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Comparison of two-dimensional echocardiography methods of ventricular volume quantification to cardiovascular magnetic resonance in left ventricular volume overload

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ABSTRACT

Assessment of left ventricular dilation plays an important role in the management of left ventricular volume overload lesions. Various echocardiographic methods exist, such as the 5/6 area-length and biplane Simpsons, but their agreement with cardiac magnetic resonance imaging in patients with chronic left ventricular volume overload from a young age has not been assessed. This was a retrospective review of patients with moderate or worse aortic regurgitation, mitral regurgitation, or ventricular septal defect who underwent both studies within 6 months. End-diastolic and systolic volumes and dimensions were measured by echocardiography using the 5/6 area-length, biplane Simpsons, and M-mode methods, and compared to cardiac MRI-derived volumes. The 5/6 area-length method showed the best agreement with MRI and remained consistent with increasing ventricular dilation. The biplane Simpsons and M-mode-based Teichholz method underestimated ventricular dilation and performed worse with increasing dilation. When comparing ventricular dimensions by M-mode, there was a non-linear relationship between linear dimension and MRI-derived volume. Linear dimension appeared to plateau with increasing ventricular dilation, leading to underestimation in severity of dilation. The 5/6 area-length method was superior to other echocardiographic methods of ventricular volume quantification when compared with MRI.

1. Introduction

Quantification of left ventricular volume plays an important role in determining timing for surgical intervention in asymptomatic patients with left ventricular volume overload lesions such as aortic regurgitation, mitral regurgitation, and ventricular septal defects. The degree of preoperative ventricular dilation has been shown to be predictive of postoperative outcomes in patients with aortic regurgitation and mitral regurgitation [1]. Emphasis on left ventricular volume quantification is particularly important when following younger patients for whom symptoms may not be a reliable indicator of need to operate. Transthoracic echocardiography is typically used for assessment of ventricular size and function due to its wide availability, ease of clinical use, and non-invasive nature. Multiple methods of left ventricular volume quantification by echocardiography exist, with the 5/6 area-length, biplane Simpsons, and M-mode the most commonly utilized. The majority of published reports in left ventricular volume overload lesions utilizing M-mode [3]. All three methods rely on different geometric assumptions in the calculation of mass and volume [2,3]. The reliability of these three methods with abnormal ventricular geometry in left ventricular volume overload lesions has not been well studied.

Recent data on the reproducibility of left ventricular measurements obtained using different echocardiography methods (e.g. 2D parasternal short-axis versus M-mode) have shown varying levels of agreement and reliability [4]. A study by Lee et al. showed that left ventricular dimensions obtained by different methods were not interchangeable, even within the same study [5]. By comparison, cardiac MRI is now considered the reference standard for ventricular volume, mass, and function assessment due to its excellent reproducibility and accuracy, which has been validated in phantom and ex-vivo models [6,7]. Some studies have compared the agreement between cardiac MRI and single 2D methods and shown poor agreement between the two modalities, but no studies have systemically compared area-length, biplane Simpsons, and M-mode to cardiac MRI [11,12]. Our main objectives were:

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1. Assess the agreement and reproducibility between cardiac MRI-derived left ventricular volume and each echocardiography method;
2. Assess for differences in the accuracy of each echocardiography method in non-dilated and dilated left ventricles (as determined by cardiac MRI);
3. Assess the accuracy of left ventricular size assessment by M-mode-derived dimensions in patients with dilated left ventricles.

2. Material and Methods

This was a single-center retrospective review of all patients from our MRI database between 2008 and 2012 with an indication of left ventricular volume dilation and/or an left ventricular volume overload lesion. Patients with an echocardiogram within 6 months of the cardiac MRI were included. Patients were excluded if they had less than moderate aortic regurgitation and mitral regurgitation by echocardiography, a ventricular septal defect without left ventricular dilation and normal estimated pulmonary artery pressures by echocardiography, or if left ventricular volume could not be assessed due to inadequate or poor image quality. This study was approved by our Institutional Review Board and consent was waived.

2.1. Imaging Protocol

Echocardiography studies were reviewed at an offline workstation by a single blinded investigator (HHK). All echocardiography studies reviewed were complete studies using the standard comprehensive protocol of our non-invasive imaging laboratory. All standard views for volume quantification by area-length (Fig. 1A, B), biplane Simpsons (Fig. 1C), and M-mode (Fig. 1D) are contained within our imaging protocol. All three left ventricular volume quantification methods were applied to the same study using three-beat averaging for the measurements per American Society of Echocardiography recommendations. Estimation of left ventricular volume by M-mode was performed using the Teichholz formula:

$$\text{left ventricular volume} = \frac{(7 * \text{dimension}^3)}{(2.4 + \text{dimension})}$$

with left ventricular end-diastolic volume and left ventricular end-systolic volume determined using left ventricular end-diastolic dimension and left ventricular end-systolic dimension, respectively [8].

