Diagnostic Value of Cardiac MRI in Aortic Valve Stenosis in Comparison with Echocardiography

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Abstract

Background: Aortic stenosis is a common problem. The principle cause of aortic stenosis is the age-related progressive calcification of the tri-leaflet valve. During the course of aortic stenosis, the pressure gradient increases and the orifice area decreases. Transthoracic Echocardiography (TTE) is the method of choice to determine the severity of aortic stenosis, however, the ultrasound has its limitations. Trans-Esophageal Echo (TEE) is not tolerated by many patients and direct planimetry is difficult in patients with heavy calcifications.

Methods: 59 patients of all age groups with aortic stenosis were examined using two dimensional echocardiography and non-contrast cardiac MRI (CMR) for assessment of the aortic valve area and aortic pressure gradient. Statistical analysis was conducted using the mean, standard deviation, student t-test and Linear Correlation tests.

Results: Good correlation was obtained between the CMR and echocardiography regarding the mean velocity, mean pressure gradient across the valve, the aortic valve area and regarding the left ventricular function and morphology.

Conclusion: CMR has shown its value as a diagnostic tool for determining the severity of an aortic valve stenosis. Ultrasound remains the method of choice, but in difficult to image patients and in non-conclusive sonographic findings, CMR could be a substitute for invasive catheter.

Key Words: Aortic stenosis – Cardiac MRI – Echocardiography.

Introduction

The aortic valve typically consists of three leaflets, it mediates blood flow from the left ventricle to the aorta during ventricular systole. Aortic stenosis is a common problem; approximately 2% of people over the age of 65, 3% of people over the age of 75, and 4% of people over the age of 85 years suffering the disorder. Younger age groups affection occurs in patients with bicuspid aortic valve, in diabetic patients and in patients with rheumatic heart disease [1].

The principle causes of aortic stenosis include age-related progressive calcification of the tri-leaflet valve, being responsible for more than 50% of cases, calcification of a bicuspid aortic valve (30-40% of cases) and the rheumatic fever which is prevalent in developing countries [2].

During the course of aortic valve stenosis, the pressure gradient increases and the orifice area decreases. For an aortic valve orifice area of 0.6 to 1.0cm² and/or a pressure gradient over 40mmHg, the aortic valve might need to be replaced if the patient is symptomatic i.e. showing manifestations of left ventricular dysfunction [3].

Accurate assessment of the orifice area and/or the pressure gradient is an important factor for determining whether surgery is necessary or not. Transthoracic Echocardiography (TTE) is the method of choice to determine the severity of aortic valve stenosis. By using Doppler ultrasound, the maximum velocity over the valve is measured and used to calculate the peak pressure gradient. However, ultrasound examination has its limitations, e.g. noise can obscure the measurement in obese or emphysematous patients or if the orientation of the heart and valve make accurate ultrasound imaging impossible. Also, in some cases of severe stenosis, the pressure gradient measured by Doppler ultrasound overestimates the actual pressure gradient. Furthermore, direct measurement of the orifice dimension is not accurate and reproducible in cases of severe stenosis [9].

Trans-Esophageal Echo (TEE) is not tolerated by many patients and direct planimetry is impos-
sible in patients presenting with heavy calcification or a poor acoustic window. Calculations from cardiac catheterization may be unreliable in the presence of altered cardiac function or concomitant aortic regurgitation. The cardiac catheterization, being an invasive technique, may also be associated with complications [4].

Cardiac Magnetic Resonance (CMR) can be used as a useful non-invasive alternative imaging modality for evaluation of aortic valve stenosis. In many clinical situations, MRI techniques can be performed rapidly and reproducibly for measuring aortic valve dimensions and provides accurate estimates of trans-valvular pressure gradient [5].

In this study; we aimed to assess the degree of aortic stenosis (planimetry of aortic valve area and trans-valvular pressure gradient assessment) by cardiac magnetic resonance and to determine the correlation between the transthoracic 2-dimensional (2D) echocardiography and the CMR in assessment of the degree of aortic stenosis.

**Patients and Methods**

59 patients of all age groups in whom a diagnosis of aortic stenosis had been established were examined using two dimensional echocardiography and non-contrast cardiovascular magnetic resonance after obtaining required consents over a period starting April 2010 till May 2013 in Cairo University Hospitals. The study population included 44 males and 15 females. The patient’s age ranged between 16 and 84 years with mean age of 67.82 years. The following subjects were excluded from the study; uncooperative patients, patients with pacemakers, impaired left ventricular function (ejection fraction less than 50%), arrhythmia, and the claustrophobic patients. The present study complied with the Declaration of Helsinki and was approved by the ethics committee of Kasr Al-Aini University Hospital, Cairo University. Each patient gave a written consent before enrollment in the study.

