Delayed Contrast-Enhanced MRI of the Aortic Wall in Takayasu’s Arteritis: Initial Experience

OBJECTIVE. Delayed contrast-enhanced MRI is increasingly being used for cardiac viability imaging. Takayasu’s arteritis is a rare inflammatory disorder of unknown cause that affects the aorta, its major branches, and the pulmonary artery; it is characterized by inflammation and fibrosis in the arterial wall. We report our initial experience with seven patients (six women, one man; age range, 25–62 years) with delayed (20 min) gadolinium-enhanced MRI (inversion recovery prepared gated fast gradient-echo pulse sequence) in patients with known Takayasu’s arteritis.

CONCLUSION. Patients with Takayasu’s arteritis (particularly those with abnormal laboratory values) have evidence of delayed hyperenhancement on delayed contrast-enhanced MRI. Thus, delayed contrast-enhanced MRI might be a useful technique to identify inflammation in arterial wall.

Takayasu’s arteritis is a rare inflammatory disorder of unknown cause that affects the aorta, its major branches, and the pulmonary artery [1–3]. Invasive or noninvasive angiography shows stenosis and dilation of the aorta, its branches, or both [4]. Thickening of the aortic wall detectable on cross-sectional imaging can precede angiographic changes [5, 6]. The mainstay of treatment is long-term corticosteroid therapy, but its attendant side effects are significant. Disease activity is usually inferred from patient symptoms, aggravation of angiographic lesions, or increased laboratory values of inflammatory markers such as erythrocyte sedimentation rate (ESR) [7, 8]. However, ESR values have been reported to be normal in up to one third of the patients with active disease determined by other parameters, and 56% of patients with disease in remission have a persistently elevated ESR level [7].

Signal intensity change of the arterial wall on gadolinium-enhanced spin-echo MRI is a potential new method to define active Takayasu’s arteritis that may offer improved specificity compared with serum laboratory measures [9]. In this method, chemical shift fat suppression is used to decrease background signal intensity and thus increase visualization of signal intensity changes in the arterial wall. In our experience, these signal changes can be subtle and may be obscured by inhomogeneous fat suppression related to susceptibility changes resulting from air–soft-tissue interfaces in the chest or neck. The purpose of this article is to describe a new MR method to show arterial wall enhancement based on delayed gadolinium enhancement combined with an inversion recovery prepared gradient-echo pulse sequence.

Materials and Methods
Patients
The study population consisted of seven patients (six women, one man; age range, 25–62 years) with a known diagnosis of Takayasu’s arteritis, who were referred to our MR laboratory for routine follow-up or to monitor progression of the disease. The diagnosis of Takayasu’s arteritis was made on the basis of previously described criteria [10]. The duration of the disease ranged from 1 to 16 years. All patients had laboratory tests, including complete blood count, ESR, and C-reactive protein lev-
els, as part of their clinical follow-up within 1 month of undergoing MRI. Six control subjects with no history of vasculitis, who were referred for aortic MRI for other clinical indications (they underwent delayed contrast-enhanced imaging after clinically ordered thoracic MR angiography to delineate pulmonary vein anatomy before atrial fibrillation ablation), served as the control group (four men, two women; age range, 40–67 years). Retrospective evaluation of patient records was approved by our institutional review board.

MRI

MRI was performed on a 1.5-T MR scanner (CV/i, GE Healthcare). A four-element phased-array surface receiver coil positioned on the chest was used for signal reception. ECG-gated axial and sagittal oblique double inversion recovery fast spin-echo images (TR/TE, 1 R-R interval/30 msec; inversion time set to null blood signal; echo-train length, 16; field of view, 32–36 cm; slice thickness, 8 mm; gap, 2 mm; 512 × 256 frequency × phase acquired matrix interpolated to 512 × 512; and 1 signal average) were used to obtain “black blood” images of the lower neck and chest. Three-dimensional contrast-enhanced MR angiography (TR/TE, 1 R-R interval/minimum; flip angle, 30°; partition thickness, 3 mm; 512 × 192 frequency × phase encodes) in the coronal plane was then performed after bolus IV administration of 0.2 mmol/kg of gadodiamide (Omniscan, Amersham Health). After 18 ± 4 min, delayed enhancement images were then obtained using segmented k-space inversion recovery prepared fast gradient-echo pulse sequences (1 R-R interval/2 msec; flip angle, 25°; views per segment, 20; field of view, 32–36 cm; slice thickness, 6–8 mm; gap, 2 mm; 256 × 160 frequency × phase encodes; signal averages, 2). The inversion time was individually optimized in each patient on the basis of the maximal suppression of the blood signal in the arterial lumen. We obtained sequential images at 25-msec increments (range, 50–125 msec) of inversion times. The inversion time that resulted in the maximal suppression of the blood signal in the arterial lumen was recorded.

