Right Ventricular Diastolic Function Evaluation in Magnetic Resonance Imaging

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Abstract

Although few studies demonstrated the ability of MRI dynamic anatomical sequences to assess right ventricular (RV) diastolic function, no data are available for velocity-encoded MRI (VE-MRI). Accordingly, our aim was to evaluate RV diastolic function from VE-MRI, as compared to reference Doppler echocardiography.

We studied 109 healthy individuals (67 men, age: 42±15 years) who underwent RV Doppler echocardiography and MRI, on the same day. VE-MRI images were analyzed using custom software, providing: tricuspid flow early peak velocity (E,cm/s) and flow-rate (Ef,ml/s), atrial peak velocity (A,cm/s) and flow-rate (Af,ml/s), longitudinal myocardial early peak velocity (E'). Same velocity parameters were extracted from Doppler echocardiography (E, A, E/A, E', E/E').

Despite the fair associations between MRI and echocardiographic indices, the highest correlation with age was obtained for MRI flow-rate ratio Ef/Af (r=0.60). Associations with age for velocity ratios (E/A) were equivalent for MRI and echocardiography (r=0.41).

Automatically extracted PC-MRI tricuspid inflow parameters were strongly related to age. These associations were comparable to echocardiography for maximal velocities ratio and were stronger when considering peak flow-rates ratio.

1. Introduction

Right ventricular (RV) dysfunction has been widely associated with an increased mortality in patients with congenital disease, heart failure, pulmonary hypertension and coronary artery disease [1]. Although the exploration of the left ventricle (LV) by imaging techniques is now widely accepted, the RV remained for a long time the forgotten ventricle. This might be due to its anatomical location, its complex shape and multiple trabeculae. Similar to LV, RV diastolic dysfunction precedes the drop in its ejection fraction. Accordingly, the early and robust detection and quantification of diastolic dysfunction are crucial for optimal patient management. In clinical routine, the evaluation of diastolic function is achieved using Doppler echocardiography [2]. Several conventional diastolic parameters are estimated: the early and late filling peak velocities of the tricuspid flow (E and A), tricuspid annular myocardial early longitudinal peak velocity (E').

MRI cine dynamic sequences have been used to evaluate RV function including diastolic indices. Indeed, MRI cine sequences enable the estimation of RV mass and volumes variations throughout the cardiac cycle. Furthermore, RV strain evaluation from cine MRI has been recently proposed [3], using feature tracking techniques. However despite its satisfactory usefulness on the LV, velocity-encoded MRI (VE-MRI) has not been used for the exploration of RV diastolic function yet.

Accordingly, our first goal was to adapt the previously developed software for transmitral flow and mitral annulus longitudinal velocity quantification [4] to the evaluation of tricuspid flow patterns as well as tricuspid annulus longitudinal motion from PC MRI data. In a second step we performed a head-to-head comparison of the derived VE-MRI diastolic function indices against those estimated using reference Doppler echocardiography performed on the same day in healthy volunteers, in terms of associations with age. Moreover, the reproducibility of MRI measurements has been studied.

2. Methods

2.1. Study population and data acquisition

We studied a group of 109 healthy volunteers (67 males, age=42±15 years) who had an echocardiographic exam for the evaluation of RV function and an MRI exam on the same day. The study protocol was approved by the institutional review board and informed consent was obtained from all participants.

Doppler echocardiography was performed by an experienced echocardiographer using a GEMS Vivid 7 system. The tricuspid early filling and atrial filling peaks (E_{US} and A_{US}) velocities as well as the free RV wall early peak (E'_{US}) longitudinal velocity were measured.

