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Accuracy of quantitative echocardiographic measures of right ventricular function as compared to cardiovascular magnetic resonance

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ABSTRACT

Background: Many echocardiographic parameters have been proposed to evaluate right ventricular (RV) systolic function. We comprehensively assessed a wide range of quantitative echocardiographic parameters in a single cohort compared with same-day cardiovascular magnetic resonance (CMR).

Methods and results: 92 subjects were examined prospectively: Group 1 consisted of 46 healthy controls (21 males, 33.4 ± 11.4 years), Group 2 consisted of 46 patients (20 males, 38.5 ± 18.9 years) undergoing RV functional assessment by CMR (1.5 T). Echocardiography was performed on the same day as CMR; fractional area change (RVFAC), myocardial performance index via spectral Doppler (RVMPI), RVMPI via Doppler tissue imaging (RVMPI-DTI), peak systolic myocardial velocity by DTI (RVSm), tricuspid annular plane systolic excursion (TAPSE), speckle tracking strain, and three dimensional right ventricular ejection fraction (3DE-RV). Linear regression, Bland–Altman and receiver-operator-characteristic (ROC) analyses were performed. At ROC analysis, the most predictive echocardiographic methods were; RVFAC (AUC = 0.892), RVMPI (AUC 0.785), TAPSE (AUC 0.849) and 3DE-RV (AUC 0.909). 3DE-RV appeared the most accurate compared to CMR, although underestimated true RV volumes.

Conclusion: As compared to CMR; 3DE-RV, RVFAC, TAPSE and RVMPI were the most reliable predictors of RV function. These parameters can be recommended for clinical use.

1. Introduction

Right ventricular (RV) systolic function is prognostically significant in the management of various cardiac conditions including many congenital abnormalities, cardiomyopathy, heart failure, valvular pathologies, and pulmonary hypertension [1–4]. Accurate quantitative assessment of this chamber is crucial for informing clinical decisions [5].

Several echocardiographic parameters for the quantitative assessment of RV systolic function have been studied (Table 1). Each method, however, has limitations. Echocardiographic methods are challenged by the uniquely crescentic and highly trabeculated anatomy of the RV. The RV is also positioned retro-sternally and anterior to the LV which can result in a differing size and functional appearance depending on the axis in which it is viewed [6].

At the present time, transthoracic echocardiography (TTE) is the most commonly used method for assessing RV function as it is non-invasive, inexpensive and widely available throughout hospitals and private institutions.

We comprehensively assessed a wide range of quantitative echocardiographic parameters of RV function in a single, large cohort compared with the reference standard of cardiovascular magnetic resonance (CMR). We aimed to identify the most accurate parameters for predicting quantitative RV systolic function, and thence to derive normal cut-off values which could be incorporated into routine TTE examination.

Abbreviation: 3DE-RV, three-dimensional echo right ventricular ejection fraction; CMR, cardiovascular magnetic resonance; DTI, Doppler tissue imaging; ε, strain; EF, ejection fraction; IVCT, isovolumic contraction time; IVRT, isovolumic relaxation time; LV, left ventricle; MPI, myocardial performance index; RVSm, peak systolic myocardial velocity; 3DE, three dimensional echocardiography; RV, right ventricular; RVOT, right ventricular outflow tract; RVSm, s prime: right ventricular peak systolic myocardial velocity; SR, strain rate; TAPSE, tricuspid annular peak systolic excursion; TOF, tetralogy of Fallot; TR, tricuspid regurgitation.

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Table 1
Echocardiographic methods & limitations for the assessment of RV function.

Echocardiographic method	Limitations
Qualitative assessment	Inter-observer variability, poorly defined endocardium (8).
RV Ejection Fraction	Poorly defined endocardium, requirement of 2 orthogonal views with a common long axis and failure to include the infundibulum (9). Relies on geometric assumptions (8).
Doppler Tissue Imaging (DTI)	Does not take segmental function into account, is affected by load and heart rate (9). Is sensitive to Doppler cursor alignment.
Three-dimensional echocardiography (3DE) (8)	Requires high quality images of the right ventricle, poorly defined endocardium produces inaccurate results (10).
Myocardial Performance Index (MPI) (11)	Does not take segmental function into account, is affected by load and heart rate (9).
Tricuspid annular peak systolic excursion (TAPSE) (12)	Is sensitive to Doppler curser alignment, does not take segmental function into account, is affected by load and heart rate (9).
Doppler Strain (ε) and Strain Rate Imaging (6)	Angle dependent, poor signal to noise ratio and is load sensitive (13). Is sensitive to Doppler curser alignment.
2D Strain (ε) and Strain Rate Imaging (6)	Motion of myocardium perpendicular to the ultrasound beam has a higher degree of error than DTI strain, through plane motion (affecting the arrangement of speckles between frames) could result in errors, lower temporal resolution (17)

2. Methods

This study was approved by the local human research ethics committee, and all participants gave informed consent.

