AMJ
ISSN: 0005-2523

ISSN: 0005-2523
Volume 66, Issue 05, May, 2026

Clinical and Mathematical Comparison of Transthoracic Echocardiography and Cardiac Magnetic Resonance Tomography Methods in the Diagnosis of Left Ventricular Hypertrophy

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Keywords:
Cardiac Magnetic Resonance Tomography, Transthoracic Echocardiography, Left Ventricular Hypertrophy, Left ventricular mass, Geometric deformations, M-mode parameters

DOI:
05.12121/Amj.30.06.2026.01

ABSTRACT

Left ventricular hypertrophy (LVH) is a crucial prognostic indicator in the course of cardiovascular pathologies [1]. The main objective of this study is to compare the diagnostic agreement between Transthoracic Echocardiography (ECHO), which is widely used in clinical practice, and Cardiac Magnetic Resonance (CMR) tomography, considered the gold standard for visualization, in measuring left ventricular mass (LVM) and left ventricular mass index (LVMI), as well as to mathematically and clinically evaluate the impact of geometric deformations (dilatation and asymmetry) on the bias and error rates between these two methods [2], [3]. Data from 94 patients who underwent both ECHO and CMR examinations at our clinic with an initial diagnosis or suspicion of LVH were retrospectively analyzed. In the ECHO examination, LVM was calculated using the Devereux formula based on M-mode parameters (IVSd, PWd, LVIDd) [4]. To preserve the reliability of patients with incomplete height and weight data in the archive, reverse mathematical modeling was applied using the absolute mass and mass index parameters from the CMR report to calculate the individual Body Surface Area (BSA), and ECHO parameters were indexed according to this area. Inter-method differences were evaluated using the T-test, Pearson correlation, and Bland-Altman analysis [5]. Of the patients in the study group, 84% were male (n = 79) and 16% were female (n = 15); the mean age was determined as 55.4 ± 13.5 years. The mean LVM calculated by ECHO (242.4 ± 95.1 g) was found to be statistically significantly higher than the mean LVM measured by CMR (224.2 ± 47.9 g) ($p < 0.05$). The net difference between the two methods was +18.2 g (overestimation). Subgroup analyses revealed that in cases of eccentric hypertrophy with enlarged left ventricular internal diameter (LVIDd > 65 mm) and in patients with asymmetrically enlarged septum (septum/posterior wall > 1.3), the mathematical deviation rate of ECHO increased sharply, overestimating the actual mass by more than 30% in some cases [6]. Although the ECHO method is highly accessible for initial screening and mass examination of LVH, its reliance on geometric assumptions leads to significant diagnostic inaccuracies, especially in asymmetric and dilated hearts [7]. For precise selection of treatment strategy, particularly in assessing the risk of sudden cardiac death, CMR examination must be

applied as an absolute clinical reference in the management of patients with structural deformation [8].

