Evaluation of right ventricular volume and function by 2D and 3D echocardiography compared to MRI

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Magnetic resonance imaging;
Radionuclide ventriculography

Abstract  Aims: Radionuclide techniques, and recently MRI, have been used for clinical evaluation of right ventricular (RV) volumes function (RVEF) and volumes; but with the introduction of 3D echocardiography, new echocardiographic possibilities for RV evaluation independent of geometrical assumptions have emerged. This study compared classic and new echocardiographic and radionuclide estimates, including gated blood pool single-photon emission computed tomography (SPECT) of RV size and function to RV volumes, and ejection fraction (RVEF) measured by magnetic resonance imaging (MRI).

Methods and results: Thirty-four subjects with (a) prior inferior ST-elevation myocardial infarction (n = 17), (b) a history of pulmonary embolism and persistent dyspnea (n = 7) or (c) normal subjects (n = 10) had 2D and 3D echocardiography, SPECT and MRI within 24 h.

End-diastolic volume and peak tricuspid regurgitation velocity were increased in patients with a history of pulmonary embolism compared to healthy subjects,
Introduction

Echocardiographic measurements of size and estimates of function of the left ventricle are widely used clinically, and are known to be of diagnostic as well as prognostic importance in patients with cardiac disease. Assessment of the right ventricle (RV) is challenging, as the 2-dimensional (2D) approaches to the evaluation of size and function of the RV fail to give accurate results, predominantly due to the complex anatomy of the RV, not resembling any known geometrical shape.¹

Several 2D echocardiographic measures or indices have been proposed but none have as of yet gained clinical impact. Classical parameters are RV diameter or 2D area. Newer parameters include the simple measurement of the tricuspid annular plane systolic elevation (TAPSE), where a correlation to RVEF by radionuclide methods for assessment of RV function has been found.²,³ The change in diameter of the RV outflow tract (RVOT) has also been shown to correlate to other echocardiographic measures of RV function.⁴

Radionuclide imaging has been widely used, especially first-pass ventriculography for the assessment of RV ejection fraction (RVEF), but RV volumes cannot be assessed by this method. By introduction of the newer electrocardiographically gated single-photon emission computed tomography (SPECT) used with blood pool tracers, possibilities of assessing RVEF, as well as RV volumes have emerged.⁵

Three-dimensional (3D) echocardiography has been available for some years, initially based on 3D reconstruction of 2D images, and more recently, real-time 3D echocardiographic imaging. Using 3D imaging, no geometrical assumptions are made, and thus 3D echocardiography should be more useful for the assessment of RV size and function.⁶

Evaluation of right ventricular volume and function

130 ± 26 ml vs. 94 ± 26 ml, P < 0.05, and 3.3 ± 1.1 m/s vs. 2.3 ± 0.3 m/s, P < 0.05, respectively, whereas no differences in RVEF were seen in the three groups. Echocardiographic as well as SPECT estimates of RV volume showed significant correlation to RV volumes by MRI. Tricuspid annular plane systolic excursion (TAPSE) had the better correlation to RVEF by MRI, r = 0.48, P < 0.01; whereas 3D echocardiography had a correlation of 0.42, P < 0.05. Compared to MRI, 3D echocardiography underestimated RVEF by 5.9%, 95% limits of agreement 1.6–10.2%.

Conclusion: 3D echocardiographic estimates of RV size and RVEF show only moderate correlation to MRI measures of these parameters, and simple 2D echocardiographic estimates of RV size and function show similar correlations. For routine clinical purposes the simple TAPSE may be preferred over 3D and SPECT techniques for RVEF estimation.

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subjects gave their informed consent for participation in the study, which had been approved by local scientific ethical committee, ref. no. KA 03059.

