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Evaluation of the right ventricle: Comparison of gated blood-pool single photon electron computed tomography and echocardiography with cardiac magnetic resonance

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ABSTRACT

Background: The evaluation of the right ventricle (RV) is a challenge; as a result six transthoracic echocardiography (TTE) parameters have been suggested. While gated blood-pool single photon electron computed tomography (GBPS) is a promising technique, there is currently no completely automated and validated processing software available clinically. Consequently, cardiac magnetic resonance (CMR) imaging remains the gold standard for RV assessment. We aimed to compare RV evaluation by GBPS and TTE to CMR.
Methods: Fifty-eight patients underwent CMR, GBPS and TTE for RV assessment, including volumes, RVEF and TTE's indices of RV function (fractional area change (FAC), RV myocardial performance index by pulsed wave Doppler (MPI-PWD) and tissue Doppler (MPI-TDI) and tricuspid annular plane systolic excursion (TAPSE) by M-Mode and tissue Doppler (TAPSE-TDI)). GBPS was performed using both a commercial (QBS) and the Montreal Heart Institute (MHI) proprietary software.
Results: Nuclear medicine derived volumes quantification showed very good correlations with CMR, for RV end-diastolic ($r = 0.84$ and 0.77, all $p < 0.001$) and end-systolic ($r = 0.82$ and 0.67, all $p < 0.001$) volumes by MHI and QBS software respectively. RVEF showed a significant correlation with CMR in patients with RVEF ≤45% ($r = 0.54$, $p = 0.029$ and $r = 0.55$, $p = 0.028$, by MHI and QBS respectively). Among TTE parameters, only FAC and MPI-TDI were significantly correlated with CMR-RVEF, mainly for RVEF ≤45% ($r = 0.63$, $p = 0.011$ and $r = 0.58$, $p = 0.046$).
Conclusions: GBPS, both with MHI and QBS software, exhibited significant correlations with CMR for evaluation of the RV (volumes and decreased RVEF estimation). Among TTE's parameters, only FAC and MPI-TDI showed significant correlation with CMR with RVEF ≤45%.

1. Introduction

Right ventricular (RV) function carries an important prognostic value in many cardiovascular and pulmonary conditions [1–4]. Cardiac magnetic resonance imaging (CMR) is currently the gold standard to quantify RV volumes and function [5,6], but its widespread utilization is limited by availability, cost and contraindications such as the presence of pacemakers or defibrillators. Transthoracic echocardiography (TTE) is readily available and many parameters have been shown to correlate with right ventricular performance [7–12], although precise RV ejection fraction (RVEF) quantification is difficult owing to the peculiar geometry of the RV. In addition, poor acoustic windows and experience may further limit TTE use [6].

Nuclear medicine methods provide accurate and reproducible quantification, not only for left ventricular evaluation, but also for RVEF. First pass planar equilibrium radionuclide angiocardiography (FPRNA) is currently the technique of choice because it allows temporal separation of structures that are spatially superimposed [5,13]. However it has many limitations such as being technically demanding, cannot provide volumetric estimate, with results highly dependent on the quality of the injected bolus [14] and is less reliable in the presence of arrhythmias [5]. Gated blood-pool single photon electron computed tomography (GBPS) offers adequate 3D resolution of the cardiac chambers, without

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the need for multiple acquisition views. Its acquisition and processing are more efficient than with FPRNA [14], while providing reliable evaluation of RVEF compared to FPRNA and CMR [14–17]. Unfortunately, the absence of completely automated and clinically validated processing software limits the utilization of this promising technique for RV evaluation. In addition, it is unclear whether the strict quantification of RVEF carries the same prognostic weight as quantitative LVEF; consequently, data are usually dichotomized between patients with low (≤45%) and normal (>45%) RVEF [18,19], based on previous CMR reports describing as normal an RVEF between 45% and 60% [20–25].

The purpose of this study is to compare the evaluation of RV function by GBPS and TTE to the gold standard CMR. Secondary objectives are to evaluate the accuracy of a recently developed GBPS algorithm (MHI) [26,27] for RV assessment (RVEF, RV end-diastolic (RVEDV) and end-systolic volumes (RVESV)), compared to a commercially available automatic software and CMR. Data were divided a priori between normal and low RVEF.

