Feasibility of MRI-based assessment of pulmonary vein flow and isovolumic relaxation time for diastolic dysfunction

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Synopsis

Motivation: Evaluation of diastolic dysfunction by transthoracic echocardiography (TTE) has limited accuracy and many indeterminate cases, leading recent guidelines to include additional parameters of diastolic function: left atrial strain, pulmonary vein flow and isovolumic relaxation time (IVRT).

Goal: To determine if MRI measurements of IVRT and PV flow agree with TTE, as has been demonstrated for E/A and E/e'.

Approach: MRI methods were developed and tested to evaluate pulmonary vein flow measurements (S/D) and IVRT using phase-contrast and cine.

Results: The MRI measurements were compared to dedicated same day TTE, and strong correlations were found (=0.76, $p=0.03$ for S/D, $r=0.92$ $p<0.001$ for IVRT).

Impact

This study compares MRI and Echocardiographic evaluation of metrics of diastolic dysfunction, including the newest parameters recently added to diastolic guidelines (pulmonary vein flow and isovolumic relaxation time). Results support the ability of MRI to provide comprehensive diastolic function assessment.

Introduction

Diastolic dysfunction (DD) impairs myocardial relaxation and ventricular filling during diastole, and its assessment is used to identify heart-failure with preserved ejection fraction (HFpEF). Many parameters are used to evaluate DD with transthoracic echocardiography (TTE) including trans-mitral LV inflow using Doppler (early and later diastolic flow E, and A), motion of the mitral valve annulus acquired by tissue Doppler imaging (TDI) (e'), indexed size of the left atrium (LAVi) using 2-dimensional imaging, and right heart pressures estimated by tricuspid regurgitant velocity[1]. For an accurate assessment, parameters need to be evaluated together. The most recent ASE guidelines[1] include three additional parameters for diastolic evaluation in conjunction with standard indices: left atrial strain(LAS), pulmonary vein (PV) flow, and isovolumic relaxation time (IVRT)[1]. Prior studies have demonstrated strong agreement between cardiac MRI and TTE for conventional diastolic indices including E, A, E/e', and LAVi[2–4], although MRI does not currently provide a reliable method to measure tricuspid regurgitant velocity. MRI-derived LAS has also been comprehensively evaluated[5]. In contrast, validation of MRI-based IVRT and PV flow remains limited, with most PV flow data originating from early velocity-encoded MRI study in the 1990s[6]. This study aims to compare MRI and TTE measurements of PV flow and IVRT, along with other established diastolic parameters.

Methods

Nine subjects (age 42±22, 3 male) were prospectively enrolled; one had a diagnosis of scleroderma, 8 were healthy subjects, all provided informed consent. We acquired dedicated research TTE to measure E, A, E/e', PV flow, and IVRT, and then on the same day or soon after (mean 3±4 days), the subjects had dedicated MRI exams on 3T Siemens. TTE was acquired using a

Philips Epiq CVxi system with standard Doppler assessment of E, A, e', and PV S/D ratio, by an experienced sonographer. IVRT was measured using both TDI and CW Doppler approaches. CW doppler IVRT measures the time of minimal flow at end systole. TDI IVRT measures the time of minimal valvular velocity at end systole (Figure 1CD). All measurements were averaged across three cardiac cycles. The MRI protocol included long-axis phase-contrast for E and A, and a dedicated PV flow acquisition, and 2ch and 4ch cine to estimate IVRT and e'. E and A were measured on breath-held 2D 4ch phase-contrast, TR/TE/flip angle=5.9ms/2.5ms/20°, with flow encoding directed long-axis, $\sim$35 ms temporal resolution, and VENC=150cm/s. For PV flow, the VENC was 100 cm/s, and through-plane flow was targeted in the right inferior PV (RIPV) (Figure 2). IVRT and e': For cine, ECG-gating, with TR/TE/flip angle=2.8/1.4/40°, 36 ms true temporal resolution 1.7 x 1.7 x 8 mm^3. For e', the valvular displacement was analyzed on 4ch cines with MVnet[7], and the derivative yielded velocity, as previously described[8]. For IVRT, the 2ch and 4ch cines were processed with MVnet[7], and IVRT was defined as the time period at end-systole, corresponding to valve displacement no greater than 5% difference from MAPSE[9], as shown in Figure 1. Statistics were performed in JMP 18.2.

