Evaluation of Aortic Regurgitation Using Cine Magnetic Resonance Imaging

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SUMMARY

Cine magnetic resonance imaging (MRI) was used to assess aortic regurgitation (AR) in 13 patients with valvular disease and 3 normal subjects, and the results were compared to color Doppler flow mapping findings. AR produced a signal void in the left ventricle during the diastolic phase in all patients by MRI. There were no false positive or negative results compared with echocardiographic findings. Visual grading of cine MRI gave results similar to color flow Doppler echocardiography (88%). The distance and the area of aortic regurgitation using MRI correlated well with color Doppler flow mapping (r=0.82 and 0.88). However, measurements of distance and area by color flow Doppler tended to be larger than those by cine MRI. With current techniques echocardiography may overestimate the severity of AR as compared with cine MRI. In addition, MRI gives clinically useful information in patients in whom transthoracic Doppler echocardiography is not adequate. (Jpn Heart J 34: 741-748, 1993)

Key Words:
Cine magnetic resonance imaging Aortic regurgitation Color flow Doppler echocardiography Signal void

In recent years the development of fast imaging techniques using ECG-gating of MRI has lead to the ability to evaluate cardiac motion and blood flow visually.1,2) One of these techniques, cine MRI, uses gradient refocused echo to produce high resolution tomographic images of cardiac motion and blood flow. The heart can be displayed at multiple levels simultaneously and the resulting images are displayed in cine loop fashion.1) Regurgitant flow appears as a signal void. On the other hand, color Doppler echocardiography is used clinically to evaluate valve regurgitation. This method is simple and reveals turbulent flow in real time. Color flow Doppler is affected by inadequate acoustic windows in a number of patients and by normal aortic valvular flow, but cine MRI is not affected by those limitations.1) This study assessed the degree of aortic regurgitation...
tion using cine MRI as compared to color flow Doppler.

**Methods**

**Patients**

Thirteen patients aged 27 to 82 years with aortic regurgitation and 3 volunteers aged 26 to 40 years without known valvular heart disease made up the study group. Patients with valvular heart disease were approached for participation in the study based on the results of a recent Doppler echocardiographic examination or angiography. All subjects were clinically stable in regular sinus rhythm and gave informed consent.

**Cine magnetic resonance imaging technique**

MRI was performed in a 1.5 Tesla Signa (General Electric) MRI system. Each study began with ECG-gated multislice coronal spin echo images of the thorax for cardiac localization. The coronal series was used to localize the inferior and superior borders of the heart. This sequence required approximately 2 minutes to complete. The gradient-recalled acquisition in steady-state (GRASS) technique employs low flip angles of 30 degrees and gradient-refocused echoes with an echo time (TE) of 13 msec and a repetition time (TR) of 25 or 33 msec. The acquisition matrix was 128×256 in a field of view of 38 cm interpolated to 256×256 for display. Pulse repetition was independent of the electrocardiographic (ECG) signal. The ECG signal was simultaneously recorded and stored in a microcomputer that controlled advancement of the phase-encoding gradient with the R wave. The number of time frames per cardiac cycle corresponded to the number of 30 degree pulses delivered within one R-R interval. Transverse images were obtained starting below the apex of the heart. Three or four tomographic levels were scanned at the same time, with a slice thickness of 10 mm and an interslice gap of 10 mm to avoid level interaction. In total, 7 tomographic images were required for each patient.

**Doppler techniques**

Echocardiographic and Doppler studies were performed using an EBU 165 (Hitachi Medico). Sixteen subjects were evaluated using standard color flow Doppler mapping of AR. A 2.5 MHz Doppler flow probe was used to perform examinations from apical and parasternal windows in the left decubitus position.