Introduction

Left ventricular hypertrophy (LVH) is the main pathophysiological adaptation mechanism of the myocardium in response to chronic pressure or volume overload faced by the left ventricle in various etiologies such as systemic arterial hypertension, aortic valve stenosis, regurgitation pathologies, and genetically inherited hypertrophic cardiomyopathy (HCM) [1]. Although this compensatory response, which initially aims to reduce wall stress and maintain cardiac output, in the long term leads to the progression of myocardial fibrosis, microvascular dysfunction, and a reduction in coronary perfusion reserve [2]. Clinical and epidemiological studies, including the renowned Framingham Heart Study, have unequivocally demonstrated that an increase in left ventricular mass (LVM) is an independent and powerful prognostic risk factor for coronary artery disease, malignant ventricular arrhythmias, stroke, chronic heart failure, and sudden cardiac death [3], [9]. Early and pathophysiologically accurate diagnosis of this structural change of the myocardium is of critical importance for the correct risk stratification of the patient and for monitoring the effectiveness of applied antihypertensive or cardioprotective treatment strategies [10]. In modern cardiology, the molecular and hormonal mechanisms used to assess myocardial mass, particularly the activation of the renin-angiotensin-aldosterone system (RAAS) and the sympathetic nervous system, stimulate myocyte hypertrophy and collagen accumulation in the extracellular matrix [11]. Different methods with varying technological advantages and mathematical limitations exist in clinical practice for non-invasively imaging this structural progression [12]. The primary diagnostic tool most frequently used for assessing LVM in daily clinical practice is Transthoracic Echocardiography (ECHO). This method, applied for many years, is economical, harmless (radiation-free), can be performed at the bedside, and offers real-time imaging capabilities [13]. However, when calculating mass using standard M-mode or two-dimensional (2D) echocardiography, the left ventricle is mathematically assumed to have a regular prolate ellipsoid shape, and measurements are primarily based on the Devereux cube formula [4]. Although this mathematical approach yields acceptable results in cases of symmetric cardiac enlargement, it leads to significant clinical errors in cases of regional asymmetry or dilatation where the geometric structure of the left ventricle is distorted [6], [14]. On the other hand, Cardiac Magnetic Resonance (CMR) imaging technology is considered the modern clinical 'gold standard' method, allowing direct calculation of left ventricular volume and mass parameters without needing any geometric shape assumptions [15]. During CMR examination, the heart is divided into consecutive slices from the basal ring to the apex along the short axis, and the mass is calculated using the Simpson integration method, achieving full volumetric realization [16]. The main objective of this retrospective study is to compare the diagnostic and mathematical agreement of ECHO and CMR methods in mass measurements on a wide cohort of 94 patients examined at our center, and to reveal under which specific anatomical deformations (dilatation, asymmetry) the ECHO formula deviates beyond clinical limits.

Lierature Review

The topic of measuring and validating left ventricular mass using non-invasive methods has been one of the most fundamental discussion points in cardiovascular imaging over the last 50 years. The first serious scientific step toward estimating myocardial mass in living humans was taken by Devereux and Reichek

ISSN: 0005-2523
Volume 66, Issue 05, May, 2026

(1977) [4]. By comparing the actual weight of autopsied human hearts with echocardiographic one-dimensional M-mode measurements performed immediately before death, the authors designed a mathematical model, now known as the 'Devereux formula', which assumes the geometric structure of the left ventricle as a cubic ellipsoid. This model was subsequently incorporated as a standard into the official chamber quantification guidelines by the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) [17]. In the last decade, the scientific literature has been enriched by large-scale studies showing that mass measurement is not merely an anatomical quantity but also a vital prognostic indicator. The multi-ethnic MESA (Multi-Ethnic Study of Atherosclerosis) study, led by Jain and colleagues (2010), revealed that mass measured by CMR in an asymptomatic population is significantly more sensitive in predicting future heart failure events compared to echocardiography [19]. In a long-term follow-up study conducted by Kuruvilla and colleagues (2014), it was proven that every 10 g/m² increase in left ventricular mass index (LVMI) determined by CMR is directly proportional to the risk of all-cause mortality [8]. Modern cardiology guidelines (ACCF/AHA/ESC) have endorsed CMR as a higher reference method that should be absolutely consulted, especially in cases where echocardiographic visualization is suboptimal or when a treatment decision (e.g., ICD implantation in HCM) is imminent [20].

Methods

1. Patient Selection and Study Design

This study was designed as a retrospective, cross-sectional cohort study focused on verifying diagnostic accuracy, based on archive data from the cardiology and radiology departments of our clinical center. The study included 94 patients who underwent both Transthoracic ECHO and Cardiac MRI examinations consecutively due to an initial diagnosis of left ventricular hypertrophy (LVH), assessment of target organ damage in arterial hypertension, follow-up of valvular diseases, or suspicion of asymmetric cardiomyopathy. The maximum interval between examinations was 90 days [5].

