps overcome some of the inherent signal inhomogeneity attributed to the phased-array coil.

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