Assessment of Aortic Regurgitation by the Acceleration Flow Signal Void Proximal to the Leaking Orifice in Cinemagnetic Resonance Imaging

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Background. The proximal acceleration flow region is a laminar flow field that is located immediately upstream from the leaking orifice. The purpose of this study was to evaluate whether cinemagnetic resonance imaging can provide information regarding the proximal acceleration flow region in patients with aortic regurgitation and to analyze the relation between the area of the proximal acceleration flow delineated by cinemagnetic resonance imaging and the severity of aortic regurgitation delineated by angiography.

Methods and Results. Thirty-eight consecutive patients who underwent aortography were examined by cinemagnetic resonance imaging. The region of proximal flow acceleration was identified as a semicircular-shaped signal void in the aorta during diastole. Cinemagnetic resonance imaging detected the proximal acceleration flow region in 26 of the 30 patients who were proved to have this lesion (sensitivity, 87%). In eight patients without aortic regurgitation according to aortography, no proximal acceleration flow region was detected (specificity, 100%). The area of the acceleration flow signal void from the long-axis view was well correlated with angiographic degree of aortic regurgitation.

Conclusions. Cinemagnetic resonance imaging is useful in detecting the proximal acceleration flow region and permits noninvasive assessment of the severity of aortic regurgitation. (Circulation 1991;83:1951–1955)

Recent developments in magnetic resonance imaging technology have made possible the acquisition of more than 30 images during a single cardiac cycle with the spatial and temporal resolution necessary for evaluating cardiac function.1–14 Such an imaging sequence displayed in a closed-loop cinematic format has been called “cinemagnetic resonance imaging” and has been used to quantify cardiac function. With cinemagnetic resonance imaging, the high-velocity jet caused by regurgitation can be readily identified because it produces a signal void in the recipient cardiac chamber. In patients with aortic regurgitation, the regurgitant jet is identified as a signal void extending from the closed aortic valve into the left ventricle during diastole.2,10 On the other hand, the proximal acceleration flow region15 is a laminar flow field that is located immediately upstream from the leaking orifice (Figure 1). With cinemagnetic resonance imaging, however, there are no published studies evaluating aortic regurgitation according to the proximal acceleration flow region. We hypothesized 1) that zones of proximal signal reduction detected by cinemagnetic resonance imaging are related to the proximal zone of flow acceleration and 2) that the maximum volume of the proximal signal void is related to the peak regurgitant flow rate. The purpose of this study was, therefore, to evaluate whether cinemagnetic resonance imaging can provide information on the proximal acceleration flow region in patients with aortic regurgitation and to analyze the relation between the extent of this region delineated by cinemagnetic resonance imaging and the severity of aortic regurgitation delineated by angiography.

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left ventricle equal to or denser than that of the aorta. The mean interval between angiography and cinemagnetic resonance imaging was 2.5 days (range, 1–5 days). The angiograms were interpreted by consensus of two observers who did not know the results of the cinemagnetic resonance imaging.

Cinemagnetic Resonance Imaging

Cinemagnetic resonance imaging was performed in a commercially available 1.5-T superconducting magnet (Siemens, Solna, Sweden). Images were obtained with the technique of fast low-angle shot imaging, which uses a low flip angle of 30° and gradient refocused echoes with an echo time of 12 msec. The slice thickness was 8 mm. The acquisition matrix was 128×256 interpolated to 256×256 for display. Pixel size was 1.25×2.5 mm. An initial multislice electrocardiographic-gated spin-echo sequence acquired in the coronal plane was used to line up the long-axis view of the left ventricle. Imaging plane was designed to go through the middle of the aortic valve and the apex of the left ventricle (Figure 2).

Cineimage Analysis

Images were first displayed on the computer monitor in a cinematic fashion to evaluate cardiac function and changes in blood pool signal intensity during the cardiac cycle. The presence of aortic regurgitation was suggested by the jet area (signal loss) in the left ventricle or by the proximal acceleration flow signal void in the aorta. From the cinematic display of images, the diastolic frame in which the area of acceleration flow signal void in the aorta was most intense and extensive was visually identified. To obtain measurements of the acceleration flow area, individual images were displayed on the computer monitor. We obtained the signal intensity curve by means of a software program already incorporated in the equipment, and then, we determined the acceleration signal loss as the area where the value of the signal intensity is less than 60% of that in the aorta during diastole. The acceleration flow area measured by this method is completely independent of display window and level. All observers were unaware of each other's interpretations and of cardiac catheterization results.

