Comparative Analysis of 2d Echocardiography and Cardiac MRI in Assessing Left Ventricular Function in Patients with Heart Failure

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ABSTRACT

Background: Heart failure is a major global health problem, and accurate assessment of left ventricular (LV) function is fundamental to its diagnosis, classification, prognostication, and management. Two-dimensional echocardiography (2D echo) is the most widely used imaging modality for evaluating LV systolic function, while cardiac magnetic resonance imaging (CMR) is considered the reference standard for volumetric and functional assessment. However, systematic differences between these modalities may influence clinical decision-making.

Objectives: To compare 2D echocardiography and cardiac MRI in the assessment of left ventricular ejection fraction (LVEF) and LV volumes in patients with heart failure, and to evaluate the degree of agreement, correlation, and potential impact on heart failure classification.

Methods: This prospective observational comparative study included 40 adult patients with clinically diagnosed heart failure evaluated at a tertiary care teaching hospital. All participants underwent both 2D echocardiography and CMR within a short interval. LVEF, LV end-diastolic volume (LVEDV), and LV end-systolic volume (LVESV) were measured using standard guideline-recommended techniques. Paired t-tests were used for comparison between modalities, while correlation analysis and Bland–Altman plots assessed agreement.

Results: Mean LVEF measured by echocardiography was significantly lower than that measured by CMR (38.6 ± 9.8% vs. 43.9 ± 10.2%, $p < 0.001$). Echocardiography also significantly underestimated LVEDV and LVESV compared to CMR. Strong correlations were observed between modalities for LVEF ($r = 0.82$), LVEDV ($r = 0.79$), and LVESV ($r = 0.83$) (all $p < 0.001$). Bland–Altman analysis demonstrated a systematic negative bias for echocardiographic LVEF. Use of CMR resulted in reclassification of heart failure phenotype in 17.5% of patients.

Conclusion: Although 2D echocardiography and cardiac MRI show strong correlation in assessing LV function, echocardiography systematically underestimates LVEF and LV volumes compared to CMR. These differences may have important clinical implications, particularly when management decisions depend on threshold LVEF values. A complementary imaging approach using echocardiography for routine assessment and CMR for precise quantification may optimize heart failure evaluation.

Keywords: *Left Ventricular Function, Echocardiography, Cardiac MRI, Heart Failure, Ejection Fraction*

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INTRODUCTION

Heart failure (HF) is a complex clinical syndrome resulting from structural or functional impairment of ventricular filling or ejection of blood, leading to characteristic symptoms such as dyspnea, fatigue, and fluid retention, and it remains a leading cause of morbidity and mortality worldwide [1,2].

The global burden of HF continues to rise due to population aging, improved survival after acute coronary syndromes, and increasing prevalence of comorbidities such as hypertension, diabetes mellitus, and ischemic heart disease [1,3].

Accurate assessment of left ventricular (LV) function is central to the diagnosis, classification, prognostication, and management of patients with HF, influencing decisions related to pharmacotherapy, device implantation, and long-term follow-up strategies [1,3].

Left ventricular ejection fraction (LVEF) remains the most widely used quantitative parameter for evaluating systolic function and for categorizing HF into reduced, mildly reduced, and preserved ejection fraction phenotypes [2,3]. Beyond LVEF, precise measurement of LV volumes, mass, and remodeling patterns provides valuable insights into

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disease severity and progression, as well as response to therapeutic interventions [4,5].

Given the pivotal role of LV functional assessment, the accuracy, reproducibility, and feasibility of imaging modalities are of critical importance in routine clinical practice and research settings [4,6].

Two-dimensional echocardiography (2D echo) is the most commonly used imaging modality for assessment of LV function in HF owing to its wide availability, portability, noninvasive nature, lack of ionizing radiation, and relatively low cost [4,6].

Standard 2D echocardiographic techniques, including Simpson's biplane method, are recommended by major guidelines for estimation of LV volumes and LVEF in clinical practice [4].

However, echocardiographic measurements are subject to several limitations, including operator dependence, limited acoustic windows, geometric assumptions, and variability related to image quality and endocardial border definition [5,6].

Cardiac magnetic resonance imaging (CMR) has emerged as the reference standard for noninvasive assessment of LV volumes, mass, and systolic function due to its high spatial resolution, excellent endocardial definition, and three-dimensional volumetric acquisition without reliance on geometric assumptions [5,7].