**Patient preparation and set up:**

No special instructions are required prior to the examinations. Medications are not to be discontinued.

A short medical history was taken and the patients were screened for contraindications to MR imaging.

Before the examinations; the heart rate and rhythm were evaluated. All steps of the study were explained in details for each patient. To evaluate patients ability of breath-withholding for relatively long time; they were required to perform a deep inspiration and to continue to hold their breath without pushing.

**Echo:**

2D transthoracic echocardiography using standard M-mode and cross-sectional echocardiographic views [short-axis, four-chamber, two-chamber and Left Ventricular Outflow Tract (LVOT) views] was performed to all patients. The following were assessed; the maximum septal wall thickness, the pressure gradient across aortic valve and the aortic valve planimetry.

**MRI:**

Magnetic resonance imaging studies were performed using 1.5 Tesla Philips, Achiva, systems (Netherland) by using a phased-array cardiac coil.

**Patient position:**

Patients were examined in the supine position, head first. The patient's knees and legs can be elevated to help relieve back strain and secure the patient's comfort.

Head phones supplied with the MRI machine are used to reduce repetitive gradient noise and in the same time allow the patient to hear the breath hold instructions.

**ECG lead positioning:**

Four ECG pads were placed on the anterior chest wall. The QRS complex was then checked on the MRI monitor, adjustments of the site of the leads is done accordingly. The patient's heart rate is also detected on MRI monitor, it is used to determine the cardiac frequency as it should be close to the patient's heart rate.

**The coil:**

The SENSE (sensitivity encoding) cardiac coil (6 element phased-array coil, receive only) was used. It has a rigid lower part and flexible upper part. The lower part contains two phased-array coil elements and the upper part contains four phased array elements.

**The respiratory sensor:**

The respiratory sensor is placed over the maximum area of respiratory movement (abdomen or thorax) under the coil. The respiratory signal is then checked as the respiratory wave appears on the monitor and used to detect the patient’s respiratory rhythm and synchronize breath hold instructions to the patient abilities.
Cardiac MR examination:
Imaging protocol:
I- Scout images were acquired in orthogonal orientations for planning of the final long-axis and short-axis views.

II- Functional cine images: were acquired using ECG gated, breath hold balanced turbo field echo (b-TFE) sequences in short axis view, two and four chamber views. Slices were obtained during repeated breath-holds 1cm apart with the following parameters:

- TR/TE: 4.4/2.5 s
- FOV: 300 mm
- Phases: 25
- NSA: 1
- Matrix: 128 x 128
- Bandwidth: 125kHz
- Flip angle: 15°
- Scan time: 0.07-0.12 sec.
- Slice thickness: 8mm
- Slice number: 8-11

III- Trans-aortic flow assessment (Q-flow):
Trans-Aortic Flow assessment (TAF) was determined from through-plane phase-contrast images obtained with retrospective or prospective ECG synchronization, breath holding was employed, and velocity of 130 cm/sec was used to avoid temporal aliasing.

To define the acquisition plane, the two-and-four-chamber views were used during systole. The section was positioned 1cm above the opened aortic valve Fig. (1).

IV- Aortic valve planimetry:
For planimetry of the Aortic Valve Area (AVA); an oblique transverse plane of the left ventricular outflow tract or an oblique coronal plane, acquired orthogonally to the outflow tract of the transverse view, were obtained. View for planimetry perpendicular to the aortic annulus in both series starting at the tips of the leaflets is acquired. To avoid overestimating the AVA, slices beyond or above the leaflet tips were avoided. Manual planimetry of the maximum visible AVA in systole was obtained.

Image analysis:
The acquired images were transferred to an offline workstation equipped with a dedicated cardiac software package for further analysis.

The following parameters were used:
- Slice thickness 7mm
- FOV: 38
- Matrix 256 X 192
- Repetition time 7.0ms.
- Echo time 3.2ms.
- Flip angle 20°.

I- Global LV function:
Global functional parameters were derived from cine MRI, with the aid of commercially available software. The endocardial borders of both ventricles were traced manually from the short axis images during systole and diastole. LV End-Diastolic Volume (EDV) and End-Systolic Volume (ESV) were calculated on the basis of Simpson's rule. Subsequently, Stroke Volume (SV) and Ejection Fraction (EF) was calculated.

