Right ventricular systolic function assessment: rank of echocardiographic methods vs. cardiac magnetic resonance imaging

Michael Pavlicek†, Andreas Wahl †, Tobias Rutz †, Stefano F. de Marchi, Ron Hille, Kerstin Wustmann, Hélène Steck, Christina Eigenmann, Markus Schwerzmann, and Christian Seiler *

Department of Cardiology, University Hospital, Bern CH-3010, Switzerland

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Aims
Right ventricular (RV) systolic function is prognostically important, but its assessment by echocardiography remains challenging, in part because of the multitude of available measurement methods. The purpose of this prospective study was to rank these methods against the reference of RV ejection fraction (EF) as obtained in a broad clinical population by magnetic resonance imaging (MRI).

Methods and results
Two hundred and twenty-three individuals were included in the study. The following seven Doppler echocardiographic parameters were tested using receiver operating characteristic (ROC) analysis for their accuracy to distinguish between normal and moderately impaired RVEF by MRI (RVEF cut-off 50%), respectively, between moderately and severely reduced RVEF (cut-off 30%): RV fractional area and fractional long-axis change (FLC), RV myocardial performance index (MPI), tricuspid annular peak systolic excursion, Doppler tissue imaging-derived isovolumic acceleration and peak systolic velocity ($S'$) at the lateral tricuspid annulus, and strain at the lateral free wall as obtained by speckle-tracking echocardiography. Survival analysis was performed. All seven Doppler echocardiographic parameters correlated significantly with RVEF by MRI (range between 5 and 85%). RVEF $\geq 50\%$ was best detected by $S' < 11$ cm/s: area under the ROC curve 0.779 (95% confidence interval 0.716–0.843), sensitivity 0.740, and specificity 0.753. RVEF $\leq 30\%$ was best detected by MPI. $0.50$: area under the ROC curve 0.948 (95% confidence interval 0.906–0.991), sensitivity 0.947, and specificity 0.852. The Kaplan–Meier analysis revealed reduced cumulative survival among patients with RVEF $\leq 30\%$ ($P = 0.0003$).

Conclusion
A systolic long-axis peak velocity of $< 11$ cm/s at the lateral tricuspid annulus most accurately detects moderately impaired RVEF as obtained by MRI; severely reduced RVEF $\leq 30\%$ is best detected by RV MPI at a value of $> 0.50$.

Keywords
Right ventricle • systolic function • echocardiography • Doppler imaging • magnetic resonance imaging

Introduction
Systolic right ventricular (RV) function is an important predictor in the course of congenital and acquired heart disease such as tetralogy of Fallot and transposition of the great arteries, or in pulmonary hypertension and RV infarction, respectively. However, one of its widely used parameters, RV ejection fraction (EF), is difficult to assess both with accuracy and ease. This is due to the complex geometrical shape of the RV rendering volume measurements by echocardiography prone to error and awkward, and because the more precise respective determinations by the reference method, i.e. magnetic resonance imaging (MRI), are not readily available and costly. Traditionally, RV fractional area or long-axis change measurements (FAC and FLC) by two-dimensional (2D) echocardiography have been employed, but also 1D parameters such as the tricuspid annular peak systolic excursion (TAPSE)²;
or an index describing global myocardial performance (MPI)\(^6\) (Figure 1). The advent of tissue Doppler imaging (TDI) has initiated long-axis function analysis of both ventricles difficult to obtain by conventional echocardiography, whereby pulsed-wave TDI at the lateral tricuspid annulus allows the recording of RV peak myocardial contraction velocity (\(S'\))\(^7\) – \(^{10}\) and the less load-dependent isovolumic contraction acceleration (IVA; Figure 1).\(^{11}\) Recently, the measurement of myocardial deformation by speckle-tracking strain echocardiography has been introduced for left ventricular (LV) and RV systolic function assessment (Figure 2).\(^{12} - {^{14}}\)

However, the numerous echocardiographic methods for RV function assessment have not been systematically ranked side by side against the reference of RVEF by cardiac MRI in a sizeable population. Therefore, the purpose of the present study was to test the accuracy of traditional and novel echocardiographic parameters for systolic RV function assessment.

