Is cardiac magnetic resonance imaging as accurate as echocardiography in the assessment of aortic valve stenosis?

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Received 20 January 2015; received in revised form 26 October 2015; accepted 12 November 2015

Summary
A best evidence topic was written according to a structured protocol. The question addressed was: is cardiac magnetic resonance (CMR) imaging as accurate as echocardiography in the assessment of aortic valve stenosis? Altogether 239 papers were found using the reported search. Only 12 demonstrated the best evidence to answer the clinical question. Nine of these 12 papers found CMR to correlate well with transthoracic echocardiography (TTE) or transoesophageal echocardiography (TOE) in the evaluation of aortic valve stenosis. When aortic valve areas were measured with cardiac tomography (CT) or cardiac catheterization (CC), four papers found CMR to be more accurate than TTE. Eight of 12 papers found CMR to have excellent reliability and reproducibility, as demonstrated by the low inter- and intraobserver variability. Four papers did not estimate intra- or interobserver variability. One paper noted a sensitivity and specificity of 96 and 100%, respectively, when using CMR to detect severe aortic stenosis (AS) that had been diagnosed during CC. A second paper noted a lower sensitivity and specificity of 78 and 89%, respectively, but this was still better than the sensitivities and specificities found when using TOE or TTE to detect severe AS, as noted on CC. We conclude that current evidence finds echocardiography and CMR to be equally reliable in assessing aortic stenosis. CMR has better inter- and intraobserver reliability and demonstrates an advantage over echocardiography in the detection of severe AS with greater specificity and sensitivity. The final choice, however, is as likely to be influenced by the availability of magnetic resonance imaging and expertise in interpreting the results as by accuracy and reliability.

Keywords: Aortic stenosis • Aortic valve • Valvular disease • Cardiac magnetic resonance imaging • Transthoracic echocardiography • Transoesophageal echocardiography

INTRODUCTION
A best evidence topic was constructed according to a structured protocol. This is fully described in the ICVTS[1].

THREE-PART QUESTION
In [patients with aortic stenosis] is [cardiac magnetic resonance imaging] as accurate as [echocardiography] in the assessment of [valve area and valve gradients]?

CLINICAL SCENARIO
You are asked to evaluate a 72-year old man with an incidental diagnosis of aortic stenosis (AS) on routine transthoracic echocardiography (TTE) following NSTEMI. He has coronary artery disease suitable for surgical revascularization. You need to decide whether to perform concomitant aortic valve replacement but TTE measurements are equivocal. You wonder whether cardiac magnetic resonance (CMR) would be a helpful and reliable investigation to guide your decision. You search the literature to inform your opinion.

SEARCH STRATEGY
Medline 1980 to October 2015 using OVID interface [aortic stenosis, mp. or Aortic Valve Stenosis/] AND [magnetic resonance imaging, mp. or Magnetic Resonance Imaging/] AND [Echocardiography, Three-Dimensional/or Echocardiography, Doppler, Pulsed/or Echocardiography, Transesophageal/or Echocardiography, Doppler, Color/or echocardiography,mp. or Echocardiography, Four-Dimensional/or Echocardiography, Doppler/or Echocardiography/or Echocardiography, Stress/]

SEARCH OUTCOME
Two hundred and thirty-nine papers were found using the reported search. Of these, 12 represented the best evidence to answer the clinical question. These are presented in Table 1.
### Table 1: Best evidence papers