Echocardiography

Echocardiography was performed with the patient in the left decubitus position. Views and measurements were recorded according to the guidelines of the American Society of Echocardiography. Imaging was obtained using a Philips® SONOS® 7500 system (Bothell, WA) equipped with s3 and x3 transducers with real-time 3D echocardiography capability. Standard 2D and Doppler echocardiography in the parasternal and apical views, and pulsed wave tissue Doppler (PWTD) recordings of the lateral RV annular velocity. Doppler and tissue Doppler echocardiography and full-volume 3D images in the apical views of the right ventricle were recorded at end-expiration. In all cases bi-plane scout views were used to ensure the full volume scans included the anterior RV free wall and RV outflow tract. Images were stored digitally for later analysis on Philips® EnConcert® software (Bothell, WA) for 2D, Philips® Q-lab software, version 2.0 for the tissue Doppler measurements and Doppler echocardiographic images, and Tomtec® 4D Echo-view® (Unterschleissheim, Germany) for 3D echocardiographic data. Papillary muscles were not included in the volume estimation. The 3D echocardiographic images were also obtained during SonoVue® contrast (Bracco®, Italy) continuous i.v. infusion of 1 ml/min for RV opacification, using low-power imaging (Mechanical Index = 0.3–0.4).

The quality of echocardiographic recordings were graded on a 5-point scale in end-diastole and in end-systole, ranging from 0 for poor quality to 4 perfect quality. If the mean end-diastolic and end-systolic quality score was 1.5 or lower, the recordings were omitted from the analysis. 3D echocardiography was repeated within the 24-h time period to assess reproducibility.

RV dimensions measured in end-diastole and end-systole were: RV diameter in the parasternal long-axis view, RV area in the apical 4-chamber view, and 3D volume by methods of discs of 10 mm thickness in short axis to match the slice thickness used as standard in cardiac MRI at Copenhagen University Hospital, Frederiksberg. RV systolic function was assessed by: tricuspid annular plane systolic elevation (TAPSE),14 RV fractional shortening (fs) of end-diastolic and end-systolic diameters (RVD fs), RV outflow tract f (RVOT fs),4 RV fractional area change (RV fac), RV annular peak systolic velocity by pulsed wave tissue Doppler and RV ejection fraction (RVEF) by 3D volume. The isovolumic acceleration (IVA) was measured by placing a 5 × 5-mm region of interest in the tricuspid annular of the color tissue Doppler images, and calculated as the ratio of peak isovolumic velocity to time to peak isovolumic velocity.12

Radionuclide techniques

**First-pass radionuclide ventriculography (FP)** (FP) is a count-based technique independent of right ventricular geometry. Calculation of right ventricle ejection fraction (RVEF) is based on the assumption that there is proportionality between count rate and blood volume in the right ventricular cavity in diastole and systole. FP was performed using a bolus of 700–900 MBq of 99mTc-labeled human serum albumin and a small field-of-view gamma camera (Trans Cam, Philips Medical Systems) positioned in RAO 30°. FP does not allow for direct calculation of RV volumes.

**Gated blood-pool SPECT** is a volumetric technique based on visualization of the contour of the 99mTc-labeled blood pool in the right ventricular cavity in diastole and systole. RVEF calculation is a mean of many cardiac cycles. GBPS was performed by a dual-headed, orbiting gamma camera (Forte EPIC Camera, Philips Medical Systems) at equilibrium following the FP study. RVEF, right ventricular end-diastolic volume and right ventricular end-systolic volume (RVESV) were automatically calculated using GBPS software (Blood Pool Gated SPECT v. 1.0, Cedars-Sinai Medical Center, Los Angeles, CA, USA installed on a ultra workstation). Prior to the calculation, images were manually re-orientated and reconstruction limits manually set.

**Magnetic resonance imaging (MRI)** is a volumetric technique based on visualization of the anatomy of the right ventricle, which does not require injection of contrast agent. The technique gives precise anatomical information. MRI was performed on a 1.5-T whole-body scanner (Intera, Philips) using a dedicated phased array cardiac coil (Synergy, Philips). Following localization of the long axis of the heart, contiguous true short-axis slices were acquired using breath-hold, ECG-triggered cine MRI. Slices were obtained during one breath-hold of 6–10 s. Typically, the heart was covered by 10–15 slices of 10 mm. The number of phases obtained was 30. The field of view was 320 mm with a matrix of 256 × 256. A turbo field echo (B-TFE) M2D cine MRI with breath hold was used (Intera, Philips, release 10.3). The sequence parameters were Relaxation time TR = 3.2 ms, Echo time TE = 1.6 ms and Flip angle FA = 60°. The endocardial
contours of the right ventricle were traced manually on all phases and slices using standard software (Philips ViewForum release 3.2). On the most basal slice, the right atrium and the pulmonary artery was avoided. The analysis we started in all cases with viewing the slice dynamically in movie-mode to get an overall impression of movements, including shortening and to visualize the functional separation of right ventricle and atrium. Following that, the endocardial contour was drawn on all phases. The end-systole and end-diastole frames were defined as the phases with highest and lowest volume, respectively. In practice, this lead to phase one always being end-diastole. Right ventricle end-systole was not always the same as end-systole of the left ventricle but could be one phase apart. RV end-diastolic and end-systolic volumes and RVEF and were then automatically calculated adding the volumes of each slice.