**Figure 1** (Upper panel) End-diastolic (left side) and end-systolic (right side) right ventricular area (dashed line) and right ventricular long axis (arrow) measurement from the apical four-chamber view for the calculation of area and long-axis change (difference between end-diastolic and end-systolic divided by end-systolic values). (Middle panel) Temporal flow velocity Doppler spectra of tricuspid regurgitation (TR; left side) and pulmonary ejection (PE; right side) for the calculation of myocardial performance index (MPI = difference between TR and PE duration divided by PE duration). (Lower left panel) M-mode recording of the lateral tricuspid systolic excursion for the measurement of tricuspid annular peak systolic excursion (TAPSE). (Lower right panel) Tissue Doppler imaging of the lateral tricuspid annular excursion for the measurement of isovolumic contraction acceleration (left side; IVA) and peak systolic velocity (right side; \(S'\)).
Methods

Study individuals

Two hundred and twenty-three individuals were included in the study (203 of them consecutively; see also below). In all of them, the following Doppler echocardiographic parameters for RV systolic function assessment and cardiac MRI (RVEF) were obtained: FAC, FLC, MPI, TAPSE, \( S' \), IVA, and average lateral RV free wall peak systolic strain (Figures 1 and 2). The patients were subdivided into three groups according to the RVEF by MRI: normal RVEF \( \geq 50\% \) \( (n = 129) \), moderately reduced RVEF \( 30–49\% \) \( (n = 67; 7 \) of them selected from our MRI database on the basis of low RVEF), and severely reduced RVEF \( \leq 30\% \) \( (n = 27; 13 \) of them selected from our MRI database on the basis of low RVEF).

The study protocol was approved by the Kantonale EthikKommission Bern, Switzerland, and all subjects provided written informed consent to participate in the study before inclusion.

Doppler echocardiography

Transthoracic Doppler echocardiography was performed using an Acuson Sequoia C 512 (Acuson Corporation, Siemens, Mountain View, CA, USA) with a 3.5 MHz transducer including second harmonic and TDI as well as speckle-tracking software for strain echocardiography (Velocity Vector Imaging™ Version 3 Software; Siemens, Erlangen, Germany). Patients were examined in the supine, left-lateral position. They underwent conventional M-mode and 2D echocardiography from a left parasternal and apical window. M-mode measurements of the LV were obtained during end-systole and end-diastole. LV mass was calculated according to the cube formula using end-diastolic values of septal and posterior wall thickness and LV cavity dimension. LV volume measurements for the calculation of LV EF were carried out in biplane projection from apical four- and two-chamber views. LV volumes were computed using the biapical Simpson rule. The tricuspid regurgitant pressure gradient between the RV and the right atrium was calculated by the simplified Bernoulli equation.

Specific right ventricular measurements

For all measurements, final values were obtained after averaging over three cardiac cycles. Two-dimensional echocardiography-derived RV area and length measurements were taken from the apical four-chamber view at end-diastole and end-systole, and the respective fractional changes (FAC and FLC) were calculated (difference between end-diastole and end-systole divided by end-diastole in %; Figure 1). RVEF using the monoplane area/length method was not analysed as an independent method for RV function assessment, because it is derived entirely on the basis of the RV area and length parameters. RV myocardial performance index (MPI, no unit; Figure 1) was determined as the difference in duration between tricuspid regurgitation and pulmonary ejection divided by pulmonary ejection duration.\(^5\) Lateral TAPSE (mm) (Figure 1) was determined by M-mode echocardiography as the distance between the basal, end-diastolic position of the tricuspid annulus taken at the beginning of the ECG QRS complex and its greatest apical long-axis movement.\(^5\) Pulsed-wave TDI of the peak systolic tricuspid annular motion velocity at the lateral free wall \( (S', \text{cm/s}; \text{Figure 1}) \) was obtained from the apical four-chamber view using a sampling gate of 2–4 mm and a sweep of 200 mm/s.\(^5\) RV IVA of the lateral tricuspid annulus, i.e. the linear velocity change of the annular motion during isovolumic contraction (IVA, cm/s; Figure 1), was determined using the same three cardiac cycles as for \( S' \).\(^5\)