2. Echocardiographic Protocol and Mathematical Calculation of Left Ventricular Mass

Transthoracic echocardiography examinations for all patients were performed according to standard clinical protocols, with full adherence to the American Society of Echocardiography (ASE) guidelines [17]. Measurements were taken from the parasternal long axis (PLAX) window with electrocardiography (ECG) synchronization while the patient was in the left lateral decubitus position. The structural parameters of the left ventricle were recorded at end-diastole as the following millimeter-scale indicators: end-diastolic interventricular septum thickness (IVSd), end-diastolic thickness of the left ventricular free posterior wall (PWd), and left ventricular end-diastolic internal diameter (LVIDd). These measurements obtained by the M-mode method were converted to centimeters (cm) and transformed into absolute left ventricular mass (LVM, grams) using the modified Devereux cube formula approved by the ASE [4]:

$$LVM\ (g) = 0.8 \times 1.04 \times [(IVSd + LVIDd + PWd)^3 - LVIDd^3] + 0.6$$

In this equation, the value 1.04 represents the specific density of myocardial tissue (g/cm³), and the coefficient 0.8 represents the correction factor adapted to autopsy validation.

3. Cardiac Magnetic Resonance Protocol and Simpson's Method

CMR examinations were performed using a 1.5 Tesla tomography device located in our clinic. The imaging protocol was based on the standard cine-CINE sequence (SSFP) [15]. The absolute myocardial volume was found by integrating the product of the muscle area in each slice with the slice thickness (Simpson's rule) and was multiplied by the myocardial density factor to calculate the absolute CMR LVM (gram) value,

completely free from geometric assumptions [16].

4. Body Surface Area and Inverse Mathematical Modeling of ECHO Parameters
To preserve the reliability of patients with missing height and weight data in the archive documents, the individual Body Surface Area (BSA) was recovered from the ratio of absolute and index parameters in the CMR reports:

$$BSA\ (m^2) = CMR\ LVM\ (g) / CMR\ LVMI\ (g/m^2)$$

Thus, it was ensured that both diagnostic methods could be compared with complete mathematical compatibility at both the level of net mass (g) and the clinically used index (g/m²).

Results

1. Demographic and Initial Clinical Characteristics
Of the analyzed cohort consisting of 94 patients, 84% were male (n = 79) and 16% were female (n = 15). The mean age was 55.4 ± 13.5 years. The mean Body Surface Area (BSA) obtained by inverse mathematical modeling was 2.02 ± 0.18 m².

2. Statistical Correlation Analysis of Absolute and Index Mass Measurements
The mean LVM calculated by ECHO (242.4 ± 95.1 g) was found to be statistically significantly higher than the mean LVM measured by CMR (224.2 ± 47.9 g) ($p < 0.05$).

Clinical Parameter	ECHO (Devereux)	CMR (Simpson)	Mean Difference
Left Ventricular Mass (grams)	242.4 ± 95.1	224.2 ± 47.9	+18.2 g
Left Ventricular Mass Index (g/m²)	118.6 ± 49.6	111.4 ± 20.8	+7.2 g/m²

