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

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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.

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Table 1: Best evidence papers

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes measured	Key results	Comments
Caruthers *et al*. (2003), Circulation, USA [2] Prospective observational (level 3)	*n* = 24 Disease process Mild–severe aortic stenosis (0.5–1.8 cm^2) Procedure Nil	Modalities Velocity-encoded CMR and TTE Measurements Aortic and LVOT velocities and pressure gradients	Concordance between CMR and TTE for: Peak pressures Level + ($r = 0.82$) Mean pressures Level + ($r = 0.83$) Peak pressures Level ++ ($r = 0.82$) Mean pressures Level ++ ($r = 0.83$) Valve area ($r = 0.83$, $P < 0.001$)* *Best correlation noted from various permutations available due to measurements at various levels	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
Kupfahl *et al*. (2004), Heart, Germany [3] Prospective observational (level 3)	*n* = 44 Disease process Severe symptomatic AS Procedure Patients referred for treatment decision-making regarding AV replacement	Modalities CMR, TTE, TOE and CC Measurements AVA	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 <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)	Conclusions (i) While all modalities resulted in similar AVA measurements, CMR and TOE were likely to overestimate AVA when compared with CC and TTE by a mean difference of 0.05–0.09 cm^2 (ii) CMR is possible in most patients, including those with heavy calcification, which results in a more difficult study but does not worsen intra- or inter-variability (iii) CMR is highly reliable and reproducible (iv) CMR had the best specificity and sensitivity of all non-invasive modalities Exclusion criteria Not stated
Debl *et al*. (2004), Invest Radiol, Germany [4] Prospective observational (level 3)	*n* = 33 Disease process Known or suspected AS Procedure Nil	Modalities CMR, CC, TOE Measurements AVA	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, $P < 0.0001$) CMR and TOE (0.13 ± 0.16 cm^2, $P < 0.001$) TOE and CC (0.08 ± 0.18 cm^2, $P < 0.0001$) Concordance of AVA between: CMR and CC ($r = 0.80$, $P < 0.0001$, $n = 33$) CMR and TOE ($r = 0.86$, $P < 0.0001$, $n = 27$) TOE and CC ($r = 0.82$, $P < 0.0001$, $n = 25$)	Conclusions (i) CMR and TOE have excellent correlation but both overestimate AVA when compared against CC (ii) Image quality of CMR is significantly better than echocardiography Exclusion criteria Nil

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Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes measured	Key results	Comments
			Adequate image quality CMR 82% (27/33) TOE 56% (15/27) Sensitivity and specificity in detecting severe AS diagnosed during CC: CMR 96 and 100% Positive and negative predictive value: CMR 100 and 83% CC 95 and 80%	
Reant *et al*. (2006), Eur J Radiol, France [5] Prospective observational (level 3)	$n = 39$ Disease process Mild-to-severe AS (mean AVA by TTE 0.93–0.31 cm^2) Procedure Patients referred for surgical aortic valve replacement	Modalities Direct: CMR, TOE Indirect: TTE, CC Measurements Absolute AVA, effective AVA	Mean AVA (cm^2) (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 ($d = 0.01 \pm 0.14$, $r = 0.58$, $P = 0.79$) CMR vs CC ($d = 0.05 \pm 0.13$, $r = 0.66$, $P = 0.10$) CMR vs TTE ($d = 0.10 \pm 0.17$, $r = 0.39$, $P < 0.01$) Concordance for AVA between: CMR and TOE ($r = 0.58$, $P < 0.01$) CMR and CC ($r = 0.66$, $P < 0.01$) CMR and TTE ($r = 0.39$, $P = 0.01$) CMR intraobserver reproducibility: $r = 0.93$ ($P < 0.0001$) CMR interobserver reproducibility: $r = 0.58$ ($P < 0.0001$)	Conclusions (i) Good concordance between CMR, TOE and CC for AVA measurements but not TTE (ii) CMR had excellent inter- and intraobserver reproducibility (iii) When considering excluded patients, feasibility for CMR was 80%, TTE 100%, TOE 80% and CC 67% Exclusion criteria Contraindications to TOE (gastro-oesophageal pathology, haemodynamic instability) or CMR (metallic implant, severe claustrophobia, pacemaker, some valvular prostheses), subvalvular outflow tract obstruction and rapid uncontrolled arrhythmia (>100 bpm)
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 cm^2) Procedure Nil	Modalities TTE, CMR Measurements LVOT, EOA	Concordance between TTE and CMR for: AV EOA ($r = 0.92$, bias = 0.06 cm^2, −0.50 to 0.62 cm^2) LVOT (3.84 ± 0.80 vs 4.78 ± 1.05 cm^2, bias = −0.94 cm^2, −2.62 to 0.74 cm^2) VTI_{LVOT} (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 cm^2) 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