<table>
<thead>
<tr>
<th>Author, date, journal and country</th>
<th>Study type</th>
<th>Patient group</th>
<th>Outcomes measured</th>
<th>Key results</th>
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</tr>
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<tbody>
<tr>
<td>Caruthers et al. (2003), Circulation, USA [2]</td>
<td>Prospective observational (level 3)</td>
<td>$n = 24$</td>
<td>Disease process Mild–severe aortic stenosis (0.5–1.8 cm$^2$) Procedure Nil</td>
<td>Modalities: Velocity-encoded CMR and TTE Measurements: Aortic and LVOT velocities and pressure gradients</td>
<td>Concordance between CMR and TTE for: Peak pressures Level ++ ($r = 0.82$) Mean pressures Level + ($r = 0.83$) Valve area ($r = 0.83$, $P &lt; 0.001$)*</td>
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<tr>
<td>Kupfahl et al. (2004), Heart, Germany [3]</td>
<td>Prospective observational (level 3)</td>
<td>$n = 44$</td>
<td>Disease process Severe symptomatic AS Procedure Patients referred for treatment decision-making regarding AV replacement</td>
<td>Modalities: CMR, TTE, TOE and CC Measurements: AVA</td>
<td>Mean difference of AVA and limits of agreement: CMR vs TTE: 0.05 ($−0.35, 0.44$) cm$^2$ ($n = 37$) CMR vs TOE: 0.02 ($−0.39, 0.42$) cm$^2$ ($n = 32$) CMR vs CC: 0.09 ($−0.30, 0.47$) cm$^2$ ($n = 36$) Sensitivity and specificity for detection of AVA &lt; 0.80 cm$^2$ (measured by CC): CMR 78 and 89% TOE 70 and 70% TTE 74 and 67% Feasibility of techniques (based on excluded patients): CMR 91% CC 89% TOE 80% TTE 83% Bias for intra- and interobserver variability of CMR ($−0.016$ and $0.019$, respectively, $n = 20$)</td>
</tr>
<tr>
<td>Debl et al. (2004), Invest Radiol, Germany [4]</td>
<td>Prospective observational (level 3)</td>
<td>$n = 33$</td>
<td>Disease process Known or suspected AS Procedure Nil</td>
<td>Modalities: CMR, CC, TOE Measurements: AVA</td>
<td>Mean AVA for: CMR 0.94 ± 0.29 cm$^2$ TOE 0.85 ± 0.31 cm$^2$ CC 0.74 ± 0.24 cm$^2$ Mean absolute difference between: CMR and CC ($0.20 ± 0.17$ cm$^2$, $P &lt; 0.0001$) CMR and TOE ($0.13 ± 0.16$ cm$^2$, $P &lt; 0.001$) TOE and CC ($0.08 ± 0.18$ cm$^2$, $P &lt; 0.0001$) Concordance of AVA between: CMR and CC ($r = 0.80$, $P &lt; 0.0001$, $n = 33$) CMR and TOE ($r = 0.80$, $P &lt; 0.0001$, $n = 27$) TOE and CC ($r = 0.82$, $P &lt; 0.0001$, $n = 25$)</td>
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**Conclusions**

(i) Excellent concordance between CMR and echo for measurement of AV pressure gradients, VTIs and AV orifice areas

(ii) Modest underestimation of severity of AS might occur with CMR for VTI > 0.8 m

(iii) Good intraobserver variability for CMR ($n = 5$)

**Exclusion criteria**

General CMR suitability, subvalvular outflow tract obstruction

**Notes**

AVA calculated with continuity equation-based CMR

**Continued**
Table 1: (Continued)

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<tr>
<td>Reant et al. (2006), Eur J Radiol, France [5]</td>
<td>Prospective observational (level 3)</td>
<td>n = 39</td>
<td>Disease process Mild-to-severe AS (mean AVA by TTE 0.93–0.31 cm²) Procedure Patients referred for surgical aortic valve replacement</td>
<td>Modalities Direct: CMR, TOE Indirect: TTE, CC Measurements Absolute AVA, effective AVA</td>
<td>Mean AVA (cm²) (range) CMR 0.92 ± 0.29 (0.41–1.66, n = 39) TOE 0.93 ± 0.31 (0.44–1.60, n = 39) TTE 0.75 ± 0.28 (0.32–1.60, n = 39) CC 0.85 ± 0.36 (0.40–1.80, n = 26) Mean difference for AVA: CMR vs TOE (d = 0.01 ± 0.14, r = 0.58, P = 0.79) CMR vs CC (d = 0.05 ± 0.13, r = 0.66, P = 0.10) CMR vs TTE (d = 0.10 ± 0.17, r = 0.39, P &lt; 0.01) Concordance for AVA between: CMR and TOE (r = 0.58, P &lt; 0.01) CMR and CC (r = 0.66, P &lt; 0.01) CMR and TTE (r = 0.39, P &lt; 0.01) CMR intraobserver reproducibility: r = 0.93 (P &lt; 0.0001) CMR interobserver reproducibility: r = 0.58 (P &lt; 0.0001)</td>
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| Garcia et al. (2011), J Cardiovasc Magn Reson, Canada [6] | Prospective observational (level 3) | n = 31 7 healthy controls | Disease process Mild-severe AS (EOA 0.72–1.73 cm²) Procedure Nil | Modalities TTE, CMR Measurements LVOT, EOA | Concordance between TTE and CMR for: AV EOA (r = 0.92, bias = 0.06 cm², −0.50 to 0.62 cm²) LVOT (3.84 ± 0.80 vs 4.78 ± 1.05 cm², bias = −0.94 cm², −2.62 to 0.74 cm²) VTILVOT (21 ± 4 vs 15 ± 4 cm, bias = 14 cm, 1–26 cm) Intra- and interobserver variability (EOA) TTE 5 ± 5 and 9 ± 5% CMR 2 ± 1 and 7 ± 5% | Conclusions (i) Good concordance between TTE and CMR for EOA (ii) TTE underestimates LVOT cross-sectional area (iii) TTE overestimates LVOT VTI (iv) CMR had lower inter- and intraobserver variability than TTE (n = 15) Exclusion criteria Age <21 years old, LVEF <50%, AF, moderate-severe MR or AR, poor TTE image quality, CMR contraindications |