**Statistical issues**

Mean and standard deviation (SD) and number and percentage were calculated for continuous and categorical variables, respectively. Differences tested with $t$-test or $\chi^2$-test, as appropriate. Differences between groups were tested with ANOVA, and differences evaluated by Tukey’s test.

The measures of RV size and function were compared by linear regression, correlation coefficient and the standard error of the residuals (SEE) using MRI as reference. For comparable values mean difference were plotted against the average and 95% limits of agreement were calculated, defined as mean difference $\pm 1.96$ SD as proposed by Bland and Altman. For RVEF, values are calculated as percentage and the SEE and absolute differences are given in percentage points.

Reproducibility of the 3D echocardiographic measurement of RV volumes were assessed by coefficient of variation (CV%) on repeated analysis of the same recording in all patients, as well as on repeated recordings in 15 patients. All computations were performed using the SAS statistical software, version 9.1 (Cary, NC).

**Results**

No differences in age, sex, blood pressures, heart rate or left ventricular function were found in the three groups. Patients with a history of pulmonary embolism had higher RV systolic pressures, as estimated by maximal tricuspid regurgitation velocity, compared to normal subjects, as well as to patients with prior myocardial infarction, see Table 1. RV end-diastolic volumes were larger in the group of patients with a history of pulmonary embolism, compared to normal subjects.

A close association between the RV and left ventricular stroke volumes measured by MRI was seen, $r = 0.94$, $P < 0.0001$, SEE 5.4 ml. MRI estimated end-diastolic volume overall at $111 \pm 28$ ml, end-systolic volume at $48 \pm 23$ ml, and RVEF at $58 \pm 13\%$. The echocardiographic recordings were of sufficient quality in 32 patients (94%) for measurements of RV diameter, in 28 (82%) for the RV area and IVA, in 30 (88%) for the 3D echocardiographic imaging and in 32 patients (94%) for the gated blood-pool SPECT study. Mean frame rate for the color tissue Doppler imaging was $122 \pm 10$ frames per second.

Significant correlations between RV volumes measured by 2D echocardiography, by 3D

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Characteristics of patients and subjects included in the study</th>
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<tbody>
<tr>
<td></td>
<td>Ischemic heart disease</td>
</tr>
<tr>
<td>Age (years)</td>
<td>$68 \pm 10$</td>
</tr>
<tr>
<td>Gender (females)</td>
<td>7 (41%)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>$77 \pm 14$</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>$176 \pm 10$</td>
</tr>
<tr>
<td>Blood pressure, systolic (mmHg)</td>
<td>$130 \pm 27$</td>
</tr>
<tr>
<td>Blood pressure, diastolic (mmHg)</td>
<td>$77 \pm 13$</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>$64 \pm 10$</td>
</tr>
<tr>
<td>MRI left ventricular ejection fraction (%)</td>
<td>$60 \pm 10$</td>
</tr>
<tr>
<td>MRI Right ventricular end-diastolic volume (ml)</td>
<td>$113 \pm 30$</td>
</tr>
<tr>
<td>Maximal tricuspid regurgitation velocity (m/s)</td>
<td>$2.46 \pm 0.35$</td>
</tr>
</tbody>
</table>

Data shown as mean $\pm$ SD or number(percentage). NS, not significant. $^*P < 0.05$ vs. normal subjects, $^1P < 0.05$ vs. patients with ischemic heart disease; $^2P$-value from $\chi^2$-test.
echocardiography or gated blood-pool SPECT was observed using MRI as reference, see Table 2, but SEE varied from 17 to 24 ml. On average, no differences in the measurements of volume were found; only a small non-significant trend towards overestimation of volumes by 3D echo and underestimation of volumes by GPBS was observed. Wide limits of agreement of up to ±61 ml for end-diastolic volumes and ±56 ml for the end-systolic volumes were found, with the widest limits found in gated blood-pool SPECT. Bland–Altman plots for of the measurements of diastolic and systolic volumes, and RVEF is shown in Fig. 1. Results of the linear regression of 3D echocardiographic estimates of RV volumes are shown in Fig. 2.