Results

Figure 3 shows excellent correlations of the major diastolic parameters E/A (r=0.80, $p<0.005$), e' average (r=0.91, $p<0.001$) and E/e' (r=0.77, p=0.01) between TTE and MRI. Figure 4 plots PV flow S/D (S and D labeled in Figure 4a) vs. TTE, showing a strong correlation (r=0.76, p=0.03). Figure 5 compares IVRT by MRI vs. TTE, using both the TDI (r=0.92, $p<0.001$), which is more similar to that which MRI-derived IVRT quantifies, and the CW Doppler approach (p=0.76, p=0.02). Without normalization by heart rate the relationship is still strong (R=0.71, p=0.03) between IVRT by MRI and by TDI (not shown).

Conclusion

This pilot study shows that cardiac MRI can feasibly assess PV flow and IVRT, two recently emphasized diastolic function measures. Accurate tracking of mitral annular motion enabled MRI-derived IVRT to closely match the physiological interval assessed by TTE. MRI-derived PV flow S/D ratio also correlated with TTE measurements. MRI's tomographic evaluation of pulmonary veins may reduce limitations of TTE related to Doppler alignment. In conjunction with conventional indices, these data support the ability of MRI to evaluate PV flow and IVRT as part of comprehensive diastolic function assessment.

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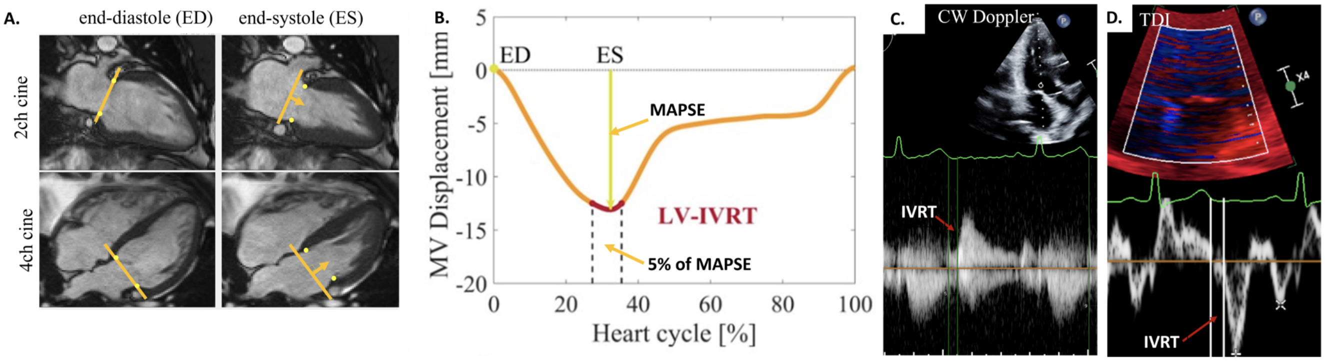

Figure 1. A) MRI-derived IVRT is performed by tracking the valve plane, and obtaining the valvular displacement curve, which can be used to identify MAPSE (Mitral Annular Plane Systolic Excursion). B) IVRT was defined as the time-period at end-systole during which excursion was within 5% of MAPSE. C-D) In different subjects, the IVRT is measured on CW Doppler (C) and by TDI (D).