Color flow Doppler mapping of the AR jet was performed in the parasternal short and long axis views as well as in the apical two and four chamber views. Color flow Doppler was used to determine the distance from the aortic valve and the size of the regurgitation jet. Based upon these parameters, all
studies were reviewed by two independent observers and were qualitatively graded into normal, mild, moderate and severe regurgitation. Aortic regurgitation determined by color flow Doppler was graded as mild if diastolic flow was localized at or just below the aortic valve in the left ventricular outflow tract. In moderate aortic regurgitation negative flow could be detected in the left ventricular outflow tract up to the tip of the anterior mitral leaflet. In severe aortic regurgitation, diastolic regurgitant flow was present beyond the tip of the anterior mitral leaflet to the left ventricular apex. All echocardiographic studies were performed within 4 weeks before or after cine MRI studies were performed.

**Evaluation of results-cine magnetic resonance imaging**

Qualitative recognition of AR by cine MRI was arrived at by consensus at a reading session attended by 2 cardiologists. Jets of AR were defined as dynamic zones of signal void in the left ventricle in diastole extending from the plane of the aortic valve. For each study, the cine MRI frame showing the maximal signal void associated with AR was selected. The width of the window was arbitrarily set to 50–75% of the level. The level of the window was set to 1130–1170, and was maintained constant at this setting for analysis in each individual patient. The images on which the signal 1055 showed the largest size were used for measurement of the signal void. The largest area and the longest distance of signal void were manually outlined with a track ball cursor system. The grading of regurgitant jets was based on the echocardiographic grading.

**Doppler echocardiography**

Qualitative recognition of AR by Doppler echocardiography was determined by two cardiologists who did not know the results of the cine MRI. Using color flow Doppler, AR was defined as a negative flow region with or without variance and extending from the aortic valve into the left ventricle during diastole. The distance and the area of regurgitant flow of AR by color flow Doppler was outlined by a track ball cursor system.

**Statistical analysis**

For the purpose of this study, Doppler echocardiography was performed as the reference standard. The AR by cine MRI and color flow Doppler was classified as normal, mild, moderate or severe on single-plane maximal jet distance, and the area was compared to define semiqualitative agreement.

**RESULTS**

Aortic regurgitation was detected in 13 of 16 subjects by cine MRI and also
Fig. 1. Axial diastolic cine magnetic resonance images and color flow Doppler images in a study of aortic regurgitation: A: Mid-diastolic frame with mild aortic regurgitation. B: Mid-diastolic frame with moderate aortic regurgitation. C: Mid-diastolic frame with severe aortic regurgitation.
Fig. 2. Comparison between visual severity derived from cine magnetic resonance imaging and from color flow Doppler.

Table I. Relationship of Signal Characteristics to Severity of AR

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<tr>
<td>Length AR jet (mm)</td>
<td>MRI</td>
<td>16.7±1.23</td>
<td>30.0±6.70</td>
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<tr>
<td></td>
<td>Doppler</td>
<td>18.7±4.10</td>
<td>38.4±13.5</td>
</tr>
<tr>
<td>p value</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Area AR jet (cm²)</td>
<td>MRI</td>
<td>0.40±0.20</td>
<td>2.56±1.01</td>
</tr>
<tr>
<td></td>
<td>Doppler</td>
<td>0.63±0.36</td>
<td>3.11±2.20</td>
</tr>
<tr>
<td>p value</td>
<td>NS</td>
<td>NS</td>
<td>0.05</td>
</tr>
</tbody>
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Mean±1SD.

Fig. 3. Comparison between distance of signal void from aortic valve derived from cine magnetic resonance imaging and color flow Doppler. \( Y = 1.08X + 3.63 \) \( r = 0.82 \) (p<0.01)
in 13 of 16 by color flow Doppler (Fig. 1). Thus all cases of AR detected by cine MRI were also found by color flow Doppler. There was no false negative or positive. Using cine MRI, intracardiac laminar blood flow generates a higher signal than myocardial structures and turbulent flow appears as a signal loss. Severity of AR was graded as mild, moderate, or severe regurgitation. Of the 13 cases of AR detected by cine MRI, three were mild, three were moderate and seven were severe. Of the same 13 cases detected by color flow Doppler, two were mild, five were moderate and six were severe. The grading of AR by cine MRI corresponded to that by color flow Doppler in 14 of 16 (88%) patients. Severity of aortic regurgitation as determined by MRI and color flow Doppler did not differ by more than one grade (Fig. 2).