For speckle-tracking strain echocardiography,\(^13,16\) three consecutive cardiac cycles of the RV with a frame rate of 70–120/s were recorded. The endocardial border of the RV was traced manually from a still frame image and automatically tracked throughout the cardiac cycle by the software. If necessary, the tracing was repeated for optimizing accurate endocardial border tracking. The RV was divided into six
segments by the software for analyses (basal RV free wall, mid-RV free wall, apical free wall, basal left septum, mid-left septum, and apical left septum). Using speckle-tracking imaging, tissue velocities in the 2D plane are displayed throughout the cardiac cycle, representing both their magnitude and the direction of the motion. Strain and strain rate (SR) (figure 2) were obtained by comparing displacement of the speckles in relation to each other along the endocardial contour throughout the cardiac cycle.

Reproducibility
Inter-observer variability for all seven Doppler echocardiographic parameters was obtained in 40 randomly selected individuals over the entire range of RVEF, whereby the measurements were repeated offline by a second observer who was blinded to both the initial analysis and the MRI data.

Cardiac magnetic resonance imaging
Study individuals were examined in the supine position using a 1.5 T (Magnetom Symphony) or a 3 T (Magnetom Trio, both from Siemens Medical Solutions, Erlangen, Germany) whole-body clinical MRI system. Cardiac synchronization was obtained from three electrodes placed on the left anterior hemithorax. The cardiac short axis was determined from three scout images: a mid-ventricular axial view, a cine breath-hold vertical long axis, and a cine breath-hold horizontal long axis. The basal short-axis slice was positioned beyond the level of the mitral valve plane, and the ventricles were imaged from the base towards the apex during short end-expiratory breath-holds using contiguous short-axis slices in 8 mm increments. Complete coverage of the ventricles with the short-axis acquisitions was confirmed on long-axis views. A cine steady-state free precession technique with retrospective gating was used. MR image analysis was done off-line in a random order by an experienced observer blinded to clinical data and echocardiographic results. Image analysis was carried out on a dedicated workstation using commercially available software (Argus version 4.01, Syngo MR B13, Siemens Medical Solutions, Erlangen, Germany). End-diastolic and end-systolic contours were manually traced for each slice. RV volumes were determined according to the modified Simpson’s rule (disk summation, no geometrical assumption).

Survival analysis
Follow-up for survival analysis (all-cause mortality) was performed by telephone interview of patients, their relatives, their general practitioners, and by searching hospital charts.

Statistical analysis
Normality distribution of continuous data was performed by the Shapiro–Wilks test. For comparison between groups of continuous demographic and Doppler echocardiographic variables, a factorial analysis of variance (ANOVA) was used (Scheffe’s test for post hoc analysis). Categorical parameters were analysed by Fisher’s exact test. Linear regression analysis was carried out for the detection of statistically relevant correlations between the Doppler echocardiographic parameters and RVEF by MRI (the reference method). Receiver operating characteristic (ROC) analysis was performed with the Doppler echocardiographic parameters as the test variables and RVEF by MRI as the state variable. Measurement reproducibility (inter-observer variability) was calculated as per cent standard error of estimate of the mean.

The Kaplan–Meier analysis for cumulative survival (log-rank test) was performed according to the three RVEF groups by MRI.