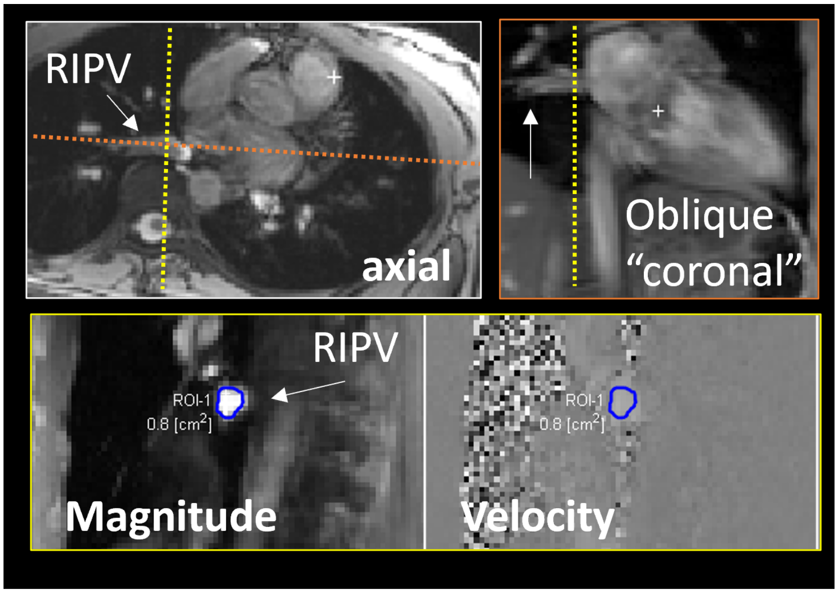

Figure 2. Localization of the right inferior PV (RIPV), and measurement of through-plane flow. This starts with an axial slice showing the RIPV, from which an orthogonal plane is prescribed, along the PV branch (orange dashed line), resulting in a “coronal” slice shown in orange frame). The en face slice to capture PV flow is then prescribed using the yellowed dashed lines in orthogonal planes. The PV is indicated by arrows.

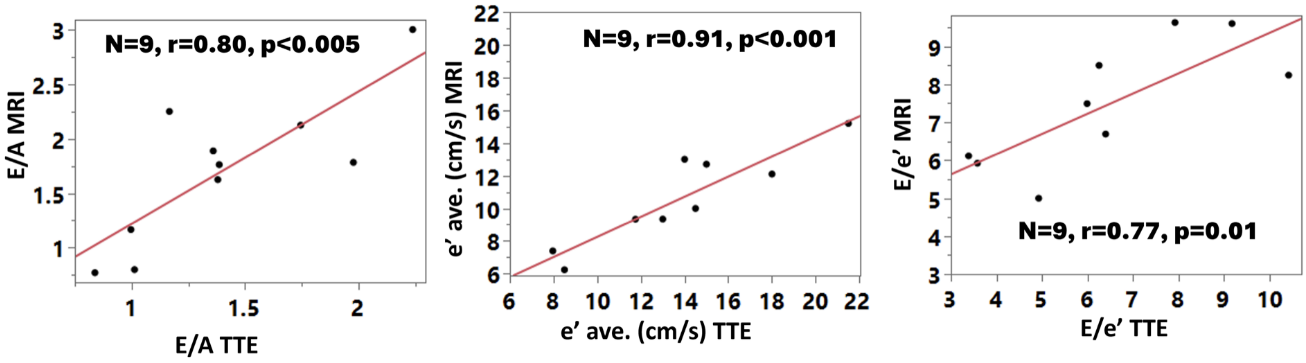

Figure 3. Close in time comparisons of MRI vs. TTE showed excellent correlation for E/A, e' average and E/e'.