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Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes measured	Key results	Comments
			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	(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
Paelinck *et al.* (2011), Am J Cardiol, UK [8] Prospective observational (level 3)	*n* = 24 Disease process Severe symptomatic AS Procedure Patient referred for TAVI screening	Modalities CMR, 2D/3D TTE, TOE, CC Measurements AVA, AV annulus, aortic root dimensions (aortic sinus, sinotubular junction, ascending aorta), LVOT diameter	No difference between measurements of AVA ($P = 0.506$): CMR 0.60 cm^2, 0.30–0.80 Doppler 0.60 cm^2, 0.37–0.80 CC 0.60 cm^2, 0.30–0.83 3D TTE 0.54 cm^2, 0.32–0.83 Significant difference between measurements of AV annulus ($P < 0.001$): Aortic valve annulus measured via CMR, TOE and 2D TTE was larger than with catheterization ($P < 0.001$, all comparisons) Significant difference between measurements of aortic sinus ($P = 0.043$) with smaller diameters with 2D TTE than with CMR ($P = 0.043$) Significant difference found between measurements of the sinotubular junction ($P = 0.037$) with smaller diameters found with 2D TTE than CMR ($P = 0.008$) Significant difference found between measurements of aortic ascendens ($P = 0.013$), smaller diameter with 2D TTE than with MRI ($P = 0.016$) No difference in measurement of LVOT ($P > 0.05$) Intraobserver reproducibility for AV annulus (mean difference ± 2 SD) CMR −0.09 ± 0.18 cm CC −0.27 ± 0.39 cm TOE 0.11 ± 0.31 cm 2D TTE −0.03 ± 0.40 Interobserver reproducibility (mean difference ± 2 SD) CMR −0.12 ± 0.21 cm CC −0.26 ± 0.44 cm TOE 0.14 ± 0.30 cm 2D TTE −0.12 ± 0.25 cm	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

