

EVALUATION OF LEFT VENTRICULAR DIASTOLIC FUNCTION WITH CINE MAGNETIC RESONANCE IMAGING: THREE-DIMENSIONAL VOLUME TRACKING OF MITRAL ANNULUS MOTION

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Target Audience: Clinicians and researchers interested in the quantification of diastolic function with cardiac magnetic resonance imaging.

Introduction: Cardiac magnetic resonance (CMR) is emerging as an accepted technique for the non-invasive assessment of diastolic function by using transmitral flow (TMF), pulmonary venous flow (PVF), left ventricular (LV) time-volume curve, and myocardial tagging [1]. However, it remains a growing discipline that is not well established. This study presents a novel CMR approach to quantification of diastolic dynamics, using 3D volume tracking of the mitral annulus (MA). The utility of this method is demonstrated by distinguishing diastolic MA excursion profiles between normal subjects and patients with hypertrophic cardiomyopathy (HCM), which is characterized by diastolic dysfunction.

Methods: Routine CMR studies were retrospectively selected from 55 patients with normal hearts (35 ± 10 years old) and 23 HCM patients (46 ± 10 years old). All HCM subjects had normal ejection fractions, defined as greater than 50% ($65.8 \pm 5.7\%$). Conventional cine CMR imaging with ECG-gating was performed using 1.5 and 3T MRI systems (Avanto and Tim Trio, Siemens, Erlangen, Germany). Images were acquired in 2-, 3-, and 4-chamber views, with the following parameters: TR/TE = 2.4/1.4 ms, temporal resolution = 37-63 ms, in-plane spatial resolution = 1.4 mm \times 1.4 mm - 1.8 mm \times 1.8 mm, flip angle = 51°, thickness = 6mm, BW = 930Hz/pixel. Atrioventricular junctions (AVJ) were tracked, using customized software developed in MATLAB (MathWorks, MA), in 2-, 3-, and 4-chamber views, creating six spatial points per cardiac phase (Fig. 1a). Reconstruction of the 3D MA geometry was achieved with cubic spline interpolation of the selected points. A 3D sweep path of the MA was reconstructed using the 3D MA area of the initial (t1) and current (t2) time points together with the distance through which the MA traversed. Given these measurements, the 3D volume (V) swept out by the MA is created and calculated for each cardiac phase (Fig. 1b) [2]. Representative MA sweep volumes are graphed and manually divided into five distinct cardiac intervals (Fig. 2): systole, early diastole, diastasis, atrial contraction (AC), and atrial relaxation (AR). The derivative of the MA sweep volume curve was calculated to determine the sweep volume rates. Parameters of interest in assessing diastolic function included the E' (peak sweep volume rate in early diastole) to A' (peak sweep volume rate in atrial contraction) ratio, peak sweep volume rate, average sweep volume rate, and total sweep volume in each cardiac interval. These values were normalized against the end systolic MA sweep volume. Student t-tests (two-tailed) were used to evaluate these parameters.

Results: Fig. 2a shows a comparison of representative normalized MA sweep volume curves from the two groups. The normal subjects typically showed a higher total sweep volume during early diastole, while the HCM patients had greater relative sweep volume during atrial contraction. The derivative of the sweep volume curves yielded the volume rate curves in Fig. 2b and showed distinct E' and A' waves, similar to those seen in TMF studies. The normal subject had a higher peak sweep volume rate in early diastole than in atrial contraction, but the HCM patient showed an opposite E' to A' pattern. Table 1 summarizes the volume tracking results of the diastolic parameters. HCM patients had lower E':A' ratios, thus reflecting slower sweep volume rates during early diastole but higher sweep volume rates during atrial contraction.

Discussion & Conclusion: 3D tracking of MA sweep volume is a novel CMR technique that characterizes diastolic dysfunction. Based on the results, the HCM patient group had a decreased E':A' ratio. This suggests impaired early diastolic relaxation, which causes the atrial contraction phase to contribute more to overall ventricular filling. These findings are consistent with the filling patterns in diastolic dysfunction seen with echo tissue Doppler imaging and TMF techniques [1]. The analysis of MA sweep volume is distinct from previously reported methods, because it provides an ability to combine both axial and longitudinal motions of the MA. MA behavior may offer further insight into LV filling biomechanics, since its motion encompasses an important part of the LV filling volume during diastole; the MA movement toward the atrium in late diastole contributes to the transformation of atrial volume into ventricular volume [3], thereby providing additional information on the role of atrial contraction.