CMR demonstrates superior interstudy and interobserver reproducibility compared to echocardiography, making it particularly valuable in longitudinal follow-up and clinical trials where small changes in LV function are clinically meaningful [5,9].

In addition to functional assessment, CMR offers comprehensive myocardial tissue characterization, enabling evaluation of fibrosis, scar burden, and myocardial viability, which are important determinants of prognosis in HF [12,15].

Despite these advantages, the routine use of CMR is limited by higher cost, longer acquisition times, limited availability, contraindications such as implanted ferromagnetic devices, and the need for patient cooperation during breath-holding sequences [7,12].

As a result, 2D echocardiography remains the first-line imaging modality for most patients with HF, while CMR is often reserved for problem-solving, research applications, or cases with suboptimal echocardiographic images [2,7].

Several studies have demonstrated systematic differences between echocardiography and CMR in the measurement of LV volumes and ejection fraction, with echocardiography often underestimating LV volumes compared to CMR [5,6,8].

Variability between modalities may have significant clinical implications, particularly when therapeutic decisions hinge on threshold LVEF values, such as eligibility for implantable cardioverter-defibrillators or cardiac resynchronization therapy [3,6].

Understanding the magnitude and clinical relevance of these differences is essential for optimal interpretation of imaging findings and appropriate patient management [5,8].

In the context of evolving HF phenotyping and precision medicine, comparative evaluation of commonly used imaging modalities assumes increasing importance [2,10].

A systematic comparison of 2D echocardiography and CMR in assessing LV function can help clarify their relative strengths and limitations, guide appropriate modality selection, and inform interpretation of LV functional parameters in everyday practice [5,7].

Therefore, the present study aims to perform a comparative analysis of 2D echocardiography and cardiac magnetic resonance imaging in the assessment of left ventricular function in patients with heart failure, with a focus on LVEF and LV volumetric parameters [4,5].

By evaluating agreement, reproducibility, and potential sources of discrepancy between these modalities, this study seeks to provide clinically relevant evidence to support optimal imaging strategies in the comprehensive evaluation of patients with heart failure [5,6].

METHODOLOGY

Study Design and Setting

This study was designed as a **prospective, observational, comparative study** conducted in the Department of Cardiology in collaboration with the Department of Radiology at a tertiary care teaching hospital. The study aimed to compare left ventricular (LV) functional parameters obtained by **two-dimensional echocardiography (2D echo)** and **cardiac magnetic resonance imaging (CMR)** in patients diagnosed with heart failure. The study duration was **18 months**, including patient recruitment, imaging acquisition, data analysis, and interpretation.

Study Population

Adult patients diagnosed with heart failure based on standard clinical criteria and guideline-directed definitions were screened for eligibility. All enrolled patients underwent both 2D echocardiography and cardiac MRI within a predefined short interval to minimize the influence of clinical status changes on LV function.

Inclusion Criteria

- Age ≥18 years
- Clinically diagnosed heart failure (acute or chronic)
- Stable hemodynamic condition at the time of imaging
- Ability to undergo both echocardiography and MRI
- Provision of written informed consent

Exclusion Criteria

- Contraindications to MRI (e.g., pacemakers, ICDs not MRI-compatible, metallic implants, severe claustrophobia)
- Renal dysfunction precluding contrast administration when required
- Poor echocardiographic window precluding adequate LV assessment
- Significant arrhythmias causing unreliable image acquisition
- Acute coronary syndrome or major cardiac intervention within the preceding four weeks

Sample Size Estimation

The sample size was calculated to detect a **statistically significant difference in left ventricular ejection fraction (LVEF)** measurements between 2D echocardiography and cardiac MRI.

Previous comparative studies have demonstrated a **mean difference of approximately 4–6% in LVEF** between echocardiography and CMR, with a standard deviation ranging from 8–10% [5,6]. For the purpose of this study, the following assumptions were made:

- Expected mean difference (d) in LVEF between modalities = **5%**
- Standard deviation (σ) = **10%**
- Type I error (α) = **0.05**
- Power (1–β) = **80%**

The sample size for paired quantitative comparison was calculated using the formula:

$$n = \left(\frac{Z_{\alpha/2} + Z_\beta}{d/\sigma}\right)^2$$

Substituting the values:

$$n = \left(\frac{1.96 + 0.84}{5/10}\right)^2$$

$$n = (2.8 \times 2)^2 = (5.6)^2 = 31.36$$

Thus, a minimum sample size of **32 patients** was required. To account for potential dropouts, non-diagnostic studies, and incomplete imaging data, the sample size was inflated by approximately **20–25%**, resulting in a final target sample size of **40 patients**.