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Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes measured	Key results	Comments
Defrance *et al.* (2012), Circulation, France [9] Prospective observational (level 3)	n = 53 21 healthy controls Disease process Moderate–severe AS group Procedure Nil	Modalities TTE and phase-contrast CMR Measurements Velocities, gradients and flow rates of the aorta and LVOT (using segmentation for CMR)	Concordance between CMR and TTE for: Aortic peak velocities (r = 0.92, P < 0.0001, mean bias = −29 ± 62 cm/s) Aortic mean gradients (r = 0.86, P < 0.0001, mean bias = −12 ± 15 mmHg). Aortic VTI (r = 0.86, P < 0.0001) Concordance between: AVA_{CMR1} and AVA_{TTE} (r > 0.90, mean bias = −0.45 ± 0.52 cm^2) AVA_{CMR2} and AVA_{TTE} (r > 0.94, P < 0.0001, mean bias = −0.01 ± 0.38 cm^2) AVA_{CMR3} and AVA_{TTE} (r > 0.97, P < 0.0001, mean bias = −0.09 ± 0.28 cm^2)	Conclusions (i) Good concordance between CMR and TTE for aortic peak velocities and mean gradients (ii) Good concordance between AVA_{TTE} and AVA_{CMR2} and AVA_{CMR3} (iii) AVA_{CMR1} was lower than AVA_{TTE} (iv) Low interoperator variability (<4.56 ± 4.40%) (n = 21) Exclusion criteria Significant MR or AR, poor echo imaging quality, contraindications to CMR Notes 3 AVA_{CMR} calculations made: AVA_{CMR1}: Hakki formula AVA_{CMR2}: Continuity equation AVA_{CMR3}: Simplified continuity equation
Pontone *et al.* (2013), Am J Cardiol, Italy [10] Prospective observational (level 3)	n = 50 Disease process Severe AS Procedure Patients referred for TAVI	Modalities CMR, TTE, TOE, CT Measurements Maximum aortic diameter, minimum diameter, aortic annulus, length of coronary aortic leaflets, degree of aortic leaflet calcification, distance between aortic annulus and coronary artery ostia	Concordance between CMR and TTE for: AoA max diameter (r = 0.4, P < 0.01) AoA min diameter (r = 0.6, P < 0.01) AoA area (r = 0.5, P < 0.01) Concordance between CMR and TOE for: AoA max diameter (r = 0.5, P < 0.01) AoA min diameter (r = 0.7, P < 0.01) AoA area (r = 0.6, P < 0.01) Concordance between CMR and MDCT* for: AoA max diameter (r = 0.9, P < 0.01) AoA min diameter (r = 0.9, P < 0.01) AoA area (r = 0.9, P < 0.01)	Conclusions (i) TTE and TOE underestimated aortic annulus area compared with CMR (P < 0.01) (ii) CMR underestimates aortic annulus area in the case of aortic leaflet calcification (iii) No comment on inter- or intraobserver variability for CMR Exclusion criteria Severe renal impairment, inability to sustain 10-s breath hold, AF, other cardiac arrhythmia, presence of pacemaker or ICD, claustrophobia Notes AVA calculated with continuity equation-based CMR
Baron-Rochette *et al.* (2013), Circ Cardiovasc Imaging, Belgium [11] Prospective observational (level 3)	n = 128 20 healthy controls Disease process AVA <0.6 cm^2/m^2 Ejection fraction >50% Procedure Patients referred for surgery	Modalities CMR and TTE Measurements AVA, indexed stroke volume, LVOT area, focal fibrosis	Concordance between CMR and TTE for: LVOT area (r = 0.7, P < 0.0001) Indexed stroke volume (r = 0.61, P < 0.0001) AVA (r = 0.65, P < 0.0001)	Conclusions (i) Good correlation between LVOT, stroke volume and AVA between CMR and TTE (ii) No comment on inter- or intraobserver variability Exclusion criteria EF <50%, previous MI, AF, more than mild concomitant mitral or aortic regurgitation, contraindications to CMR, renal insufficiency
Chin *et al.* (2014), Can J Cardiol, Canada [12] Prospective observational (level 3)	n = 133 33 healthy controls Disease process Mild-to-severe AS Procedure Nil	Modalities TTE, CMR Measurements Stroke volume, LVOT area, AVA	Weak concordance between: Stroke volume calculated* using $LVOT_{area}$ by echo (r^2 = 0.12, P < 0.001) and CMR stroke volume Strong concordance between: Stroke volume calculated* using $LVOT_{area}$ by CMR (r^2 = 0.87, P < 0.001) and CMR stroke volume (n = 40)	Conclusions (i) TTE underestimates LVOT area, stroke volume and consequently AVA when compared with CMR (ii) Excellent intra- and interobserver reproducibility of planimetric LVOT measurements using CMR

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Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes measured	Key results	Comments
			*using formula: Doppler stroke volume = $LVOT_{area}$ × LVOT flow Intraobserver variability: $LVOT_{CMR}$ 0.5 ± 2.7%, r^2 = 1.00, $P < 0.001$ Interobserver variability: $LVOT_{CMR}$ 1.1 ± 5.4%, r^2 = 0.98, $P < 0.001$	Exclusion criteria Other significant valvular heart disease, contraindications to CMR, cardiomyopathy (inherited or acquired)
Speiser *et al*. (2014), Scand Cardiovasc J, Sweden [13] Prospective observational (level 3)	*n* = 48 Disease process Mild to moderate AS Procedure Nil	Modalities 3T CMR, TTE Measurements AVA, LVOT diameter, LVOT flow velocity, maximum jet velocity above aortic valve	Correlation between planimetric estimates of AVA by TTE and CMR: *r* = 0.92 Correlation between AVA estimates by the continuity equation by TTE and CMR: *r* = 0.94 CMR estimated AVA: Intraobserver variability 0.013 ± 0.04 cm^2 Interobserver variability 0.007 ± 0.09 cm^2 CMR planimetric AVA: Intraobserver variability 0.027 ± 0.06 cm^2 Interobserver variability 0.027 ± 0.13 cm^2	Conclusions Good correlation between planimetric AVA for TTE and CMR Good correlation between estimated AVA for TTE and CMR Low inter- and intraobserver variability Exclusion criteria 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

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; CT: cardiac tomography; 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;

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 cm^2. 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.

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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. VTI_{TTE} was however overestimated compared with CMR, resulting in good concordance between EOA_{TTE} and EOA_{CMR}. 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_{CMR1}), continuity equation (AVA_{CMR2}) and simplified continuity equation (AVA_{CMR3}). Compared with TTE, AVA_{CMR1} underestimated AVA. AVA_{CMR2} and AVA_{CMR3} 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.

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