To evaluate interobserver variability, measurements of the acceleration flow signal void were obtained in 20 randomly selected patients by two independent observers who had no knowledge of angiographic data. The average intraobserver variability for the quantitative estimation of acceleration flow area was 3.8% of the mean value, and the average interobserver variability was 4.6% of the mean.

Statistical Analysis

In the statistical analysis of the results, differences among groups for the studied variables were evaluated by analysis of variance and Scheffe's method for multiple comparisons. A value of \( p < 0.05 \) was considered significant.
Results

The region of proximal flow acceleration (Figure 3) was identified in the aorta as a semicircular-shaped signal void in diastole. There was a clear constricted site between the proximal acceleration flow signal void and the distal jet flow signal void. Cinemagnetic resonance imaging detected the proximal acceleration flow region in 26 of the 30 patients with aortic regurgitation according to angiography (sensitivity, 87%). All four patients without acceleration flow signal void according to cinemagnetic resonance imaging had mild aortic regurgitation according to angiography. All eight patients without aortic regurgitation according to angiography had no acceleration flow signal void according to cinemagnetic resonance imaging (specificity, 100%). The area of the acceleration flow signal void was well correlated with angiographic grading (Figure 4). Individual values of the acceleration flow area for 10 patients with mild aortic regurgitation according to angiography ranged from 0 to 0.20 cm² (mean, 0.09±0.09 cm²). Individual values of the acceleration flow area for 10 patients with moderate aortic regurgitation according to angiography ranged from 0.18 to 0.70 cm² (mean, 0.38±0.15 cm²), whereas acceleration flow area for 10 patients with severe aortic regurgitation ranged from 0.48 to 1.40 cm² (mean, 0.89±0.35 cm²). There were significant differences in the acceleration flow area between mild and moderate (p<0.01), mild and severe (p<0.01), and moderate and severe aortic regurgitation (p<0.01).

Discussion

This study shows that cinemagnetic resonance imaging is useful in detecting the region of proximal flow acceleration in patients with aortic regurgitation and that the area of acceleration flow signals can predict the severity of aortic regurgitation. The proximal acceleration flow region was demonstrated as a signal void within the aorta by cinemagnetic resonance imaging, and the regions were detected in 87% of the patients with aortic regurgitation. Although some cases might have had false-negative results, identifying such cases did not seem to be clinically important because in those cases in which false-negative results were identified, regurgitation was trivial or mild on the angiogram.

During the last several years, cinemagnetic resonance imaging has provided optimal imaging quality for the comprehensive anatomic and functional assessment of the heart.1-14 Using cinemagnetic resonance imaging, Aurigemma et al10 reported that the ratio of the maximal low-signal jet area to the left ventricular area correlated well with the severity of aortic regurgitation estimated by Doppler echocardiography. However, their approach introduces an additional variable to jet area in the assessment of regurgitation (that is, the size of the left ventricle).
To our knowledge, studies evaluating the severity of aortic regurgitation by the acceleration flow signal void in cinemagnetic resonance imaging have not been published. In the present study, we chose to evaluate the simple measurement of the area of the acceleration flow signal void obtained from the long-axis view. This measurement proved to be accurate in delineating mild, moderate, and severe grades of aortic regurgitation.

The proximal acceleration flow region is a symmetrical, laminar flow field located within the high-pressure chamber, immediately upstream from the regurgitant orifice. Using color Doppler flow imaging, Bargiggia et al. reported that the regurgitant flow rate can be calculated in vitro by measuring the area of acceleration flow signals (flow convergence region). Utsunomiya et al. also reported the same results. We also reported that the proximal acceleration flow region detected by color Doppler flow imaging is useful in evaluating the severity of mitral regurgitation and the site of mitral valve prolapse. However, the relation between the area of the proximal signal void detected by cinemagnetic resonance imaging and the proximal isovelocity surface area detected by Doppler remains unclear. Further investigation with a phantom is necessary to determine whether the boundary of the proximal flow void represents an isovelocity surface contour.