| Jabbour et al. (2011), JACC, UK [7] | Prospective observational (level 3) | n = 202 (133 also had CT) 7 healthy controls | Disease process Severe AS (AVA <1 cm²) Procedure Patients referred for TAVI | Modalities CMR, CT and TTE Measurements Aortic root dimensions (annulus, sinus of Valsalva, sinotubular junction, ascending aorta) | Concordance between CMR and TTE for: Largest AV annulus (bias 4.52 mm, −1.93 to 10.97) Largest sinus of Valsalva (bias −0.45, −7.22 to 6.32) Largest sinotubular junction (bias −0.70, −8.42 to 7.01) Largest ascending aorta (bias 1.78, 1.78–4.21) | Conclusions (i) Good concordance between CMR and CT for dimensions of aortic annulus, sinus of Valsalva, sinotubular junction, ascending aorta (ii) TTE significantly underestimated the largest AV annulus diameter (P < 0.0001) and had significantly greater variability compared with CMR |
Table 1: (Continued)

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<td>Study type (level of evidence)</td>
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<tr>
<td>Paelinck et al. (2011), Am J Cardiol, UK [8]</td>
<td>n = 24</td>
<td>Disease process Severe symptomatic AS</td>
<td>Inter- and intraobserver variability of AV annulus: (coefficients of variation expressed as percentage) CT 10.6 and 3.6 CMR 5.1 and 1.7 TTE 8.9 and 6.8</td>
<td>(iii) CMR had low inter- and intraobserver variability, and was also the most reproducible of all the modalities (n = 20). Inter-study reproducibility of CMR was similarly low (iv) Presence and severity of AR after TAVI is associated with larger aortic annulus measurements by CMR and CCT but not TTE (postulated to be related to variability in TTE measurements) Exclusion criteria Patients with inadequate images were excluded from analysis</td>
</tr>
<tr>
<td>Prospective observational (level 3)</td>
<td>Procedure Patient referred for TAVI screening</td>
<td>Modalities CMR, 2D/3D TTE, TOE, CC Measurements AVA, AV annulus, aortic root dimensions (aortic sinus, sinotubular junction, ascending aorta), LVOT diameter</td>
<td>No difference between measurements of AVA (P = 0.506): CMR 0.60 cm², 0.30–0.80 Doppler 0.60 cm², 0.37–0.80 CC 0.60 cm², 0.30–0.83 3D TTE 0.54 cm², 0.32–0.83</td>
<td>Conclusions (i) No differences in AVA between all modalities studied (ii) TOE and CMR offer accurate aortic valve dimensions particularly at the limits of the TAVI range. 2D TTE underestimated AV annulus compared with TOE and CMR (iii) Low inter- and intraobserver variability (n = 10) Exclusion criteria Not described</td>
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<td>DeFrances et al. (2012), Circulation, France [9]</td>
<td>Prospective observational (level 3)</td>
<td>n = 53 21 healthy controls</td>
<td>Disease process Moderate-to-severe AS</td>
<td>Measurements Aortic mean gradients ( r = 0.86, P &lt; 0.0001 ), mean bias = (-29 \pm 62 \text{ mmHg}). Aortic VTI ( r = 0.86, P &lt; 0.0001 )</td>
</tr>
<tr>
<td>Pontone et al. (2013), Am J Cardiol, Italy [10]</td>
<td>Prospective observational (level 3)</td>
<td>n = 50 Moderate-to-severe AS</td>
<td>Procedure Patients referred for TAVI</td>
<td>Modality CMR, TTE, TOE, CT</td>
</tr>
<tr>
<td>Baron-Rochette et al. (2013), Circ Cardiovasc Imaging, Belgium [11]</td>
<td>Prospective observational (level 3)</td>
<td>n = 128 Moderate-to-severe AS</td>
<td>Procedure Patients referred for TAVI</td>
<td>Modalities CMR and TTE</td>
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<tr>
<td>Chin et al. (2014), Can J Cardiol, Canada [12]</td>
<td>Prospective observational (level 3)</td>
<td>n = 133 Moderate-to-severe AS</td>
<td>Procedure Nil</td>
<td>Modalities TTE, CMR</td>
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</table>
RESULTS