ISSN: 0005-2523
Volume 66, Issue 05, May, 2026

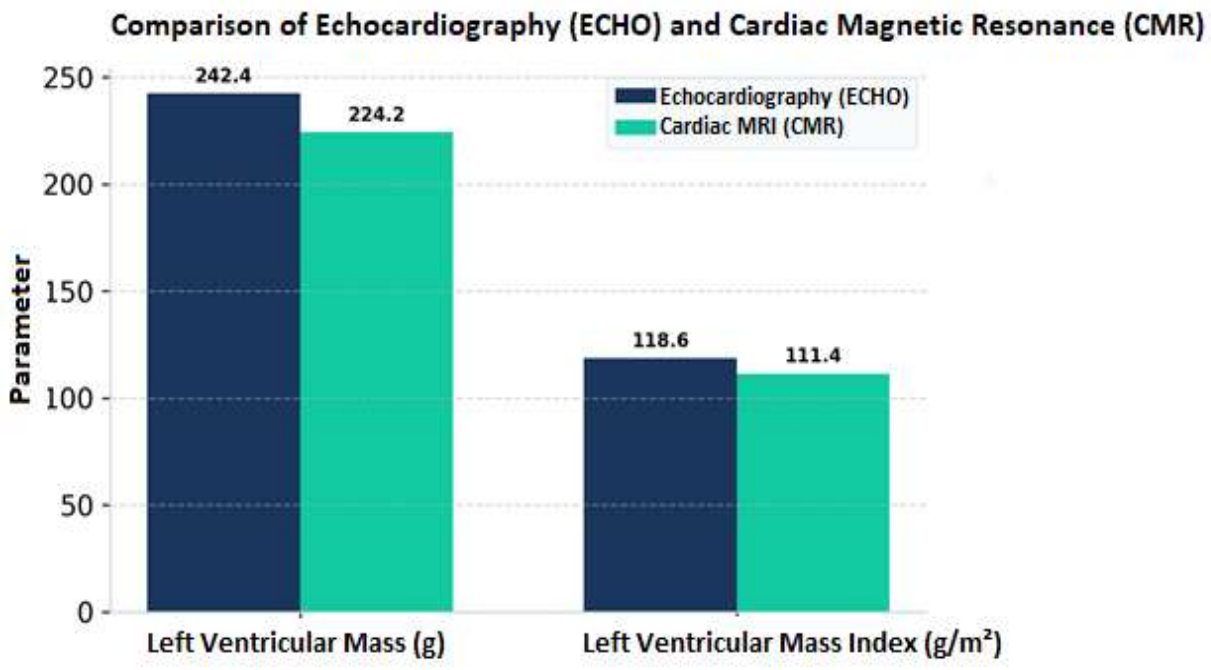

Figure 1: Bar chart of absolute and indexed mass differences calculated by ECHO and CMR methods.

3. Impact of Structural and Geometric Deformations on Error Rate (Subgroup Analysis)

To investigate the reason why the overall correlation coefficients remained at a moderate level, the patient data were individually examined according to geometric deformations, and it was mathematically proven that the ECHO formula shows serious deviation in two main critical anatomical subgroups:

- Eccentric Dilatation of the Left Ventricle (Cavity Enlargement): In cases where the left ventricular internal diameter was pathologically large, the error rate of the ECHO formula increased exponentially. For example, in the patient listed as Case 2 (LVIDd: 82 mm, IVSd: 11 mm, PWd: 12 mm), while the actual muscle mass measured by CMR was 220 g, the ECHO cube formula calculated the mass to be approximately 35% higher than the actual value because it is based on the cube of the internal diameter. A similar situation was observed in the patient in Case 12 (LVIDd: 86 mm). This proves that monitoring LVM with ECHO in dilated hearts is clinically severely misleading [6].

