Using Velocity-Encoded MRI and The Velocity-Time Integral Approach To Analyze the Aortic Valve in Patients with Aortic Stenosis: A Reproducibility Study

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Abstract

The purpose of this study is to define the reliability and repeatability of MRI as a routine method for quantifying the functional area of stenotic aortic valves. Using velocity-encoded MRI, flow proximal and distal to the aortic valve was measured in 20 patients. The flow data was analyzed using the velocity-time integral approach. Five of the patients underwent 2 identical MR examinations. The data from the separate exams were compared for repeatability. The results agreed well with the gold standard of Doppler Ultrasound ($r=0.84$, $p<0.001$), and intrasubject repeatability of valve dimension was also good ($r=0.95$, $p<0.02$).

Introduction

Using Doppler ultrasound, heart valves can be easily and accurately analyzed. While quantifying flow with MRI using velocity-encoding techniques is becoming more widely accepted, the *in vivo* validation of MRI in quantifying flow through the valves has scant support in the literature and is plagued with difficulty due to through-plane movement of the valve plane. With ultrasound, the velocity-time integrals (VTI) are measured before and after the valve; and, with a measure of left ventricular outflow tract (LVOT) diameter, the aperture of the aortic valve can be calculated. Similar applications of the continuity equation based on the conservation of mass can be used in a VTI method for MRI. We propose to employ these methods using velocity-encoded MRI to examine the accuracy and repeatability of such measurements.

Purpose

The purpose of this study is to define the reliability and repeatability of velocity-encoded MRI as a routine method for quantifying the functional area of stenotic aortic valves in patients. To do so, this method is compared with the accepted standard of Doppler ultrasound for characterization of valvular dysfunction. Duplicate acquisitions of velocity-encoded MRI data are acquired and evaluated for consistency of results. Specific comparisons include the VTI's acquired proximal and distal to valves (using both Doppler ultrasound and MRI), which are used for calculation of absolute valve dimension by the continuity equation, and pressure gradients across the aortic valve.

Methods

Twenty patients with aortic valve disease were imaged using a 1.5T whole body MRI (Philips Medical Systems, Best, Netherlands). In addition to standard cine views for qualitative assessment of function, multiple free-breathing velocity-encoded cine MR images were acquired with a retrospective cardiac gating technique (TE/TR/α = 2.9/6/30, FOV = 350mm, Matrix = 128x256, thk = 9mm, 30 frames/ heartbeat). The maximum encoding velocity parameter was chosen such that no flow aliasing occurred in the systolic flow jet (typically about 4m/s in the aorta, 3m/s in the LVOT). Two imaging planes parallel to the aortic valve plane were interrogated – one placed in the ascending aorta 1.5cm distal to the aortic valve plane, and one in the LVOT at 1.5cm proximal to the valve plane. Quantitative flow data was analyzed on an offline workstation (EasyVision R5.1, Philips Medical Systems). To calculate VTI, the area under the curve of the peak flow velocity versus time was summed over systole. VTI was calculated at each level and statistically compared to the respective Doppler ultrasound measurements of aortic VTI and LVOT VTI. As in Doppler ultrasound, functional aortic valve dimension was calculated (using the continuity equation) by the ratio of VTIs times LVOT area. Using the modified Bernoulli equation (4 times velocity squared), peak and mean gradients were also calculated and compared by the two methods. For testing repeatability of the MRI acquisition, five patients were removed from the scanner after completion of the first MR exam, and, within 10 minutes, returned to the MR scanner for a duplicate session. Using the Pearson correlation test, similarity of ultrasound and MRI values, as well as repeated MR values, were tested for each of these parameters.

Results

The VTI measurements between velocity-encoded MRI and Doppler ultrasound correlated well. Correlation coefficients between ultrasound and MRI measurements of VTI were $r=0.89$ for aorta and $r=0.86$ for LVOT ($p<0.001$) (see fig. 1). Similarly, using the ratio of these values to calculate valve size gave a correlation coefficient between methods of $r=0.84$ ($p<0.001$). Using this VTI method, the average valve size for these 20 patients was 1.04 ± 0.30 cm² for ultrasound and 0.95 ± 0.36 cm² for MRI. Calculations of the pressure gradients, both mean and peak, also correlated well ($r=0.88$ and 0.92, respectively). The average peak pressure gradient for these patients was 29.1 ± 16.6 mmHg measured with MRI compared with 40.8 ± 23.8 mmHg for ultrasound.

Comparing measurements between repeated MRI acquisitions, the results were similar (see fig. 2). For aortic valve size, the repeated MRI measures had a correlation coefficient of $r=0.95$ ($p<0.02$). Correlation coefficients between measurements for VTI were $r=0.97$ for aorta ($p<0.01$) and $r=0.89$ for LVOT ($p<0.05$). Pressure gradient measures were also reliably repeated, with $r=0.95$ and $r=0.96$ ($p<0.02$) for peak and mean gradients, respectively.

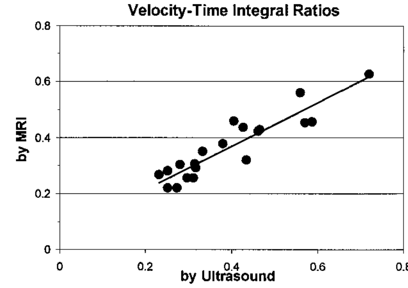

Figure 1. The Velocity-Time Integral ratios (unitless) are used to calculate functional valve dimensions. The measurements agree well between velocity-encoded MRI and Ultrasound methods.

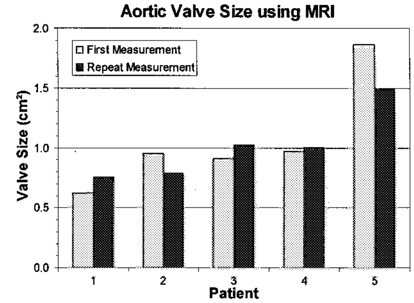

Figure 2. Measurements of Aortic Valve size can be reproduced reliably between MR scanning sessions.

Conclusion

Velocity-encoded MRI can be used as a reliable tool to evaluate flow through stenotic aortic valves. The measurements of pressure gradients, VTI, and the valve diameter as calculated by the VTI continuity equation method all correlate well with the accepted standard of Doppler ultrasound and can be reliably repeated.

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