Results
Patient characteristics
All patients underwent Doppler echocardiography and cardiac MRI within 10 ± 34 days (no difference between the study groups). Patients in the low RVEF group were older than in the other groups. They did not differ in regard to gender and body mass index (Table 1). Systemic blood pressure was significantly higher and heart rate lower in the group with normal when compared with the groups with impaired RVEF. The primary cardiovascular diagnosis (initial diagnosis before Doppler echocardiography) of the study participants differed significantly among the groups (Table 1). The diagnosis of a normal cardiovascular system (38/223 = 17% of all patients) was predominant in the group with normal RVEF; coronary artery disease (16%) was prevalent in the groups with normal and moderately reduced RVEF; cardiomyopathy (i.e. dilative, hypertrophic, and restrictive; 23%) was the most frequent diagnosis in the group with severely reduced RVEF; valvular heart disease (5%) was evenly distributed among the study groups; tetralogy of Fallot (13%) was the most prevalent diagnosis in the group with moderately reduced RVEF; transposition of the great arteries (9%) and other congenital heart disease (13%) were similarly distributed among the groups; pulmonary hypertension (4%) was similarly present in the study groups.

Doppler echocardiographic data
The following parameters shown in Table 2 were different between the study groups: LV end-diastolic diameter and LVEF. The occurrence of moderately severe or severe tricuspid regurgitation was 1% (1/129) in the normal RVEF group, it was 4% (3/69) in the group with moderately reduced RVEF, and it was 15% (4/27) in the group with severely reduced RVEF; valvular heart disease (5%) was evenly distributed among the study groups; coronary artery disease (16%) was prevalent in the groups with normal and moderately reduced RVEF; cardiomyopathy (4%) was similarly distributed among the groups; and heart rate lower in the group with normal when compared with the groups with impaired RVEF.

Reproducibility of RV systolic function parameters: the interobserver variabilities (standard error of estimate of the mean) for FAC, FLC, MPI, TAPSE, S', IVA, and lateral RV free wall average strain were as follows: 29.9% (r² = 0.299), 62.0% (r² = 0.161), 41.9% (r² = 0.582), 10.8% (r² = 0.918), 7.7% (r² = 0.928), 8.0% (r² = 0.615), and 28.0% (r² = 0.431), respectively.

All of the seven Doppler echocardiographic parameters evaluated for RV systolic function assessment differed significantly between the groups (Table 2). All Doppler echocardiographic parameters correlated linearly and significantly with the reference parameter of RVEF by MRI (Figures 3 and 4). In accordance with the group definition, RVEF by MRI (range between 5 and 85%) was significantly different between the groups. MRI-derived LV mass index and LV EF did also differ among the groups.

Figure 5 illustrates the results of the ROC analysis for an RVEF cut-off of 50% distinguishing normal from reduced systolic RV function and for an RVEF cut-off of 30% differentiating between moderately and severely reduced systolic RV function. The Doppler echocardiographic parameter detecting best the upper RVEF...
The variable detecting best the lower RVEF cut-off was MPI at a level of 0.50 (Figure 5 and Table 3). The ranking order of Doppler echocardiographic variables for the distinction between different categories of RVEF shows that FAC scored second for both cut-offs.

Survival analysis

Follow-up for survival analysis with regard to all-cause mortality was complete, i.e. data could be obtained for all study participants. Eighteen patients died during an average follow-up duration of 16 ± 10 months. Mortality was highest in the group with severely impaired systolic RV function (Figure 6).
Figure 3 Correlation in all study patients between right ventricular (RV) ejection fraction as obtained by magnetic resonance imaging (MRI; vertical axis; dependent variable; 50% threshold indicated by the horizontal red dashed line) and the following independent Doppler echocardiographic variables (horizontal axes): lateral tricuspid annular peak systolic velocity as obtained by tissue Doppler imaging, $S'$ (left upper panel; best cut-off indicated by the vertical red dashed line), lateral tricuspid annular isovolumic contraction acceleration, IVA (right upper panel; best cut-off indicated by the vertical red dashed line), RV fractional area change (left lower panel; best cut-off indicated by the vertical red dashed line), and tricuspid annular peak systolic excursion, TAPSE (right lower panel; best cut-off indicated by the vertical red dashed line).