II- Flow measurements:
Phase contrast velocity encoded mapping (PC-VENC); this method is based on the principle of phase shift, and so it is also called phase-contrast imaging. It is used to measure flow and velocity in any blood vessel; through plane Fig. (4) where the cross sectional area of the vessel perpendicular to flow is used, or in plane Fig. (5) where the parallel to flow in the blood vessel can be used.
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Fig. (2): Approach for slice positioning to perform planimetry of the aortic orifice by CMR. (A) Left Ventricular Outflow Tract (LVOT) view shows positioning of the next plane centrally through the trans aortic valve level. (B) Long-axis view of the LVOT and the proximal aorta also shows positioning of the next plane centrally through the trans-prosthetic jet. (C) Adjusted LVOT view shows positioning of slices perpendicular to the jet from inferior to the valve to the sino-tubular level. Selection of the optimally positioned slice is shown with cusp closure in diastole (D) and flow within the proximal ascending aorta in systole (E), using cross references. (F) Manual contouring of the largest systolic orifice area [7].

Fig. (3): End systolic phase contour tracing for the right and left ventricles [5].

Fig. (4): PC-VENC through plan of the aortic artery for flow Measurements [6].
III- Planimetry of the aortic valve:

The aortic valve area is measured manually at the end of the systolic phase.

Statistics:

Statistical analysis of the present study was conducted, using the mean, standard deviation, student t-test and Linear Correlation tests by SPSS V 17.

Results

The study group consisted of 59 patients, in two patients; no echo could be performed/evaluated: In one due to noise in the ultrasound signal, making the measurement of the orifice inaccurate. Other one was obese and was difficult to have good acoustic window. Both MR and ultrasound flow measurements were available for the rest of the patients.

Patients exhibited a wide range in severity of aortic stenosis, with the aperture dimensions ranging from 0.5 to 2cm², as measured by ultrasound. All patients were in sinus rhythm.

The mean velocity and mean pressure gradients obtained by MRI and by TTE are presented in (Table 1).

Very good correlation was obtained between the two modalities with $p=0.143$ and $p=0.493$, respectively.

The orifice area determined using planimetry in the MR images correlated well with the orifice area calculated using the continuity equation from the ultrasound examination, $p=0.922$ (Table 1).

### Table (1): Flow variables and aortic valve area mean between ECHO and MRI.

<table>
<thead>
<tr>
<th>Variables</th>
<th>ECHO</th>
<th>CMR</th>
<th>$p$</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>M Vel. (ml/sec)</td>
<td>1.949</td>
<td>2.195</td>
<td>0.143</td>
<td>NS</td>
</tr>
<tr>
<td>MPG (mmHg)</td>
<td>23.09</td>
<td>21.28</td>
<td>0.493</td>
<td>NS</td>
</tr>
<tr>
<td>AVA (cm²)</td>
<td>1.361</td>
<td>1.370</td>
<td>0.922</td>
<td>NS</td>
</tr>
</tbody>
</table>

CMR : Cardiac Magnetic Resonance.
ECHO : Echocardiogram.
M vel : Mean velocity.
MPG : Mean Pressure Gradient.
AVA : Aortic Valve Area.
NS : Non Significant.

The orifice determined by MR was consistently slightly larger than the area derived from the ultrasound measurements Fig. (6).
Regarding the left ventricular function and morphology; the comparison of variables between the two modalities; the CMR and ECHO, is shown in (Table 2).

No statistically significant difference observed in the calculation of end diastolic volume, end systolic volume, ejection fraction or septal wall thickness variables between CMRI and ECHO.

Table (2): Correlation between left ventricle functional and morphological variable means between MRI and ECHO.

<table>
<thead>
<tr>
<th>Variables</th>
<th>ECHO</th>
<th>CMR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDV</td>
<td>179.14</td>
<td>185.89</td>
<td>0.665</td>
</tr>
<tr>
<td>ESV</td>
<td>75.60</td>
<td>78.23</td>
<td>0.842</td>
</tr>
<tr>
<td>EF</td>
<td>62.18</td>
<td>61.77</td>
<td>0.890</td>
</tr>
<tr>
<td>Spetal thickness</td>
<td>13.32</td>
<td>13.61</td>
<td>0.567</td>
</tr>
</tbody>
</table>

CRI : Cardiac Magnetic Resonance.
ECHO : Echocardiogram.
AoS : Aortic Stenosis.
EF : Ejection Fraction.
EDV : End Diastolic Volume.
ESV : End Systolic Volume.

Discussion

We have shown that MRI can be used to investigate the severity of an aortic valve stenosis by determining the orifice planimetricaly and the velocity in nearby the valve. A good correlation is observed in the velocity and orifice between the MR and the ultrasound examination. However, several factors influence both the MR measurements and the ultrasound measurements.

I- Flow measurements:

The mean velocity and pressure gradient determined by MRI, is comparable with the values measured by Doppler ultrasound (significant correlation).

For high velocities, the value determined by MR seems to overestimate the velocity compared with the ultrasound measurement. This is in contrast to the study by Sondergaard et al., who observed that MR underestimates the velocity due to the averaging in a voxel and due to the limited time resolution [9].