2. Methods

Seventy-two consecutive patients referred to the Montreal Heart Institute Nuclear Medicine Department for the assessment of ventricular function, from May 2006 to September 2008, were approached and 58 were included (14 patients presented exclusion criteria or refused to participate). A detailed description of the protocol has been previously published [28]. Exclusion criteria included pregnant or breast-feeding, hemodynamic instability, acute cardiac event, uncontrolled arrhythmias or any contraindication to CMR.

2.1. Cardiac magnetic resonance imaging

CMR was performed using a 1.5-T scanner (Philips Achieva, Release 1.5.4.7, Best, Netherlands). Ventricular function acquisitions were carried out in ECG-gated "white blood" cinema, in steady state of free precession (balanced turbo-field echo). RV endocardial contours were manually drawn by a single experienced cardiologist for every ventricular slice at end-diastole and end-systole in short axis view. Ventricular volumes represented the summation of all appropriate slices determined from the product of cavity area and slice thickness.

2.2. Radionuclide ventriculography

GBPS is a volumetric technique based on determination of the end-diastolic and end-systolic contours of the 99mTc-labeled blood pool in the RV cavity. Labeling of autologous red blood cells was performed as usual, with intravenous administration of cold stannous pyrophosphate followed 20 min later by 1110 MBq of 99m technetium. A triple-head gamma camera (Prism 3000S, Picker Corporation, Cleveland, Ohio) was used to collect images in 63 projections over a 360° ellipsoidal arc.

2.3. Calculation methods

2.3.1. QBS segmentation

QBS ventricular segmentation was performed by applying a ventricular mask that excludes activity from the atria and extra-cardiac structures [29]. Ventricular surfaces were spatially and temporally used to compute RVEDV, RVESV, and RVEF. Region of interest (ROI) was then defined using dynamic ventricular surfaces, considering only voxels over 35% of the maximum of the ventricular region. A time activity curve (TAC) for these ROIs was used to estimate count-based RVEFs.

2.3.2. MHI segmentation

This software consists of a fully automated algorithm that may be assisted by simple manipulation. Two isosurfaces are estimated to the left and right of the septum under the valvular plane and are then replaced by a 3D self-organizing map based on the invariance of the Laplacian. ROI are determined by the software and manually evaluated by the user. TAC curves are computed from these ROIs and the RVEF is estimated.

2.4. Transthoracic echocardiography

Transthoracic echocardiograms were performed using a GE Vivid-7 (General Electric Medical System, Milwaukee, USA) ultrasound system. The RV function was assessed using five different methods: fractional area change (FAC) [12], myocardial performance index by pulsed wave Doppler (MPI-PWD) [30], myocardial performance index by tissue Doppler Imaging (MPI-TDI) [11], tricuspid annular plane systolic excursion (TAPSE) by M-Mode and by tissue Doppler (TAPSE-TDI) [7,8]. For each parameter, measurements from three (in sinus rhythm) to five (in atrial fibrillation) beats were averaged and data analysis was performed off-line. The two MPI indices (MPI-PWD and MPI-TDI) were not measured in patients found to be in atrial fibrillation during the exam. Data analysis was performed by a single experienced echocardiographer while blinded to CMR and radionuclide ventriculography results. A second sonographer analyzed all the TDI tracings.

The protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the Montreal Heart Institute's research and ethics committees. All patients signed informed consent form.

2.5. Statistical methods

Analyses were performed using IBM SPSS Statistics 19.0 and SAS 9.2 programs. Differences between baseline characteristics for patients with RVEF ≤45% and >45% were measured with chi-square test. Correlations for GBPS and the 5 RV-echocardiographic parameters with CMR were evaluated by Pearson test and univariate linear regression. Systematic biases for the same parameters compared to CMR were evaluated by Bland–Altman paired absolute differences with univariate linear regression. Receiver operating curves analysis was performed for every parameters using CMR as the state variable with a cut-off of ≤45% as abnormal. A p value <0.05 was considered statistically significant.