Figure 4 Correlation in all study patients between RV ejection fraction as obtained by magnetic resonance imaging (MRI; vertical axis; dependent variable; 50% threshold indicated by the horizontal red dashed line) and the following independent Doppler echocardiographic variables (horizontal axes): lateral tricuspid annular peak systolic velocity as obtained by speckle tracking, RV lateral basal free wall peak systolic strain rate, SR (right upper panel; best cut-off indicated by the vertical red dashed line), RV fractional long-axis change (left lower panel; best cut-off indicated by the vertical red dashed line), and RV myocardial performance index, MPI (right lower panel; best cut-off indicated by the vertical red dashed line).
Discussion

In this cohort of 223 patients covering a broad range of cardiovascular diagnoses, lateral tricuspid annular peak systolic velocity ($S'$ at 11 cm/s) when compared with other echo parameters most accurately distinguished between normal and reduced RVEF by MRI; differentiating between moderately and severely impaired RVEF was achieved best using RV MPI (0.50). TAPSE (and not RVEF by MRI nor $S'$, MPI) was the only RV function parameter predicting survival.

Table 3  Receiver operating characteristics analysis

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<th></th>
<th>AUC</th>
<th>AUC (95% confidence interval)</th>
<th>P-value</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Cut-off</th>
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<tr>
<td>$S'$ (cm/s)</td>
<td>0.779</td>
<td>0.716–0.843</td>
<td>0.000</td>
<td>0.740</td>
<td>0.753</td>
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<td>0.728</td>
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<td>0.675</td>
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<td>TAPSE (mm)</td>
<td>0.716</td>
<td>0.647–0.785</td>
<td>0.000</td>
<td>0.614</td>
<td>0.708</td>
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<td>IVA (m/s²)</td>
<td>0.701</td>
<td>0.630–0.772</td>
<td>0.000</td>
<td>0.622</td>
<td>0.697</td>
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<td>$S$ lateral average (%)</td>
<td>0.697</td>
<td>0.625–0.770</td>
<td>0.000</td>
<td>0.651</td>
<td>0.688</td>
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<td>MPI (no unit)</td>
<td>0.681</td>
<td>0.600–0.761</td>
<td>0.000</td>
<td>0.651</td>
<td>0.624</td>
<td>0.30</td>
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<td>FLR (%)</td>
<td>0.669</td>
<td>0.599–0.740</td>
<td>0.000</td>
<td>0.620</td>
<td>0.621</td>
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<tr>
<td>MPI (no unit)</td>
<td>0.948</td>
<td>0.906–0.991</td>
<td>0.000</td>
<td>0.947</td>
<td>0.852</td>
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<td>FAC (%)</td>
<td>0.884</td>
<td>0.830–0.939</td>
<td>0.000</td>
<td>0.814</td>
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<td>$S$ lateral average (%)</td>
<td>0.878</td>
<td>0.805–0.951</td>
<td>0.000</td>
<td>0.789</td>
<td>0.810</td>
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<tr>
<td>$S'$ (cm/s)</td>
<td>0.795</td>
<td>0.715–0.874</td>
<td>0.000</td>
<td>0.747</td>
<td>0.727</td>
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<td>TAPSE (mm)</td>
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<td>0.000</td>
<td>0.779</td>
<td>0.478</td>
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<td>IVA (m/s²)</td>
<td>0.681</td>
<td>0.557–0.805</td>
<td>0.000</td>
<td>0.779</td>
<td>0.622</td>
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<td>FLR (%)</td>
<td>0.663</td>
<td>0.545–0.782</td>
<td>0.011</td>
<td>0.600</td>
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For abbreviations, see text.
Cardiac magnetic resonance imaging for right ventricular systolic function assessment