Our overestimation might be due to the signal void that influences the phase (and thus determined velocity) in the voxel. The signal void can be reduced by choosing different scanning parameters. However, on our MR system further optimisation was not possible.

II- Orifice measurements:

Using MRI, the orifice is determined planimetricaly in the anatomic images, whereas with transthoracic ultrasound a physiological approach is used.

The orifice determined using MR is slightly larger than the orifice calculated from the ultrasound measurements.

A small overestimation in the orifice was also observed by Kupfahl et al., 2004 [2]. However, in our study the agreement between transthoracic ultrasound and MRI was much better. One explanation could be that an overestimation occurs since the valve moves (even up to 8mm) with respect to the selected slice [10].

Although the planning of the imaging sequence has been optimised for measuring the orifice during systole, partial volume effects and the manual ROI determination influence the accuracy of the measurement and can result in overestimation of the orifice.

In particular in patients with a severe stenosis, the partial volume effect contributes significantly. Automatic orifice detection would solve the interobserver variability [11].

On the other hand, the orifice calculated from the ultrasound measurements is also prone to inaccuracies, since the orifice is derived indirectly. Omran H et al., 2003, showed that by using the continuity equation and assuming that the LVOT is circular, the orifice is significantly underestimated.

III- MR in clinical practice:

Doppler ultrasound remains the method of choice because it is fast and patient-friendly. However, for patients in whom ultrasound does not give unambiguous results, catheterisation is used. Replacing catheterization by trans-esophageal echocardiography is not an option, since this technique has been reported to be unreliable, in particular in patients with heavy calcifications. Furthermore, trans-esophageal echocardiography is considered to be unsuitable for Doppler measurements in the aortic valve since the flow direction is perpendicular to the transducer. Besides, it is a semi-invasive application and is not comfortable for the patient [11].

In our opinion, catheterization could be replaced by a noninvasive MR scan, since the velocity determined by MRI can be compared with the velocity determined by Doppler ultrasound. MRI
gives direct information about the orifice of the aortic valve, its geometry and its motion. MRI is well reproducible and can give additional information, such as wall motion, wall thickness, and cardiac output.

Finally, with MR, no patients with a calcified valve will be at risk for brain injury as is the case with catheterization [12].

However, MR cannot be used in patients with pacemakers and arrhythmias, because of a malfunctioning triggering method.

In addition, the duration of the MRI acquisition is long, although the complete acquisition time can be shorter than one hour by reducing the number of scans perpendicular to the outflow trajectory.

Further scan time reduction can be obtained by using high-field MRI systems (less averaging), parallel imaging and stronger gradients.

Pros and Cons of MRI and ECHO:

The scenarios of valvular heart diseases in general need frequent and regular follow-up. Providing non-invasive, accurate techniques with no exposure to radiations or contrast materials is essential.

Of the numerous advantages of MRI are its accurate functional and descriptive anatomical morphology in the form of accurate ventricular volumetric and functional results, measuring valvular flow parameters, providing 3D anatomical information by overcoming abnormal and difficult anatomical geometry and assessing myocardial and wall motions. Cardiac MR imaging (CMR) also does not expose the patient to ionizing radiation and is therefore ideal for serial post-surgical follow-up [12].

The limitations of MRI include long scan durations which were recently overcome by understanding the hemodynamic changes and the clinical request in order to hit the targeted sequences and not waste time with a large number of useless acquisitions [12].

One of the limitations is also the fact that the patient has to remain motionless during the whole examination, so anesthesia might be required for pediatric patients. For older patients, usually no sedation required and patients are cooperative.

The cost of MRI is an important obstacle. However, with recent advances in MRI sequences and contrast material is being less used, which helped greatly in decreasing the costs of MRI [3].

In the presence of a strong magnetic field, the ECG trace distorted. In the presence of these artifacts, four-lead vector ECG provides a more reliable detection of the R-wave and thus better cardiac synchronization than the three-lead (scalar) ECG.

On the other hand, echo has many advantages including low cost, availability and speed. It is validated as a method of hemodynamic assessment in valvular heart diseases, but shows some difficulties, especially in case of poor acoustic windows or valve calcification. It is also worth mentioning that echo is an operator dependent method, especially in the field of valvular heart disease in which high caliber physicians are required [3].

Limitations:

One of the limitations of our study is the relatively small number of patients included. Another limitation is that the value of MRI as a replacement of cardiac catheterization in patients where the ultrasound examination is not conclusive could not be shown, since we compared ultrasound results with MRI to evaluate the latter with the gold standard.

Conclusion:

In conclusion, MRI has shown its value as an extra diagnostic tool for determining the severity of an aortic valve stenosis. Ultrasound remains the method of choice, but when ultrasound does not give reliable results, MRI can be used as a substitute for catheterization.

References

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