References: [1] Caudron et al. Radiographics 31:239-261 (2011). [2] Bhagavatula et al. RSNA (2012). [3] Carhall et al. Am J Physiol Heart Circ Physiol 293:H1473-H1479 (2007).

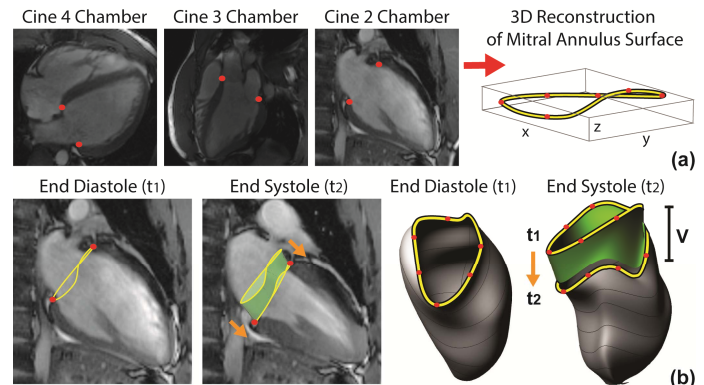


Figure 1: (a) Six AVJ points are used to reconstruct the mitral annulus in 3D for each cardiac phase; (b) 2D and 3D representations of the mitral annulus sweep volume (V) from phase 1 (t1) to phase 2 (t2).

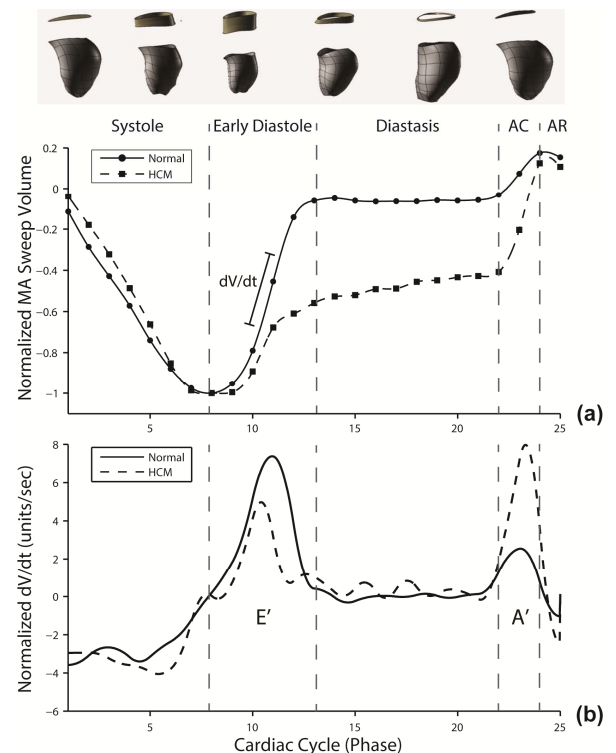


Figure 2: Comparison between normal and HCM (a) Mitral annulus normalized sweep volume profiles; (b) Normalized sweep volume rates.

Table 1: CMR Mitral Annulus Volume Tracking Diastolic Parameters

	Normal (n=55)	HCM (n=23)	P
E':A' Wave	2.24 \pm 1.31	1.21 \pm 0.76	<0.001*
Normalized† Peak Sweep Volume Rate, Early Diastole	8.18 \pm 1.40	6.08 \pm 2.06	<0.001*
Normalized† Peak Sweep Volume Rate, Atrial Contraction	4.50 \pm 1.84	5.89 \pm 2.25	0.013*
Normalized† Average Sweep Volume Rate, Early Diastole	4.41 \pm 1.54	3.52 \pm 1.13	<0.001*
Normalized† Average Sweep Volume Rate, Atrial Contraction	1.22 \pm 3.00	3.55 \pm 1.34	<0.001*
Normalized† Sweep Volume, Early Diastole	0.736 \pm 0.110	0.559 \pm 0.143	<0.001*
Normalized† Sweep Volume, Diastasis	0.043 \pm 0.066	0.159 \pm 0.150	<0.001*
Normalized† Sweep Volume, Atrial Contraction	0.298 \pm 0.108	0.382 \pm 0.106	<0.001*

*P < 0.05, †Adjusted to end systolic mitral annulus sweep volume