The RVEF estimated by MRI showed significant correlation to TAPSE, RVD fs, RVOT fs and 3D echocardiography, whereas no correlation with RV fac, systolic annular velocity or IVA was found, see Table 3. The RV annular systolic velocity was 15 ± 4 cm/s but did not correlate to RVEF by MRI, r = 0.18, not significant (NS), SEE = 12%. IVA was 1.83 ± 0.63 m/s², r = 0.15, NS, SEE 11%. First-pass ventriculography was significantly correlated to RVEF by MRI, but gated blood-pool SPECT failed to show a significant relation the RVEF by MRI. Wide SEE of 11–12% was found for all methods. 3D RVEF underestimated RVEF by about 8% and wide limits of agreement were found for all comparisons. In Fig. 3 the results of the linear regression of the relation of echocardiographic estimates RVEF to MRI are shown.

If contrast was administered for RV opacification in the real-time 3D echocardiography, the correlation of RV volume and RVEF estimation to MRI were low and non-significant, r = 0.05, r = 0.06, and r = 0.06 for end-diastolic and end-systolic volumes and RVEF, respectively. No adverse events were seen during the infusion of SonoVue® contrast.

Reproducibility of analysis of the 3D echocardiographic recordings without contrast were CV% = 4, CV% = 9 and CV% = 8 for repeated analysis on the same recording, and CV% = 10, CV% = 15 and CV% = 11 for analysis of repeated recording done in two visits with-in the 24-h limits for RV end-diastolic, end-systolic volumes and RVEF, respectively.

Discussion

3D echocardiography is a new modality in ultrasound allowing us to overcome the limitations of 2D echocardiography, where assumptions of geometric shapes of the right ventricle are rarely applicable. This study is the first head-to-head comparison of classic and recently developed echocardiographic and radionuclide approaches to the assessment of RV volume and function in a single population.

Significant correlations between estimates of volumes and ejection fraction from echocardiographic and radionuclide methods compared to the MRI were found. Only minor systematic errors of RVEF estimates were observed, but with relatively wide variation between the methods, limiting the use of the methods interchangeably.

3D echocardiography

The feasibility of 3D echocardiography was 88% in the present study, which is comparable to the findings of 3D echocardiography measurements of the left ventricle, and better than previously published series of 3D echocardiography in the RV.

Earlier studies have used reconstructed 3D echocardiographic images from rotational 2D images of the RV. To the best of our knowledge

| Table 2 | End-diastolic size of the RV compared to end-diastolic volume measured by MRI |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Mean ± SD       | Mean diff. (95% CI) | 95% LOA          | Correlation coefficient | SEE |
| End-diastole    |                 |                  |                  |                  |      |
| 2D RVD (cm)     | 2.7 ± 0.5       |                  |                  | 0.58*            | 23 ml|
| 2D RVA (cm²)    | 20 ± 5.4        |                  |                  | 0.50*            | 22 ml|
| 3D RV volume (ml)| 116 ± 29        | 5.4 (−4.7 to 15.5) | −49 to 60        | 0.56*            | 24 ml|
| Blood-pool SPECT (ml)| 105 ± 32 | −4.8 (−15.8 to 6.2) | −66 to 56 | 0.47* | 24 ml |
| End-systole     |                 |                  |                  |                  |      |
| 2D RVD (cm)     | 1.9 ± 0.7       |                  |                  | 0.67*            | 17 ml|
| 2D RVA (cm²)    | 11.6 ± 3.4      |                  |                  | 0.57*            | 18 ml|
| 3D RV volume (ml)| 57 ± 19        | 8.0 (0.90 to 15.2) | −30 to 46        | 0.62*            | 19 ml|
| Blood-pool SPECT (ml)| 46 ± 22 | −2.0 (−10.2 to 6.2) | −47 to 44 | 0.45* | 20 ml |