Caruthers et al. [2] compared echo and CMR in the evaluation of AS in 24 patients with mild to severe AS. There was good correlation in mean and peak pressure gradients obtained by both techniques. CMR slightly underestimated AS severity when the velocity-time integral (VTI) was greater than 0.8 cm². Aortic valve area (AVA) correlated well between CMR and echocardiography. To determine the reproducibility of CMR, 5 patients underwent CMR twice and results from both images were compared. CMR was noted to have good reproducibility.

Kupfahl et al. [3] used CMR, TTE, transoesophageal echocardiography (TOE) and cardiac catheterization (CC) to measure AVA in 44 patients with symptomatic severe AS. Similar AVA means and standard deviations were obtained by each technique. To test interobserver variability, 20 patients were examined by an additional observer and, to test intraobserver variability, the patients were re-examined by the same observer 4 weeks after the initial analysis. CMR was found to have low intra- and interobserver variability. The authors concluded that CMR is a highly reliable and reproducible method to measure the severity of AS. CMR also had the best specificity and sensitivity for detection of severe AS when compared with all other non-invasive modalities studied.

Debl et al. [4] used CMR, CC and TOE to measure AVA. CMR generated AVA correlated closely to TOE measurements. Both CMR and TOE tended to overestimate AVA when compared with CC. CMR was noted to have better image quality than TOE, and excellent sensitivity, specificity, positive and negative predictive values.

Reant et al. [5] used CMR and TOE to evaluate absolute orifice area, and TTE and CC to evaluate effective orifice area (EOA). TOE was thought to be the most accurate as it allowed direct evaluation of AVA but was also less ideal than CMR as it is a semi-invasive technique. When comparing measurements taken with CMR, CC or TTE to TOE, CMR was found to have best correlation. CMR was repeated on all patients 3 months after the initial assessment. Measurements were also repeated by a second blinded observer. CMR was shown to have excellent intra- and interobserver variability.

Table 1: (Continued)

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<tr>
<td>Speiser et al. (2014), Scand Cardiovasc J, Sweden [13]</td>
<td>n = 48</td>
<td>Disease process Mild to moderate AS</td>
<td>Modalities 3T CMR, TTE</td>
<td>Correlation between planimetric estimates of AVA by TTE and CMR: r = 0.92</td>
</tr>
<tr>
<td>Prospective observational (level 3)</td>
<td>Procedure Nil</td>
<td>Measurements AVA, LVOT diameter, LVOT flow velocity, maximum jet velocity above aortic valve</td>
<td>Correlation between AVA estimates by the continuity equation by TTE and CMR: r = 0.94</td>
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<tr>
<td>*using formula: Doppler stroke volume = LVOT(_{area}) × LVOT flow</td>
<td>CMR estimated AVA: Intraobserver variability 0.013 ± 0.04 cm², Interobserver variability 0.007 ± 0.09 cm²</td>
<td>CMR planimetric AVA: Intraobserver variability 0.027 ± 0.06 cm², Interobserver variability 0.027 ± 0.13 cm²</td>
<td>CMR estimated AVA: Intraobserver variability 0.5 ± 2.7%, r(^2) = 1.00, P &lt; 0.001</td>
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<tr>
<td>Exclusion criteria</td>
<td>Other significant valvar heart disease, contraindications to CMR, cardiomyopathy (inherited or acquired)</td>
<td>Exclusion criteria</td>
<td>Good correlation between planimetric AVA for TTE and CMR</td>
<td>Good correlation between estimated AVA for TTE and CMR</td>
</tr>
<tr>
<td>Low inter- and intraobserver variability</td>
<td>Any contraindication for CMR (claustrophobia, intracranial clips, pacemaker, defibrillator etc.), age less than 18 years, history of aortic valve surgery, intolerance to lying supine, not rate-controlled atrial fibrillation, insufficient acoustic window for TTE</td>
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</table>

All measurements noted in this table are indirect measurements and no comparison has been made directly via a surgical procedure.