MRI was performed using a 1.5 T system (Signa HDx, GEMS, Waukesha, WI, USA). Previously acquired 2-chamber and 4-chamber views allowed positioning of a retrospectively ECG-gated PC pulse sequence, in a plane perpendicular to the tricuspid inflow and located below the tricuspid annulus at the level of the tips of the opened tricuspid valve leaflets. At this location, two dynamic PC series, corresponding to an entire cardiac cycle, were acquired during breath-hold: 1) the trans-tricuspid flow velocity series (encoding velocity Venc = 180 cm/s, echo time TE = 3.1 ms, repetition time TR = 7.6 ms, views per segment = 2, view sharing was used resulting in an effective temporal resolution of 15 ms), and 2) the myocardial longitudinal velocity series (Venc = 15 or 20 cm/sec, TE = 5 ms, TR = 9.5 ms, views per segment = 2, view sharing was used resulting in an effective temporal resolution of 20 ms). For both sequences, the following acquisition parameters were used: flip angle = 20°, slice thickness = 8 mm, pixel spacing = 1.9 x 1.9 mm, matrix 256 x 128.

2.2. Analysis of blood flow velocity images

Phase contrast MRI modulus images were difficult to segment because of the flow-related contrast variations along time. We therefore preferred to process velocity images, which presented connected areas in terms of velocity sign in tricuspid inflow regions.

Based on these connectivity properties, our segmentation algorithm comprised three main steps. First, a rough region of interest (ROI) was manually drawn on a single phase around the tricuspid valve. This cardiac phase was automatically set to the middle of the cardiac cycle. The mean velocity curve was calculated within this ROI, and the cardiac phase corresponding to its highest absolute value was detected. In the second step, this latter cardiac phase was used to initialize the segmentation algorithm, by an automated detection of the biggest connected area, in terms of velocity sign. The centre of mass of this area was calculated and reported on the neighbouring phases. In the third step, the biggest connected areas containing this centre of mass were automatically detected on these neighbouring phases, and their centres of mass were used to repeat the process toward the beginning and the end of the cardiac cycle.

After tricuspid orifice segmentation, time variations of mean velocity and flow rate, were derived. The tricuspid flow mean velocity curve was used to estimate velocity-related parameters (E_{MR} and A_{MR}), by automatically detecting the two highest local peaks during the diastolic period. Similar processing was applied on the tricuspid flow rate curve to detect the peak filling rate (Ef_{MR}, in ml/s) and the peak atrial rate (Af_{MR}, in ml/s). The Ef_{MR}/Af_{MR} ratio, as well as the peak filling rate normalized by the filling volume Ef_{MR}/FV_{MR} (in s-1), were calculated. The filling volume (FV_{MR}, in ml) was defined as the area under the tricuspid flow-rate curve comprised between the beginning and the end of the filling period (Figure 1).

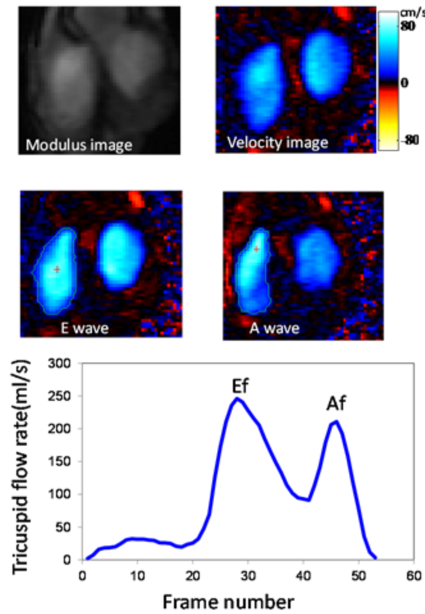

Figure 1: analysis of VE-MRI tricuspid flow data. Line 1: modulus and color-encoded through-plane velocity images. Line 2: segmented tricuspid flow. Line 3: extracted flow-rate curve and diastolic function indices.

2.3. Analysis of myocardial velocities

Again, velocity images were preferred for myocardial longitudinal motion analysis. However, the connectivity process was not adapted because of the bi-directional (up and down) longitudinal motion of the RV base during a single cardiac cycle through the acquisition plane, which implies changes in velocity sign. Accordingly, a classification based on the k-means algorithm was applied on temporal velocity profiles of fixed pixels during a whole cardiac cycle, within a rough ROI manually drawn around the RV on a single phase. This classification allowed isolating the biggest connected cluster, defined as the "myocardial" cluster. The myocardial mean longitudinal velocity curve, corresponding to the whole myocardium, was used to derive the parameter E'_{MR}, which was the highest local peak occurring first during the filling period. This peak velocity was used to further estimate the E_{MR}/E'_{MR} ratio.