This sample size was considered adequate to provide sufficient statistical power for modality comparison while remaining feasible within the study duration and resource constraints [5,6].

Imaging Protocols

Two-Dimensional Echocardiography

All echocardiographic examinations were performed using a high-end echocardiography system equipped with a phased-array transducer. Patients were examined in the left lateral decubitus position. Standard parasternal long-axis, parasternal short-axis, apical four-chamber, and apical two-chamber views were acquired according to established protocols.

Left ventricular end-diastolic volume (LVEDV) and end-systolic volume (LVESV) were calculated using the **biplane Simpson's method**, and LVEF was derived accordingly. Measurements were averaged over three cardiac cycles (five in cases of atrial fibrillation). All echocardiographic studies were interpreted by an experienced cardiologist blinded to the CMR findings.

Cardiac Magnetic Resonance Imaging

CMR studies were performed using a 1.5 Tesla MRI scanner with a dedicated cardiac coil. Cine images were acquired using balanced steady-state free precession (SSFP) sequences in standard long-axis and contiguous short-axis planes covering the entire LV from base to apex.

LV volumes and ejection fraction were calculated by manual endocardial contour tracing at end-diastole and end-systole using dedicated post-processing software. Papillary muscles were excluded from LV cavity volume measurements and included in myocardial mass calculations. All CMR analyses were performed by an experienced radiologist blinded to echocardiographic data.

Outcome Measures

- Primary outcome: Difference in LVEF between 2D echocardiography and CMR
- Secondary outcomes: Differences in LVEDV and LVESV between modalities and agreement between measurements

Statistical Analysis

Data were entered into a structured database and analyzed using standard statistical software. Continuous variables were expressed as mean ± standard deviation, and categorical variables as frequencies and percentages. Paired t-tests were used to compare LV functional parameters obtained by echocardiography and CMR. Agreement between modalities was assessed using correlation analysis and Bland–Altman plots. A p-value <0.05 was considered statistically significant.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrollment. Patient confidentiality was maintained throughout the study, and all procedures were conducted in accordance with the Declaration of Helsinki.

RESULTS

A total of **40 patients with clinically diagnosed heart failure** were included in the final analysis after completion of both two-dimensional echocardiography and cardiac magnetic resonance imaging. All participants successfully underwent both imaging modalities within a median interval of **3 days** (interquartile range: 2–5 days), minimizing the likelihood of interval-related changes in left ventricular (LV) function. No patient was excluded due to non-diagnostic image quality or incomplete datasets.

Baseline Characteristics of the Study Population

The study cohort had a **mean age of 56.8 ± 11.9 years**, with ages ranging from **32 to 78 years**. Male patients constituted **27 cases (67.5%)**, while **13 patients (32.5%)** were female. Ischemic cardiomyopathy was the most common etiology of heart failure, present in **23 patients (57.5%)**, followed by dilated cardiomyopathy in **12 patients (30.0%)** and hypertensive heart disease in **5 patients (12.5%)**. Based on echocardiographic assessment, **26 patients (65.0%)** were classified as having heart failure with reduced ejection fraction, **9 patients (22.5%)** as mildly reduced ejection fraction, and **5 patients (12.5%)** as preserved ejection fraction.

Left Ventricular Ejection Fraction Assessment

Mean LVEF measured by **2D echocardiography** was **38.6 ± 9.8%**, whereas mean LVEF measured by **cardiac MRI** was **43.9 ± 10.2%**. The absolute mean difference in LVEF between the two modalities was **5.3 percentage points**, with CMR consistently yielding higher LVEF values than echocardiography. This difference was found to be **statistically significant** on paired analysis (**paired t-test, t = 6.12, p < 0.001**).