Values as mean ± standard deviation (SD); CI, 95% confidence intervals of the mean; LOA, 95% limits of agreement; SEE, standard error of the estimate in linear logistic regression. 2D, 2-dimensional echocardiography; RVD, right ventricle diameter; RVA, right ventricular area; 3D RV, 3-dimensional echocardiography. *P < 0.05, †P < 0.01, ‡P < 0.001.
this study is the first to evaluate the newer real-time 3D imaging technology in the RV. Studies of the left ventricular volumes by real-time 3D imaging have found good correlation of classical equilibrium radionuclide ventriculography and MRI.\textsuperscript{15,17,18} Compared to MRI, 3D echocardiography slightly overestimated RV end-diastolic and end-systolic volumes, although the level of overestimation was not statistically significant. Earlier studies, not using real-time technology, also found no significant bias.\textsuperscript{19,20}

In animal studies of excised hearts and in unselected smaller populations, correlations between MRI and rotational 3D echocardiography of the RV have been found to be good. In 1998 Papavassiliou et al. reported an SEE of 9 ml equal to 16% for end-diastolic volume measurements in heterogeneous group of children with congenital heart disease.\textsuperscript{8,16,19–21} A significant correlation to RV volumes measured by MRI was found in the present study, although the SEE of 21% for diastolic volumes suggests more variation than found in earlier studies. Considering previously established intra-observer variation in the measurements on MRI and the unselected nature of the population with only a limited range of RV volumes and preserved RV function in most patients, a weaker correlation between the echocardiographic and radionuclide measurements and the MRI would be expected. End-systolic volumes by 3D echocardiography were relatively less accurate (SEE of 33%) than end-diastolic volumes, which is in concordance with earlier studies.\textsuperscript{16,21}

RVEF was underestimated by 3D echocardiography, but was still significantly correlated to RVEF by MRI, confirming the tendency that has been reported in earlier studies.\textsuperscript{16} The reproducibility of the analysis of RVEF and 3D volumes, as assessed by repeated recordings, were acceptable. Possible reasons for the differences between the MRI and 3D echocardiographic estimates of RV volume and function include difficulties in delineating the endocardial borders and valvular planes, artifacts due to the respiratory motion during acquisition. In our experience the main reasons are problems visualizing the anterior RV free wall due to its retrosternal position, even though the 3D full-volume scans were acquired.
with special care to include all parts of the RV free wall. The TomTec system allows for post-processing which increase the ability of the reader to delineate the valvular planes, which were visible in most patients. The patients were instructed to hold their breath for the duration of the 5–10 s of acquisition of the full volume, and images with obvious artifacts were repeated. 3D echocardiography does not overcome problems with poor echocardiographic windows, and the time required to acquire the images could negatively influence the accuracy and precision of the measurements. Harmonics and increasing the size of the imaging sector can potentially limit these problems, when the 3D technology is further developed.

**Contrast enhanced 3D echocardiography**

The use of saline contrast for opacification with 3D echocardiography has been addressed in an earlier study that found the method to be feasible. In the present study we used SonoVue infusion, which gives a constant level of opacification of the cavity, which is useful with low-power imaging (Mechanical Index = 0.3) for the image acquisition. However, no relation of the measured values to the MRI volumes was found. Difficulties in delineating the anterior wall and identifying the tricuspid and, in particular, the pulmonary valvular planes, were experienced during the analysis. Thus contrast echocardiography and low-power imaging did not improve the accuracy of RV volume estimation by 3D echocardiography the in present study, as was found for 2D echocardiography of the LV. Further studies may explore the effect using high power imaging and/or reducing the amount of contrast infused.

**2D echocardiography**

The RVD and RVA were significantly related to RV volumes measured by MRI as shown in a previous study. The TAPSE as an estimate of RVEF has previously been shown to be correlated to RVEF measured by first-pass ventriculography. The level of correlation between TAPSE and RVEF by MRI in the present study was superior to that of the radionuclide techniques and 3D echocardiographic estimates of RVEF. Significant variation in the estimate was found, however, with a SEE of 11%. The RVEF as

![Figure 3](image)

**Figure 3** Linear regression (solid line) of RVEF by 3D echocardiography and tricuspid annular plane systolic excursion compared to MRI. Symbols represent groups according to legend.