2.4. Inter-operator variability

Inter-operator variability of our analysis in terms of functional velocity and flow rate parameters calculation was studied on a sub-group of 46 subjects (age = 43±16 years) randomly selected from the study group.

2.5. Statistical analysis

An Anova test was used to test significance of the differences in basic characteristics and MRI RV volumes, mass as well as diastolic parameters across age sub-groups (group 1: age <30 years, group 2 : age between 35 and 50 years, group 3: age >51 years). linear regression was used to study associations with age and the resulting Pearson correlation coefficients are provided. A p value < 0.05 was considered as significant. For both tricuspid blood flow and myocardial parameters, inter-operator variability was calculated as the absolute difference of the repeated measurements in the percentage of their mean.

3. Results

For each subject, the processing time was less than 3 minutes, on a personal computer (CPU 2.67 GHz, 3 Gb RAM). In addition, VE-MRI data analysis was reproducible, as reflected by an averaged percentage of variation < 1.7 ± 4.6 % for the tricuspid flow and velocity parameters and = 9.9 ± 8.8% for tricuspid annulus longitudinal velocity.

3.1. MRI RV volume indices

Table 1 summarizes healthy individuals basic characteristics as well as MRI RV volumes and mass indices for three age groups (<35 years, 36-50 years, >50 years).

Table 1. Individuals basic characteristics and RV end diastolic (EDV) and end-systolic (ESV) volumes, ejection fraction (EF) and mass, indexed for body surface area.

Age groups	<35 years	36-50 years	>50 years	Anova -p value
N° of subjects	41	35	33	
Age (years)	27±4	42±4	60±8	<0.0001
Gender (F/M)	18/23	13/22	11/22	
BMI (kg/m²)	23.9±4.3	24.4±2.9	25.1±3.2	0.36
MRI RV volumes indices				
EDV/BSA (ml/m²)	79±15	73±17	69±21	0.05
ESV/BSA (ml/m²)	34±9	30±10	26±10	0.006
EF (%)	58±7	60±8	62±7	0.04
RV mass/BSA (g/m²)	20±5	20±4	21±5	0.63

As previously shown [5], we found a drop in end-systolic and end-diastolic volumes along with a slight increase in RV ejection fraction and a stable RV mass through age groups.

3.2. Diastolic MRI indices vs. Doppler indices

Table 2 summarizes echocardiographic and MRI RV diastolic function indices. We found the expected decrease in E wave and increase in A wave with age for both modalities, resulting in a significant decrease in E/A ratio. This latter decrease was more pronounced for MRI index, especially when estimated from flow rate curves rather than from velocity curves (Figure 2.A).

Table 2. MRI and echocardiographic diastolic function indices. Anova was used to test differences through age groups.

Age groups	<35 years	36-50 years	>50 years	Anova -p value
N° of subjects	41	35	33	
Age (years)	27±4	42±4	60±8	<0.0001
Gender (F/M)	18/23	13/22	11/22	
Echocardiographic diastolic function				
E (cm/s)	58.4 ± 16	57± 18	53± 12	0.4
A (cm/s)	40± 10	42± 13	50± 19	0.004
E' (cm/s)	14.5± 3.3	13.3± 3.3	12.1± 2.7	0.007
E/A	1.5± 0.5	1.4± 0.5	1.1± 0.4	0.001
E/E'	4.1± 1.3	4.5± 1.7	4.6± 1.5	0.36
MRI diastolic function				
Emean (cm/s)	28± 7	24± 5	21± 7	<0.0001
Amean (cm/s)	19± 5	19± 5	22± 4	0.06
E'mean (cm/s)	7.4± 3.2	7.0± 3.3	5.6± 3.4	0.07
E/A mean	1.5± 0.4	1.4± 0.3	0.9± 0.3	<0.0001
E/E' mean	4.5± 1.7	5.2± 4.4	5.2±3.3	0.57
Ef(ml/s)	333±97	271±76	225±90	<0.0001
Af(ms/s)	215±66	209±76	259±92	0.01
FV(ml)	97±30	83±23	79±30	0.02
Ef/Af	1.6±0.5	1.4±0.5	0.8±0.3	<0.0001
Ef/FV(1/s)	3.5±0.64	3.3±0.6	2.9±0.5	0.0001