3. Results

The baseline characteristics and mean results for CMR, GBPS and TTE parameters are presented in Table 1. Results are divided between low (≤45%) and normal (>45%) RVEF, as measured by CMR. A total of 58 patients were included in the study; three had severe RV dysfunction with RVEF ≤30%, and none exhibited features of congenital heart disease, moderate to severe right-sided valvular involvement (TR > 2/4) or RV dysplasia. Ischemic cardiomyopathy was prevalent in both the low- and normal-RVEF groups. Mean delay was 13.2 ± 11.4 days between radionuclide and CMR studies, 1.9 ± 3.7 days between echocardiography and CMR and 14.5 ± 12.5 days between radionuclide and echocardiography. All patients underwent a comprehensive TTE exam with comprehensive evaluation of RVEF, RVEDV and RVESV by GBPS with the MHI algorithm and 55 patients had evaluation with QBS software. Mean RVEF and volumes by GBPS and TTE RV function parameters are presented in Table 2.

Correlation coefficients between CMR, radionuclide and echocardiography are presented in Table 3. Linear regression and corresponding Bland–Altman graphics for RVEF and echocardiographic parameters are presented in Fig. 1 (only the statistically significant parameters are presented). Linear regression and the corresponding Bland–Altman graphics for volumes are presented in Fig. 2. MHI algorithm exhibited a strong correlation with CMR for evaluation of RVEDV and RVESV in both groups of RVEF ($r = 0.79$ and 0.81 for RVEF ≤45%, respectively; 0.84 and 0.77 for RVEF >45%, respectively; all $p < 0.001$). Correlation

Table 1
Baseline characteristics of the patients.

Characteristic	All, $N = 58$	RVEF >45%, $N = 42$	RVEF ≤45%, $N = 16$	p
Age, mean ± SD (years)	62.3 ± 9.2	61.6 ± 8.9	64.3 ± 9.9	0.320
Female sex, n (%)	9 (15.5)	8 (19.1)	1 (6.3)	0.229
BMI, mean, SD (kg m^{-2})	27.9 ± 5.2	27.7 ± 4.6	28.6 ± 6.5	0.558
Systemic hypertension, n (%)	28 (48.3)	21 (50.0)	7 (43.8)	0.670
Diabetes mellitus, n (%)	10 (17.2)	6 (14.3)	4 (25.0)	0.334
Dyslipidemia, n (%)	46 (79.3)	33 (78.6)	13 (81.3)	0.822
Smoking (active/past), n (%)	5/34 (8.6/58.6)	4/24 (9.5/57.1)	1/10 (6.3/62.5)	0.898
Ischemic cardiomyopathy, n (%)	28 (48.3)	20 (47.6)	8 (50.0)	0.871
Coronary artery bypass graft, n (%)	15 (25.9)	11 (26.2)	4 (25.0)	0.926
Percutaneous coronary intervention, n (%)	19 (32.8)	13 (30.9)	6 (37.5)	0.635
LVEF, mean ± SD (%)[a]	39.5 ± 12.9	41.8 ± 12.1	33.5 ± 13.4	0.027
Pulmonary systolic arterial pressure, mean ± SD[b]	35.6 ± 7.4	33.5 ± 5.4	39.3 ± 9.3	0.058
Pulmonary systolic arterial pressure >35 mm Hg, n (%)[b]	9 (36.0)	4 (25.0)	5 (55.6)	0.127
Tricuspid regurgitation 2/4, n (%)[c]	6 (11.5)	4 (10.5)	2 (14.3)	0.177
Atrial fibrillation (at time of TTE)	5 (8.6)	2 (4.8)	3 (18.8)	0.089

SD, standard deviation; BMI, body mass index; LVEF, left ventricular ejection fraction.
[a] Measured by CMR with the same exam for RVEF.
[b] Obtained using the TTE tricuspid regurgitation velocity jet by CWD; it was available for 25 patients (9 in the group with RVEF ≤45% and 16 in the group with RVEF >45%).
[c] No patient had moderately severe or severe tricuspid regurgitation (3–4/4).