One of the disadvantages of cinemagnetic resonance imaging in the quantitative analysis of the jet area in the left ventricle is the direction of the jet itself. Eccentric jets such as seen in patients with aortic valve prolapse can lead to underestimation of the severity of regurgitation as a result of the regurgitant jet impinging with the left ventricular walls. Furthermore, it is often difficult to evaluate aortic regurgitation in patients with mitral stenosis by measuring the jet area in the left ventricle because inflow jets from stenotic mitral valves themselves form the low-intensity signals in diastole. On the other hand, the proximal acceleration flow region seems to be completely independent of the inflow jets from the stenotic mitral valve and the aortic regurgitant jet direction, even in the presence of a highly eccentric jet.

In the present study, the proximal acceleration flow region was represented as a signal loss in the aorta. The causes of decreased signals in this area are not fully understood. However, the decrease may be related to both turbulence and the high velocity of acceleration flow. Turbulence will produce a rapidly varying phase of the signal from the jet, which will result in a decrease in the net image intensity. In addition, the velocity shear between the jet and the slower blood adjacent to the wall will produce a corresponding shear of phase, which will again result in decreased image intensity. Velocity effects alone do not

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**Figure 3.** Cinemagnetic resonance image (long-axis view) from a patient with aortic regurgitation. In diastole, the acceleration flow signal void (arrows) was demonstrated as a signal loss in the aorta. Fan-shaped regurgitant jet area of signal loss in the left ventricle is also demonstrated. AO, aorta; LV, left ventricle; LA, left atrium.

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**Figure 4.** Plot of proximal acceleration flow area obtained from the long-axis view of cinemagnetic resonance imaging compared with the severity of aortic regurgitation from aortography.
appear to be responsible because signal loss can be seen when blood flow is both parallel to and perpendicular to the imaging plane. These two effects might be difficult to separate because turbulence arises when the blood flow velocity is high, especially in the presence of an irregularity or narrowing formed by the surface over which the blood flows. Further investigation of these signal characteristics needs to be undertaken in flow models to fully understand and, therefore, maximize the potential usefulness of these phenomena for cardiovascular diagnosis.

Limitations of the Study

Our present study has some important limitations. Although we have compared the area of the acceleration flow signal void in cinemagnetic resonance imaging with angiographic gradings, it must be recognized that angiography itself has significant limitations that include variability of the position of the catheter within the aorta, volume and rate of injection of contrast medium, left ventricular volume in which the regurgitant contrast medium is diluted, and the volume of forward flow that partly determines the clearance of contrast medium. Croft et al. demonstrated that a significant overlap exists when the angiographic grading of aortic regurgitation is compared with catheterization-derived indexes of regurgitant volume. Some of the discrepancies noted between cinemagnetic resonance imaging and angiographic grading of the severity of aortic regurgitation may be caused by the different loading conditions present at the time of cardiac catheterization in the patient who has been premedicated or sedated.

Although we evaluated the acceleration flow signal void in the long-axis view, it might not be always perpendicular to the aortic regurgitant orifice. The alignment of the imaging plane is very important for detecting the proximal acceleration flow region with cinemagnetic resonance imaging because the acceleration flow signal void is localized just above the coapted aortic valve in the aorta during diastole. Because the area of the acceleration flow signal void is relatively small, there are potential difficulties in measuring the proximal acceleration flow region. In addition, a variety of technical factors inherent in the performance of cinemagnetic resonance imaging are capable of influencing the size of the acceleration flow signal void, including echo time, pulse sequence, and flip angle.

Last, although our data show that the area of acceleration flow signal void detected by cinemagnetic resonance is useful for estimating the severity of aortic regurgitation, examination time of cinemagnetic resonance imaging is fairly long. Development of a high-speed magnetic resonance imaging system may be required to further improve the capability of the cinemagnetic resonance imaging in patients with heart disease.

References


KEY WORDS • cinemagnetic resonance imaging • aortic regurgitation • acceleration flow signal void
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