AS: aortic stenosis; AVA: aortic valve area; CC: cardiac catheterization; CMR: cardiac magnetic resonance; EOA: effective orifice area; LVOT: left ventricular outflow tract; TOE: transoesophageal echocardiography; VTI: velocity-time integral SD: standard deviation; TTE: transthoracic echocardiography; TAVI: transcatheter aortic valve implantation; AV: aortic valve; LVEF: left ventricular ejection fraction; AoA: aortic annulus; AF: atrial fibrillation; AR: aortic regurgitation; CCT: cardiac computed tomography; MRI: magnetic resonance imaging; MDCT: multiple detector computed tomography;
Garcia et al. [6] used CMR and TTE to measure EOA in 31 patients with AS. TTE underestimated left ventricular outflow tract (LVOT) cross-sectional area when compared with CMR due to the assumption of circularity in echocardiography. VTITTE was however overestimated compared with CMR, resulting in good concordance between EQA_TTE and EQA_CM. Using the same set of TTE and CMR images, two blinded observers repeated the EOA measurements. In a subset of 15 patients, 5 were also imaged twice within 4 weeks. There was lower intra- and interobserver variability in CMR when compared with TTE, which suggested that CMR was a more reliable imaging modality in the assessment of AS.

Jabbour et al. [7] used CMR, cardiac tomography (CT) and TTE to assess the aortic root in patients referred for transcatheter aortic valve implantation (TAVI). They found that CMR and CT yielded comparable measurements of the aortic annulus, sinuses of Valsalva, sinotubular junction and ascending aorta. In contrast, TTE significantly underestimated aortic valve (AV) annulus size. In order to assess intra- and interobserver variability, two blinded specialists reported the same studies for 20 patients. One of the specialists then reported the same study on another day. CMR achieved the lowest rate of intra- and interobserver variability.

Paelinck et al. [8] measured AVA, aortic valve annulus and aortic root dimensions using CMR, 2D-TTE, 3D-TTE, TOE and CC. They found no significant difference in AVA using the different modalities. However, they found a significant difference in other aortic root measurements, with 2D TTE underestimating the diameters for AV annulus, aortic sinuses, sinotubular junction and ascending aorta, when compared with CMR. Inter- and intraobserver variability was lower than CC or TOE.

Defrance et al. [9] used TTE and CMR to evaluate aortic velocities, gradients and flow rates. They noted good concordance between TTE and CMR measurements of peak velocity and mean gradients. They calculated AVA using the Hakki formula (AVA_CM1), continuity equation (AVA_CM2) and simplified continuity equation (AVA_CM3). Compared with TTE, AVA_CM1 underestimated AVA. AVA_CM2 and AVA_CM3 had good concordance with AVA_TTE. Twenty patients were then chosen to undergo CMR twice by two different observers and low interobserver variability was noted.

Pontone et al. [10] compared CMR with echo and CT for evaluation of the aortic annulus. TTE and TOE underestimated absolute AV area when compared with CMR. CT is thought to be more accurate than echo given the 3D capabilities of the former. There was excellent correlation between CMR and CT for all parameters except aortic leaflet calcification, which was underestimated by CMR.

Barone-Rochette et al. [11] used echo and CMR to compare remodelling and fibrosis in different types of AS (different gradient and flow categories). LVOT area, indexed stroke volume and AVA correlated well between the two modalities, thus confirming the similar accuracy between CMR and echo.

Chin et al. [12] used TTE and CMR to measure stroke volume, LVOT and AVA. TTE underestimated LVOT area and consequently stroke volume and AVA when compared with CMR. CMR was noted to have excellent intra- and interobserver variability.

Speiser et al. [13] used 3-Tesla CMR and TTE to measure AVA in 33 patients without severe AS. For each patient, AVA was measured via planimetry and estimated via the continuity equation. Planimetric measurements of AVA by CMR and TTE were strongly correlated, as were continuity equation estimates of the AVA. Inter- and intraobserver variability of CMR measurements were found to be low.

**CLINICAL BOTTOM LINE**

CMR is as accurate as echocardiography in the evaluation of patients with aortic valve stenosis. It has better inter- and intraobserver reliability and demonstrates an advantage over echocardiography in the detection of severe AS with greater specificity and sensitivity.

**Conflict of interest:** none declared.

**REFERENCES**