Cardiac MRI studies were performed on a 1.5-T Siemens scanner (MAGNETOM Avanto, Siemens Medical Solutions, Erlangen, Germany). Cardiac MRI images for left ventricular volume quantification were obtained from balanced steady-state free precession short-axis sequences obtained during breath holds. Slice thickness varied from 6–9 mm with inter-slice gaps of 0.5–2 mm, as appropriate for patient size. Left ventricular volume and mass were calculated using the summation of discs method. Papillary muscles were included in left ventricular mass and excluded from the left ventricular volume as per the Society of Cardiac Magnetic Resonance recommendations [9]. All volume measurements were indexed to BSA and z-scores were obtained for each index, based on composite normative data published by Kawel-Boehm et al. [10].

2.2. Data Analysis

Left ventricular end-diastolic volume and end-systolic volume measurements were obtained from the three echocardiography methods (area-length, biplane Simpsons, M-mode) and from the cardiac MRI data. Agreement was compared in two ways: the absolute end-diastolic and end-systolic volumes were compared, as well as the z-scores for left ventricular end-diastolic volume and left ventricular end-systolic volume from each of the echocardiography methods and cardiac MRI-

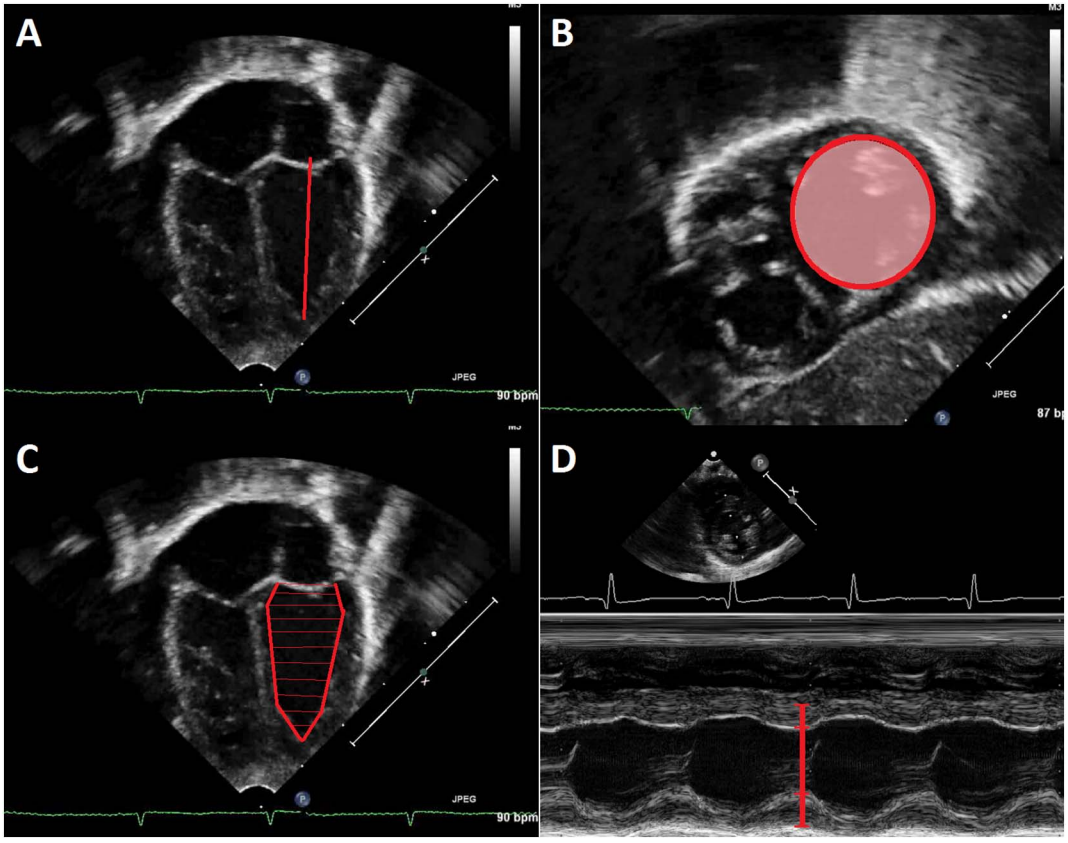

Fig. 1. 2D Methods of Left Ventricular Volume Quantification by Echocardiography. A) LV long axis measurement for 5/6 area-length method, B) Short axis cross-sectional area for 5/6 area-length, C) LV 4-chamber measurement for biplane Simpsons, D) M-mode of LV at level of the papillary muscles for linear dimensions.