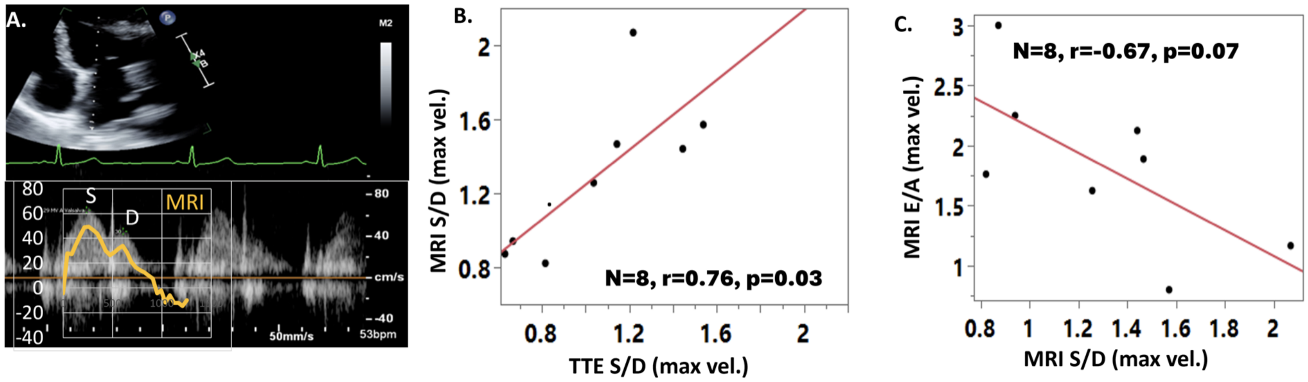

Figure 4. Pulmonary vein flow. A) Comparison of MRI and TTE PV flow maximum velocity curves on overlay in one subject. S and D are labeled. The absolute velocity values are not expected to match, but the shape and ratio match well. B) PV flow parameter S/D shows robust correlation between MRI vs. TTE, but one subject had a non-diagnostic PV flow by TTE. C) S/D showed expected relationship to E/A (p=NS due to small sample size).

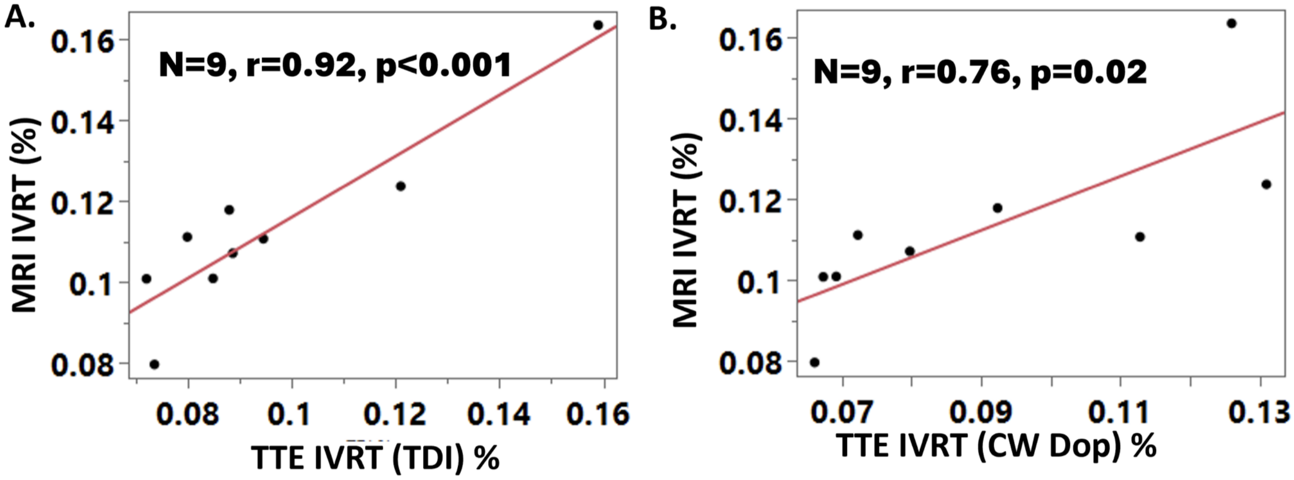

Figure 5. IVRT comparisons. A) We found excellent correlations between MRI-derived IVRT vs. TTE-based IVRT, using TDI, (B) which was still strong using CW doppler.