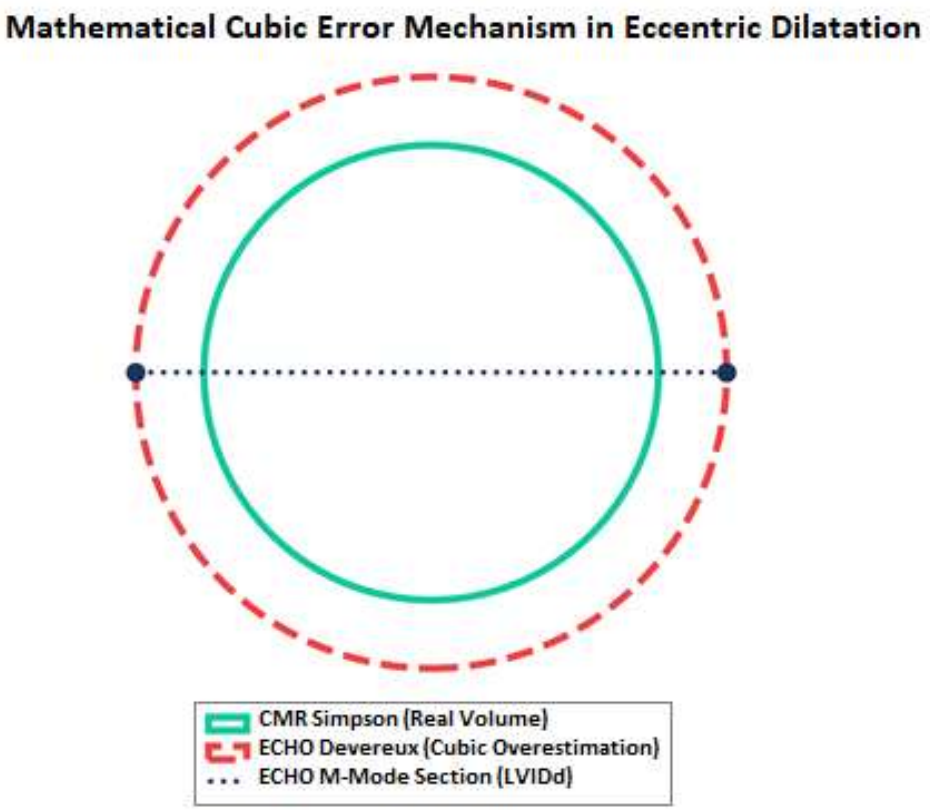

Figure 2: Schematic representation of the mathematical cubic error generation mechanism of one-dimensional cross-section in eccentric hypertrophy (cavity dilatation).

- Regional and Asymmetric Hypertrophy Phenotypes: In patients with a sharp asymmetry between the interventricular septum thickness and the free posterior wall, the measurements of the two methods differed completely. For example, in the patient in Case 9 (IVSd: 31 mm, PWd: 26 mm, LVIDd: 35 mm) and in the patient in Case 51 (IVSd: 33 mm, PWd: 17 mm), there is clearly visible asymmetric septal hypertrophy (Septum/PW ratio > 1.5). Because the ECHO formula assumes the walls are symmetric and constructs a mathematical hypothesis based on the total diameter, the clinical correlation with the gold standard mass values obtained by the three-dimensional Simpson method of CMR is completely broken [14].

Discussion and Conclusion

Within the framework of this study, the results we obtained demonstrate that in our cohort of 94 patients with left ventricular hypertrophy, the mass indices calculated by Transthoracic ECHO using the Devereux cube formula were on average 18.2 grams (7.2 g/m² at the index level) higher than the gold standard indices obtained by the three-dimensional Simpson method of CMR. The tendency of ECHO to systematically overestimate LVM primarily stems from the geometric limitations of the mathematical equation used by this method [6], [14]. The cubic model underlying the Devereux formula likens the left ventricle to a structure with uniform wall thickness on all sides and an internal cavity formed as a regular prolate ellipsoid [4]. However, in the real clinical setting, the hypertrophic process of the myocardium is not always concentric or homogeneous in nature. Particularly in chronic valvular regurgitations or end-stage ischemic/dilated cardiomyopathies, myocardial fibers lengthen and eccentric hypertrophy develops. In patients from our cohort where the left ventricular internal diameter exceeded the normal limits, reaching over 80 mm (Case 2 and Case 12), the sharp deviation of ECHO from CMR is precisely the consequence of

ISSN: 0005-2523
Volume 66, Issue 05, May, 2026

this geometric incompatibility. Because the diameter parameter is cubed in the formula, even a millimeter-scale difference in dilated cavities can artificially increase the final mass value by hundreds of grams [6]. The same mathematical error mechanism manifests itself differently in asymmetric hypertrophy phenotypes. In patients who drew attention in our study with IVSd thickness of 31–33 mm (e.g., Case 9 and Case 51), the septum was locally and sharply thickened compared to the free posterior wall. ECHO measures this sharply thickened septum with a one-dimensional M-mode cross-section and performs mathematical calculations in its formula as if all walls of the left ventricle were of the same thickness. Consequently, the mass increase localized only to the septal region is dispersed across the entire heart in the formula, leading to an excessive miscalculation of the mass [14]. CMR, however, thanks to Simpson's method, calculates and sums the area of real muscle tissue in each slice regardless of the heart's geometry, thus it is not affected in any way by these types of anatomical asymmetries or dilatations [16]. In the clinical decision-making process, especially in valve patients who are about to undergo surgical intervention, and in asymmetric hypertrophies carrying the risk of sudden cardiac death, Simpson's method of CMR, which is free from geometric assumptions, should be accepted as the primary reference [8], [20]. Furthermore, considering the tissue characterization advantages of CMR, such as late gadolinium enhancement (LGE), including CMR examination at earlier stages in the diagnostic algorithms of patients with structural deformation will minimize the risk of clinical error.

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