In the context of a validation study, the adequacy of the reference system as well as the parameter must be considered. Cardiac MRI is, nowadays, regarded as the reference method for assessing RV function.\textsuperscript{3,17} It has been applied for the measurement of LV and RV volumes, systolic function, and mass for several years.\textsuperscript{18} MRI-derived RV volumes show a good correlation with in vivo standards,\textsuperscript{19} and the technique has shown good accuracy and reproducibility for RV measurements.\textsuperscript{20,21} However, as opposed to echocardiographic techniques, MRI is not widely available and quantitative MRI analysis of RV volumes is time-consuming (manual endocardial contour drawing) requiring expertise in defining the most basal short-axis slice and the endocardial border complicated by the thin free wall and extensive trabeculations. Thus, the reference method of cardiac MRI used in this study is accountable for some unknown amount of data variability found in the associations between the dependent and independent echocardiographic parameters.

RVEF as the reference parameter employed in this study can be interrogated as well, since it is influenced by myocardial contractility, RV pre- and afterload. The contribution of pre- and afterload to RVEF was not evenly distributed among the study groups. Theoretically, the high afterload on the systemic RV in transposition of the great arteries resulted in an underestimation of RV systolic function predominantly in the RV dysfunction groups. However, RV—right atrial pressure gradient was not different between the groups. Conversely, RV afterload reduction in the presence of severe tricuspid regurgitation was most prevalent in the group with RVEF <30%, the fact of which lead to an overestimation of systolic RV function by EF in this group. That is, systolic function in the most severely impaired RVEF group was even worse than estimated. Nevertheless, the ease of obtaining RVEF by MRI as opposed to ‘pure’ contractility parameters such as invasively measured elastance or maximal pressure rise during isovolumic contraction favoured it as the reference parameter. Other clinical variables known to influence MRI-derived RVEF such as gender, age, and body mass index were not different between the study groups.\textsuperscript{3}

In the context of the present study’s survival analysis, RVEF by MRI was less valid as a predictive variable than one of the echo parameters, i.e. TAPSE. This may challenge the status of cardiac MRI as the reference method for assessing RV function. Conversely, the power of the present survival analysis is probably not sufficient (18 deceased patients) to question MRI’s position.