MR images were evaluated for thickening and enhancement of the aortic wall on delayed enhancement images. Aortic wall thickening was considered to be present when wall thickness was greater than or equal to 2 mm [11]. The MR reviewers were blinded to the clinical results at the time of MR image interpretation. Contrast-to-noise ratio (CNR) of the aortic wall was calculated on the delayed images as (signal intensity of the aortic wall – signal intensity of the lumen) / SD of background noise. Comparison of CNR between the patient groups was performed using an unpaired Student’s t test.

Results

The demographic data of the patients diagnosed with Takayasu’s arteritis are shown in Table 1. In the patient group, the C-reactive protein and ESR levels were less than 0.3 to 6.4 mg/L and 8–48 mm/hr, respectively.

All arteritis patients had evidence of wall thickening of the aorta and great vessels on unenhanced images (Figs. 1A, 1B, and 2A and Table 1). The maximal arterial wall thickness was 2.3–9.2 mm. The length of the thoracic aortic segment affected by arteritis was 9–27 cm.

All control subjects underwent clinically ordered thoracic MR angiography to delineate pulmonary vein anatomy before an ablation procedure for atrial fibrillation. None of these patients had a history or evidence of vasculitis. None of the patients in the control group had any evidence of the characteristic aortic wall thickening. No evidence of aneurysms or aortic atherosclerotic changes was seen in the patients or the control subjects.

In five of the seven patients with Takayasu’s arteritis, evidence was seen of marked delayed enhancement on contrast-enhanced MR images (Figs. 1C, 1D, and 2B and Table 1) using the inversion recovery prepared gradient-echo pulse sequence. The delayed enhancement was present only in the region of aortic wall thickening. The other two patients had no delayed enhancement on contrast-enhanced images despite characteristic aortic wall thickening on unenhanced images. No individual in the control group had any evidence of delayed enhancement on contrast-enhanced images (Figs. 3A and 3B and Table 1). In three patients, the unenhanced wall thickening and delayed hyperenhancement were localized rather than diffuse.

The CNR of the aortic wall was 8–12 (mean, 8 ± 2 [SD]) in the Takayasu’s group and 1–3 (mean, 2.5 ± 1) in the control group (p < 0.001).

The five patients with evidence of delayed enhancement on contrast-enhanced MR images had elevated high-sensitivity C-reactive protein (range, < 0.3–6.4 mg/L) and ESR (range, 20–48 mm/hr), and the two patients with no evidence of delayed hyperenhancement on contrast-enhanced images had normal values.

Discussion

This study describes our initial experience with the inversion recovery prepared gradient-echo MR pulse sequence in patients with Takayasu’s arteritis. The method showed marked enhancement of the aortic wall that was achieved by nulling signal from the adjacent blood pool. The signal intensity of mediastinal fat was also suppressed using the method, so that the conspicuity of the enhanced wall was high (Figs. 1 and 2). Although all seven patients had characteristic arterial wall thickening, only five patients had evidence of delayed enhancement. Four of these five patients had ongoing symptoms, and all four had elevated inflammatory markers.

The pulse sequence that was used for imaging-delayed enhancement of the aortic wall was adapted from that previously used to show necrosis and fibrosis in the myocardium after myocardial infarction [12]. By nulling signal from normal myocardium with an inversion pulse, the depiction of differential enhancement of abnormal myocardium is substantially improved compared with spin-echo pulse sequences. For myocardial infarction depiction, the improvement in CNR achieved by nulling normal myocardium is reported to be 1,080% [12]. By adjusting inversion times to null signal from blood, we