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**Table 3** Estimates of RV ejection fraction (RVEF) compared to MRI

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Mean difference (95% CI)</th>
<th>95% LOA</th>
<th>Correlation coefficient</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D TAPSE (cm)</td>
<td>2.3 ± 0.5</td>
<td>—</td>
<td>0.48</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>2D RVD fs</td>
<td>0.32 ± 0.11</td>
<td>—</td>
<td>0.43</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>2D RVOT fs</td>
<td>0.45 ± 0.12</td>
<td>—</td>
<td>0.37</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2D RVA fac</td>
<td>0.40 ± 0.10</td>
<td>—</td>
<td>0.34</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>3D RVEF (%)</td>
<td>51 ± 7</td>
<td>−5.9 (−10.2 to −1.6)</td>
<td>−28 to 16</td>
<td>0.42</td>
<td>11%</td>
</tr>
<tr>
<td>FP RVEF (%)</td>
<td>60 ± 6</td>
<td>1.4 (−2.7 to 5.6)</td>
<td>−23 to 23</td>
<td>0.38</td>
<td>12%</td>
</tr>
<tr>
<td>Blood-pool SPECT RVEF (%)</td>
<td>58 ± 13</td>
<td>−0.3 (−6.1 to 5.6)</td>
<td>−33 to 31</td>
<td>0.12</td>
<td>12%</td>
</tr>
</tbody>
</table>

*Values as in Table 2. TAPSE, tricuspid annular plane systolic elevation; fs, fractional shortening; FP, first-pass ventriculography. *P < 0.05, ^P < 0.01.*
estimated RVD fs, but not the RVA fac, was significantly correlated to RVEF by MRI. In an earlier study, the RVD as well as the RVA fac were correlated to RV end-diastolic volume by MRI; another study found that the RVA fac was correlated to RVEF by MRI and to RVEF by first-pass ventriculography. The feasibility of RVA measurements is lower than for the other echocardiographic parameters, since the entire endocardium has to be visible in end-diastole and in end-systole. The RVOT fs has previously been found to be related to other echocardiographic measures of RV function, but the present study is the first to evaluate this parameter using MRI as gold standard. The RV annular velocity by pulsed wave tissue Doppler has previously been found to correlate to RVEF by first-pass ventriculography, but no association to MRI or first-pass ventriculography (data not shown) could be demonstrated in the present study. The IVA is a promising new parameter, closely correlated to RV contractility in an animal model, and unaffected by changes in pre- and afterload. The relation between IVA and volumetric RVEF as used for RVEF estimation by MRI has not been demonstrated, and thus the lack relation to RVEF found in the present study is not inconsistent with a close relation to RV contractility. Data on the contractility were not available in the present study.

Even if RVEF estimates from radionuclide methods had a significant correlation to MRI, these methods were no better than the echocardiographic methods in the present study, as judged by the SEE of the regression line.

MRI

In the present study MRI was used as reference in the assessment of RV volumes. MRI has been validated in several earlier studies and has been found to be very accurate in vitro and precise in vivo. The axial orientation of the disks used for the volumetric measurements during breath hold as used in the present study has been found to give accurate results and good reproducibility. Papillary muscles were not included in the volume estimations as the bias induced by inclusion of the papillary muscles is small and insignificant.

In earlier studies the reproducibility of measurements of volumes in repeated recordings is 6% for end-diastolic and 14% for end-systolic volumes, and 8% for RVEF, which is a little poorer than for the reproducibility of measurements of the left ventricle. Furthermore, in a thorough study, Pattynama et al. reported that the intra-observer variation by far was the major contributor to the total variation seen in volume measurements of the RV using MRI. As no serial measurements were performed in the present study, accuracy was the important parameter. The subsequent comparison of left ventricular to right ventricular stroke volume suggest that the accuracy of volume measurements by MRI in the present study is good. The correlation between RV and left ventricular stroke volumes found in the present study corresponds to findings of an earlier study.

Study limitations

The correlation of measures of RV volumes and RVEF to MRI overall were lower than found in previous studies, but the SEE using MRI as reference corresponds to findings in earlier studies. The limited range of RV volumes in the population studied may explain this. We were therefore unable to evaluate the methods for very large and very small RV volumes and RVEF. The study population does, however, resemble everyday clinical patients.

Conclusions

Real-time 3D echocardiography, although able to measure RV volumes and function without geometric assumptions, proved no better than 2D echocardiographic estimates of RV volumes in a population of everyday patients. TAPSE, as a simple echocardiographic measure, may be the better approach for evaluation of RV function.

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