We examined a total of 92 subjects in a prospective manner: Group 1 consisted of 46 healthy age-matched control subjects investigated under the study protocol; Group 2 consisted of 46 patients undergoing routine clinical CMR for quantitative evaluation of RV function. All subject's age, gender and body surface area (BSA), were recorded at the time of the study. Table 2 lists the demographics and clinical characteristics of subjects within each group. The majority of the subjects in group 2 were being evaluated by CMR for congenital heart disease, including tetralogy of Fallot, arrythmogenic right ventricular dysplasia, Ebstein's anomaly, pulmonary hypertension and septal defects (Table 3). Of the subjects in group 2, 13 subjects (29%) were found to have pulmonary hypertension by echo (RVSP >40 mmHg) and 17 subjects (38%) were found to have grade ≥ 2/4 tricuspid regurgitation (TR). The controls were assessed by a consultant cardiologist for normal cardiac status via a standard 12-lead ECG, blood pressure assessment, clinical examination and a questionnaire. One test patient was excluded due to limitations of the CMR equipment (non-compatible implant). The population group was indicative of a 'real life' data set in that no patients were excluded due to poor image quality and all measurements were able to be obtained.

3. CMR assessment

CMR imaging was performed on a 1.5 Tesla GE Signa Twinspeed system (GE Medical Systems, Milwaukee, WI, USA) with an 8-element cardiac phased array coil. Cine images were acquired using a steady state free precession (SSFP) acquisition (TE 1.3 ms, TR 3.0 ms, flip angle 45, bandwidth +/− 125 kHz, FOV 35 cm, slice thickness 8 mm, gap 2 mm, matrix 224 × 224, number of averages 1). Twenty cardiac phases per slice location were reconstructed. All images were acquired at end expiration using respiratory bellows. Quantitative analysis of the right ventricle (including end diastolic volume, end systolic volume and ejection fraction) was performed using the modified RV short axis series, which has been shown to have increased accuracy and reproducibility [7].

Table 2
Demographic and clinical characteristics of study groups.

Parameter	Control (group1)	Test (group2)
Gender (M:F)	21:25	20:25
Age (yrs)	33.4 ± 11.4	38.5 ± 18.9
BSA (m^2)	1.84 ± 0.20	1.79 ± 0.24

Age and BSA values are expressed as mean ± standard deviation.

4. Echocardiographic assessment

Echocardiography was performed on the same day as CMR using a commercially available ultrasound platform (iE33, Philips Medical Systems, Andover, Massachusetts) with an S5–1 transducer and an X3–1 matrix-array transducer. Two-dimensional (2D), motion-mode (M-mode), Pulsed-wave (PW) Doppler, Continuous-wave (CW) Doppler, DTI and three-dimensional (3DE) imaging was performed primarily from standard apical 4-chamber view. Atypical views were not utilized in this study to ensure reproducibility. RV quantitative parameters were consistent with current American Society of Echocardiography (ASE) guidelines [8] and acquired as follows; fractional area change (RVFAC), myocardial performance index via spectral Doppler (RVMPI), RVMPI via Doppler tissue imaging (RVMPI-DTI), peak systolic myocardial velocity by DTI (RVSm), tricuspid annular plane systolic excursion (TAPSE), strain (ε) and strain rate (SR) rate via DTI, ε and SR via speckle tracking, and three dimensional right ventricular ejection fraction (3DE-RV). Images were stored digitally on the Prosolv database (Prosolv Cardiovascular Analyser, Indianapolis). 3D images were obtained from the apical 4-chamber view with the patient in the left lateral decubitus position. Full volume loops were acquired over four cardiac cycles with held respiration and analysis of RV function was performed offline. Strain and SR images were obtained from the apical 4-chamber view, and a clip of three consecutive cycles obtained for off line analysis. Using QLAB software (Philips), 3DE-RV and peak ε/SR systolic velocities were taken at the basal, mid and apical segments. The RV systolic period was defined as the time from pulmonary valve opening (PVO) to pulmonary valve closure (PVC).

5. Statistical analysis

Continuous variables are expressed as mean ± standard deviation (SD) unless otherwise stated. Demographic and clinical characteristics of the subject groups were assessed for significant differences using a two-tailed t-test assuming equal variances.

To compare test modalities (CMR and echo parameters) for significant similarity based on the raw data, Kendall's tau non-parametric correlation analysis was performed. Linear regression analyses were performed to assess the relationship between CMR and echo parameters. The CMR RVEF parameter was identified as the dependent variable while the echo parameters of RV function assessment were identified as the independent variables. For 3D RVEF, CMR REVF and volume comparisons, Bland–Altman analysis was performed to assess the level of agreement. The results of all testing parameters including CMR and echo parameters were placed into the categories of normal or abnormal RV function based on published values. McNemar Chi-squared analyses were conducted to evaluate for normal and abnormal RV function as referenced by CMR. Correlation coefficients were computed for the seven RV function analysis methods, being 3DE-RV, RVFAC, RVMPI, RVMPI (DTI), RVSm, TAPSE and ε and SR (18 parameters as identified in Table 3). Using the modified Bonferroni approach to control for Type 1 errors across the 18 correlations, a p value of less than 0.01 was required for significance. Receiver operating characteristic curves were then applied to evaluate the predictive ability of echo parameters compared to CMR RVEF.