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**TABLE 1**

Clinical and Radiologic Data on Patients with Takayasu’s Arteritis

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Duration of Disease (yr)</th>
<th>Symptoms and Signs</th>
<th>CRP (mg/L)</th>
<th>ESR (mm/hr)</th>
<th>MWT (mm)</th>
<th>Delayed Hyperenhancement</th>
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<tr>
<td>1</td>
<td>1</td>
<td>F</td>
<td>15</td>
<td>Absent</td>
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<tr>
<td>2</td>
<td>2</td>
<td>F</td>
<td>6</td>
<td>Present</td>
<td>0.9</td>
<td>30</td>
<td>4.3</td>
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</tr>
<tr>
<td>3</td>
<td>3</td>
<td>M</td>
<td>1</td>
<td>Present</td>
<td>1.7</td>
<td>25</td>
<td>9.2</td>
<td>Present</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>F</td>
<td>16</td>
<td>Present</td>
<td>3.9</td>
<td>48</td>
<td>5.2</td>
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</tr>
<tr>
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<tr>
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<tr>
<td>7</td>
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<td>6</td>
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<td>1.0</td>
<td>35</td>
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</table>

Note.—CRP = C-reactive protein, ESR = erythrocyte sedimentation rate, MWT = maximum aortic wall thickness on fast spin-echo images.

aOf the aortic wall on contrast-enhanced inversion recovery prepared gradient-echo images.
have similarly observed marked enhancement of the aortic wall in patients with arteritis. The enhancement was readily seen in the descending aorta in comparison to the low signal intensity of the lung. The inversion times that suppressed arterial wall signal also resulted in fat suppression (Figs. 1C, 1D, and 2B), so that arterial enhancement in the mediastinum was also clearly depicted. We noted a wide variation in the optimal inversion times among patients. The variation in inversion times reflects differing gadolinium concentrations in the aorta. The most common reasons for this variation is difference in cardiac output and renal function among vasculitis patients.

The mechanism of arterial wall enhancement in patients with vasculitis with the technique we have shown is not known, because histologic confirmation of pathologic changes in the aorta is generally not available. Although our sample size was small, we did observe differences in the degree of arterial wall enhancement in patients with elevated ESR and C-reactive protein levels versus those with normal ESR and C-reactive protein values. Our findings are consistent with those of Choe et al. [9], who also reported increased gadolinium enhancement in active vasculitis. Those authors showed that measured signal intensity of the aortic wall relative to that of the myocardium correlated well with ESR and C-reactive protein levels. With active inflammation, there

![Fig. 1.—39-year-old woman with Takayasu's arteritis. A and B, ECG-gated double inversion recovery images of thoracic aorta in sagittal (A) and axial (B) planes show characteristic wall thickening associated with Takayasu's arteritis (arrows). C and D, Inversion recovery prepared (inversion time, 100 msec) fast gradient-echo images in sagittal oblique (C) and axial (D) planes show marked enhancement of thoracic aortic wall (arrows).]
Physician assessment regarding the activity of Takayasu’s arteritis is usually derived from patient symptoms, aggravation of angiographic lesions, or increased laboratory values of inflammatory markers such as C-reactive protein and ESR [7, 8]. However, ESR values have been reported to be normal in as many as one third of patients with active disease determined by other parameters, and 56% of patients with disease in remission have a persistently elevated ESR level. Surgical biopsy of the arterial wall is not routinely performed, but specimens from patients with clinically active disease showed histologically active disease in 44% of patients [7]. An imaging marker for arterial wall inflammation may be useful to objectively assess disease status and response to therapy. Takayasu’s arteritis is a rare disorder (three cases per million people [13]), so documentation of the underlying mechanisms of contrast enhancement that we have observed is difficult. Furthermore, as in other areas of the body, gadolinium enhancement of the arterial wall is probably not a specific marker of inflammation. For example, delayed myocardial enhancement is seen with myocardial necrosis, fibrosis, and myocarditis [14]. In the vasculature, Wasserman et al. [15] reported that the fibrous cap in atherosclerotic plaque showed preferential enhancement after gadolinium contrast administration. Barkhausen et al. [16] also showed that in Watanabe heritable hyperlipidemic rabbits, gadofluorine contrast material enhances the imaging of atherosclerotic plaques and enables improved plaque detection of even nonstenotic lesions that are not visible on unenhanced MRI. Thus, the improved depiction of arterial wall enhancement that we observed may be more generally useful in applications such as imaging of atherosclerosis. Indeed, it is becoming increasingly evident that atherosclerosis is an inflammatory disease, and
MRI of Takayasu’s Arteritis

Ref: MRI of Takayasu’s Arteritis

In conclusion, inversion recovery prepared gradient-echo images with nulling of blood and fat signal show excellent conspicuity of the enhanced aortic wall in Takayasu’s arteritis. Delayed enhancement of the artery using this method in this preliminary study corre-
lated with the presence of serum markers of disease activity. This technique may have a role in monitoring disease activity or inflammation in the arterial wall.

References