Echocardiographic parameters for right ventricular systolic function assessment

Several Doppler echocardiographic parameters have been tested separately for the assessment of RV systolic function.\textsuperscript{22} They are based on systolic area or volume changes (FAC and RVEF by echo), whereby the latter are difficult to obtain using one or two image planes because of the RV shape unsuitable for geometric modelling. Furthermore, RV function assessment is performed on the basis of RV long-axis changes (TAPSE, S', IVA, FLCl, strain echocardiography) and on global myocardial performance estimation (MPI). However and with the exception of one rather underpowered study,\textsuperscript{14} side-by-side ranking in a broad population representing most of the diagnoses relevant for RV function assessment has not been performed. Wang et al. found in 43 normal individuals and in 10 patients with arrhythmogenic RV dysplasia that among the parameters described above, S' at a cut-off value of 8.8 cm/s detected best a low RVEF by MRI <45%; there were only five patients in this study with an RVEF of <45%.\textsuperscript{54} The result of a superior accuracy of S' for the distinction between normal and abnormal RV function is consistent with our study findings, despite the low power of the abnormal RV function group in Wang et al.’s investigation. Furthermore, the missing correlation between MPI and RVEF by MRI in that study can be interpreted as consistent with our result of a poor accuracy of MPI in the normal to moderately reduced RVEF group. Evaluating regional and global MPI as well as TDI-derived long-axis function parameters, Sade et al.\textsuperscript{23} found in 69 patients with heart failure that on average S' between the lateral and septal tricuspid annulus of 7 cm/s was the most accurate means to detect an RVEF cut-off by MRI of 45% (sensitivity and specificity around 85%). Though S' has been consistently found useful for RV function assessment,\textsuperscript{7,9,10,15,24} the best S' threshold varies substantially among different studies from 7 to 11 cm/s, the fact of which is only partially explained by a variable cut-off for the definition of normal vs. abnormal RVEF. Other factors contributing to this variability are the low number of data points in the RVEF segment <30% (n = 27 in the present study and n = 17 in a previous study by our laboratory)\textsuperscript{10} and the heterogeneous populations included in the investigations. Furthermore and as opposed to MPI, S' tends to be related to RVEF <30% in a curvilinear rather than a linear fashion. As a consequence, S' remains almost constant around a value of 9–10 cm/s below an RVEF of 40% (see also Figure 3). This is probably due to the loss of longitudinal RV function as the main contributor to systolic RV function at an RVEF of around 50% and not at a lower threshold.\textsuperscript{25} In comparison to other investigations, the present study was designed to examine a cohort of consecutive ‘all-comers’, i.e. a population with a broad spectrum of diagnoses (Table 1). The purpose of
the wide view was to limit the numerous echocardiographic parameters for RV assessment to one or two practically and most extensively useful. Conversely, our study did not aim at nominating several different parameters for varying RV nosological entities. For example, load-dependent parameters are strongly influenced by conditions such as severe tricuspid regurgitation or by the systemic circulation in the case of transposition of the great arteries. Pathophysiology, this would be an argument in favour of excluding such conditions from our study. However and with the exception of IVA, none of the seven parameters tested nor the reference employed were load-independent. Lateral tricuspid annular long-axis acceleration during isovolumic contraction (IVA) has been evaluated against RV pressure volume loops and confirmed to be a load-independent contractility parameter. In the clinical routine as reflected by our study, IVA is obtainable less reliably than $S'$ to RVEF than by speckle-tracking imaging. In this context, it is surprising that lateral basal load-independent contractility parameter. In the clinical routine evaluated against RV pressure volume loops and confirmed to be a load-independent contractility parameter. In the clinical routine as reflected by our study, IVA is obtainable less reliably than $S'$, the fact of which explains the intermediate-to-low accuracy rank among the variables tested (Table 3).

Theoretically, RV myocardial strain and SR data are superior to pure velocity measurements such as $S'$, because translational motion of the heart is accounted for using the former but not the latter parameters. This is even more so if strain imaging is not based on Doppler data but on angle-independent myocardial speckle tracking. In this context, it is surprising that lateral basal SR performed just intermediate in predicting RVEF by MRI. Among a total of six radial and six longitudinal RV segments interrogated for myocardial tissue deformation (not all data shown), average lateral peak systolic $S'$ was the best. The principal explanation for the divergence between theoretical expectations and reality is the more pronounced dependence on image quality by the echocardiography-based method (strain imaging) than the Doppler-based method ($S'$) at the particular location of the lateral tricuspid annulus. In this context, lateral tricuspid annular velocity by Doppler ($S'$) was associated closer to RVEF than by speckle-tracking imaging.

The finding that RV MPI most accurately detects severely impaired RVEF was unexpected and illustrated by the decreasing data variability in the lower range of RVEF (Figure 4). In comparison, variability of $S'$ was increasing in cases with poor RVEF (Figure 3).

**Study limitations**

Aside from the limitations alluded to above, it has to be mentioned that MRI data were not obtained simultaneously with echocardiography. Considering the stable clinical condition of all the patients, it is unlikely that this relevantly affected our results.

Based on the correlations between the Doppler echo parameters for RV systolic function assessment and RVEF by MRI, the current echo methods could be generally judged quite limited. However and from a statistical standpoint of view, the accuracy of methods is based on ROC analysis, and sensitivity and specificity values between 75 and 95% in a population of the current size are regarded as satisfactory.