In cine MRI, the length of the AR jet was 16.7±1.23 mm in mild, 30.0±6.70 mm in moderate, and 58.5±10.5 mm in severe cases. In color flow Doppler, it was 18.7±4.1 mm in mild, 38.4±13.5 mm in moderate, and 68.3±25.2 mm in severe cases. There was no significant difference in the length of the AR jet between cine MRI and color flow Doppler, but the relative length of the regurgitant jet determined using cine MRI tended to be smaller than that by color flow Doppler. The area of the AR jet was 0.40±0.20 cm² in mild, 2.56±1.01 cm² in moderate, and 8.83±3.72 cm² in severe cases using cine MRI. It was 0.63±0.36 cm² in mild, 3.11±2.21 cm² in moderate, and 17.9±7.28 cm² in severe using color flow Doppler (Table I). The area of the AR jet in severe regurgitation showed the only significant difference between cine MRI and color flow Doppler (p<0.05). Figure 3 shows the distance or signal void from the aortic valve by cine MRI and color flow Doppler. The regression equation was \( Y=3.63+1.08X \) (r=0.82). Figure 4 shows the area of signal void from the AR jet.
by cine MRI and color flow Doppler. The relation was $Y=0.11+1.74X$ ($r=0.87$). AR jets determined by cine MRI tended to be smaller than those by color flow Doppler.

**DISCUSSION**

Aortic regurgitation is found in patients with valvular disease, ischemic heart disease, and cardiomyopathy. Aortic regurgitation was formerly estimated semiquantitatively primarily by aortography or Doppler echocardiography. However, aortography requires cardiac catheterization and the use of a contrast agent, and Doppler echocardiography is dependent on the operator and occasionally limited by body habitus. It is possible to constitute images of arbitrary direction in MR imaging. Therefore it is possible to evaluate the regurgitation in cases where it would have been impossible to detect the regurgitation using color flow Doppler because of a narrow echo window or body habitus. Recently cine MRI has been performed to evaluate regurgitation secondary to valvular disease without using contrast agents. In cine MRI views, the cardiac blood pool and blood flow at normal velocities show a high signal intensity and are clearly differentiated from the myocardium, which has a low signal intensity. The turbulent flow appears as signal loss while valvular regurgitation forms a different level of high velocity turbulent flow. Cine MRI is a noninvasive technique and the imaging has the advantage of the regurgitant jet being visible as a discrete area of low signal intensity and the procedure not being operator dependent. In our study, the severity of aortic regurgitation determined by cine MRI imaging correlated with that by color flow Doppler. Overall qualitative correlation between cine MRI and color flow Doppler was good with no evaluations differing by more than 1 grade. The quantitative correlation (distance and area of signal void) was also good. The relation of distance between cine MRI and color flow Doppler was $r=0.82$, while for area it was $r=0.87$. The distance and the area determined by cine MRI tended to be smaller than those by color flow Doppler. This may have been due to slice thickness on cine MRI and may have been dependent on the color flow Doppler technique. Pflugfelder et al evaluated the degree of regurgitation by measurement of regurgitant volume. Nishimura et al measured the length and the area of mitral regurgitation by cine MRI compared with color flow Doppler. In our study, it was also shown that measurement of the length and the area of aortic regurgitation by cine MRI alone correlated well with these by color flow Doppler.

There were several limitations in this study. One was the size of regurgitant flow of AR on color flow Doppler. This has been shown to vary depending on technique factors, including gain adjustment and filter setting. Cine MRI tech-
nical factors also influence the size of the signal void which is dependent on heart rate and number of slices per acquisition. It is difficult to evaluate a case with an irregular heart rate (for example, atrial fibrillation or premature conduction), and it is likely that the target lesion is not contained in the slice. Window and threshold settings of the cine MRI display were set to provide maximum contrast for each image.

In conclusion, cine MRI is a promising tool for the noninvasive clinical study of aortic regurgitation. The distance and area of the signal void on cine MRI were closely correlated with those lesions mapped by color flow Doppler echocardiography.

REFERENCES
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