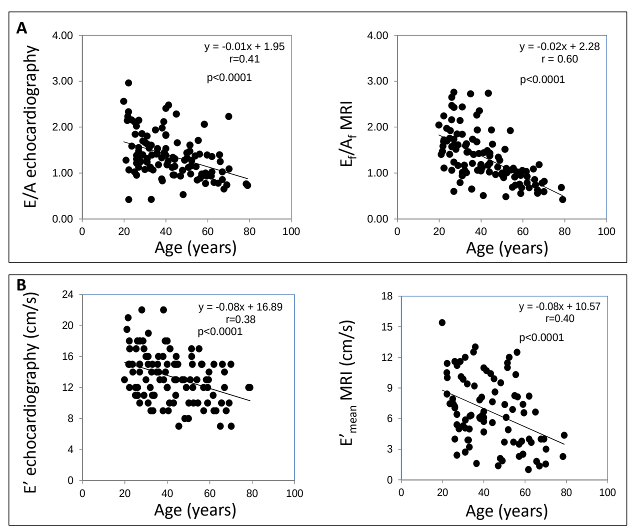

Figure 2: Linear associations between age and echocardiographic and MRI indices of tricuspid flow (A) and myocardial longitudinal velocities (B).

Regarding myocardial longitudinal velocities (E'), we found the expected decrease with age, with a more pronounced drop when considering MRI indices. Of note, the linear associations between age and such index resulted in equivalent correlation coefficients for both echocardiography and MRI (Figure 2.B). The decrease in E' was associated with a slight increase in E/E', indicating slightly increased filling pressures with age, although remaining within a normal range for both modalities. Of note, only fair correlations were found for the associations between MRI and echocardiographic indices (r=0.40 for E/A, r=0.43 for E/E').

4. Discussion

The early diagnosis of RV diastolic dysfunction has an important prognostic value and may impact the management strategy and the follow-up of patients with incipient heart failure, congenital disease and pulmonary hypertension. Although MRI is known as the modality of choice for the evaluation of RV volumes and mass, Doppler echocardiography remains the clinical reference for the evaluation of diastolic dysfunction. Previous studies, based on cine dynamic MRI images indicated slight changes in RV volumes and mass with aging and among such studies, only few focused on the evaluation of diastolic dysfunction using the analysis of temporal RV volume variation curves [6]. Regarding velocity-encoded data, although very popular on LV and aortic root evaluation, there is, to the best of our knowledge, no studies focusing on RV diastolic function evaluation using such data. Accordingly, this is the first study to demonstrate the feasibility of RV diastolic function evaluation from velocity-encoded MRI data on a large population of 109 healthy volunteers. In addition, in parallel to such evaluation, a head to head comparison with Doppler echocardiography was achieved in terms of age-related associations of the estimated parameters.

Despite the fair associations between echocardiographic and MRI RV diastolic indices, the strongest correlation with age was obtained for the MRI flow-rate ratio Ef/Af. Associations with age for velocity ratios were equivalent between MRI and echocardiography and were in line with previous echocardiographic findings [7]. The superiority of flow-related indices might reside in the fact that they are more robust to tricuspid jet direction throughout the cardiac cycle than velocity-related indices, which can be underestimated if the acquisition plane is not positioned exactly perpendicular to the tricuspid inflow. Imaging tricuspid inflow is particularly challenging for both MRI and echocardiography given the complex shape of the RV.

Automatically extracted MRI tricuspid inflow parameters were strongly related to age. These associations were comparable to echocardiography for maximal velocities ratio and were stronger when considering peak flow-rates ratio, this index being less sensitive to changes in tricuspid flow orientation during the cardiac cycle. These findings highlight the consistency of PC MRI for RV diastolic function assessment and its potential usefulness for clinical RV function evaluation, particularly in congenital disease.

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