Tricuspid annular systolic motion primarily reflects the function of longitudinal myocardial fibres, but RVEF is influenced by both the contractility of longitudinal and concentric myocardial fibres. However, the primary function of the RV free wall is to move the atrioventricular valve ring from base towards the apex and in contrast to the LV, twisting and rotation do not contribute significantly to RV function. Limitations inherent in obtaining $S'$ such as dependency of the velocity measurement on the angle of interrogation and cardiac motion are minimized during long-axis function assessment from the apical four-chamber view. This is due to the fact that the direction of baso-apical tricuspid annular systolic motion is almost parallel to the Doppler beam and that apical cyclic cardiac motion is minimal when compared with the base. However, the variability in the data obtained in this study illustrates that the stated details specific for the chosen image projection are not absolute and that deviations from them constitute sources of $S'$ data overlap between the different RVEF groups.

The present study did not evaluate 3D volumetric echocardiography for RVEF measurement, which has been recently introduced. Most volumetric 3D matrix TTE transducers are large-sized, the fact of which frequently poses a handicap in the acquisition of images for the purpose of RV systolic function assessment and, for the time being, renders the technique much less robust than $S'$, MPI, or TAPSE in an ‘all-comers’ population.

In conclusion, a systolic long-axis peak velocity of $<11$ cm/s at the lateral tricuspid annulus most accurately detects moderately impaired RVEF as obtained by MRI; severely reduced RVEF $\leq 30\%$ is best detected by RV MPI at a value of $>0.50$. In regard to clinical relevance of all the obtained RV function parameters including RVEF by MRI, TAPSE is most predictive for survival.

**Conflict of interest:** none declared.

**References**


Effect of migraine treatment on heart

Amol Raizada1, Sathy S. Vittala1, Mohammad Q. Najib1, Patrick A. DeValeria2, and Hari P. Chaliki1*

1Division of Cardiovascular Diseases, Mayo Clinic, 13400 E Shea Blvd, Scottsdale, AZ 85259, USA and 2Division of Cardiovascular and Thoracic Surgery, Mayo Clinic, Scottsdale, AZ, USA

* Corresponding author. Tel: +1 480 301 8000, Fax: +1 480 301 8018, Email: chaliki.hari@mayo.edu

Case report

A 59-year-old woman presented for evaluation of palpitations, orthopnoea, and dyspnoea on exertion. On examination, the patient was found to have an apical holosystolic murmur suggestive of mitral regurgitation. She had no history of rheumatic heart disease but had experienced migraine headaches for which she started taking methysergide when she was 51 years old. She had no history of use of appetite suppressants. A transthoracic echocardiogram (TTE) conducted after discontinuation of the methysergide revealed mild mitral regurgitation. She subsequently used dihydroergotamine (DHE) for migraines for about 6 years. At age 59, TTE revealed severe mitral regurgitation, with thickening of the valve and restricted motion of the leaflets (Figure 1A and B).

The tricuspid valve showed partial fusion of the leaflet to the septum, with severe tricuspid regurgitation and right atrial enlargement (Figure 1C and D). Left ventricular function was normal, and there was no evidence of endocarditis. Cardiac catheterization showed normal right heart pressures and no clinically significant coronary disease. The patient underwent mitral valve replacement and tricuspid valve repair. Histopathologic findings indicated myxomatous disease of the mitral valve. Postoperatively, DHE was discontinued and the patient subsequently experienced considerable improvement in cardiac symptoms and exercise tolerance.

In contrast to carcinoid heart disease, drug-induced valve disease primarily affects the left heart valves. Although related to stimulation of serotonin receptors, the exact mechanism of preferential left-sided valve involvement is still unclear. Our case is notable because both the right- and left-sided valves were involved.

Figure 1. Transthoracic echocardiogram. (A) Parasternal long-axis view shows thickened mitral valve (arrow); (B) Apical long-axis view shows regurgitant jet across dysfunctional mitral valve; (C) right ventricular (RV) inflow view shows thickened tricuspid valve (arrow); and (D) RV inflow view shows regurgitant jet across dysfunctional tricuspid valve. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

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