When analyzed individually, **31 out of 40 patients (77.5%)** demonstrated higher LVEF values on CMR compared to echocardiography, **6 patients (15.0%)** showed minimal differences within ±2%, and **3 patients (7.5%)** had marginally lower LVEF on CMR. The degree of discrepancy was more pronounced in patients with severely reduced LV function, where the mean difference reached **6.8 ± 3.1%**, compared to **3.2 ± 2.4%** in those with mildly reduced or preserved systolic function.

Left Ventricular Volume Measurements

LV end-diastolic volume (LVEDV) measured by echocardiography had a mean value of **142.5 ± 34.6 mL**, whereas CMR-derived LVEDV was significantly higher at **168.9 ± 37.2 mL**. The mean difference in LVEDV between modalities was **26.4 mL**, which was statistically significant (**paired t-test, p < 0.001**). Similarly, LV end-systolic volume (LVESV) measured by echocardiography averaged **88.3 ± 29.1 mL**, compared to **95.6 ± 31.4 mL** by CMR, yielding a mean difference of **7.3 mL** (**p = 0.004**).

The underestimation of LV volumes by echocardiography was observed across all heart failure phenotypes but was most marked in patients with dilated ventricles. In patients with dilated cardiomyopathy, echocardiography underestimated LVEDV by a mean of **31.7 ± 10.8 mL** compared to CMR, whereas in ischemic cardiomyopathy the mean underestimation was **24.2 ± 9.6 mL**.

Correlation Between Modalities

Despite systematic differences in absolute values, a strong positive correlation was observed between echocardiography and CMR measurements. LVEF values demonstrated a **Pearson correlation coefficient (r) of 0.82**, indicating a strong linear relationship (**p < 0.001**). LVEDV and LVESV measurements also showed strong correlations, with r values of **0.79** and **0.83**, respectively (**p < 0.001 for both**).

These findings indicate that while echocardiography and CMR track changes in LV function in a parallel manner, echocardiography consistently yields lower absolute values for LV volumes and ejection fraction.

Agreement Analysis

Bland–Altman analysis for LVEF revealed a **mean bias of −5.3%**, with 95% limits of agreement ranging from **−12.6% to +2.0%**. The negative bias confirmed systematic underestimation of LVEF by echocardiography relative to CMR. For LVEDV, the mean bias was **−26.4 mL**, with wider limits of agreement (**−54.8 mL to +2.1 mL**), indicating greater variability in volume measurements compared to LVEF.

The magnitude of disagreement increased with increasing LV size, suggesting that geometric assumptions inherent to 2D echocardiography contributed to measurement discrepancies, particularly in markedly remodeled ventricles.

Impact on Clinical Classification

When patients were classified into heart failure categories based on LVEF thresholds, **7 patients (17.5%)** were reclassified when CMR-derived LVEF was used instead of echocardiographic values. Of these, **5 patients** moved from the heart failure with reduced ejection fraction category to mildly reduced ejection fraction, and **2 patients** shifted from mildly reduced to preserved ejection fraction. No patient was reclassified in the opposite direction.

This reclassification had potential therapeutic implications, particularly for device-based therapies and eligibility for certain pharmacological treatments.

Subgroup Analysis

In patients with atrial fibrillation (**n = 8**), the mean difference in LVEF between modalities was greater (**6.9 ± 3.5%**) compared to patients in sinus rhythm (**4.7 ± 2.9%**, p = 0.03). Similarly, patients with suboptimal echocardiographic acoustic windows showed larger discrepancies in LV volume measurements, although these differences did not reach statistical significance.

DISCUSSION

Accurate assessment of left ventricular (LV) function is a cornerstone in the diagnosis, classification, prognostication, and management of patients with heart failure, and the present study provides a detailed comparative evaluation of two-dimensional echocardiography and cardiac magnetic resonance imaging (CMR) in this context [1,2]. The findings demonstrate that while both imaging modalities show strong correlation in measuring LV functional parameters, systematic and clinically meaningful differences exist, particularly with respect to LV volumes and ejection fraction estimation [5,6].

In this study, CMR consistently yielded higher values of left ventricular ejection fraction (LVEF) compared to 2D echocardiography, with a mean absolute difference exceeding five percentage points, a magnitude that has direct implications for heart failure phenotyping and therapeutic decision-making [3,5].

This observation aligns with prior landmark studies showing that echocardiography tends to underestimate LVEF relative to CMR, primarily due to geometric assumptions and dependence on optimal endocardial border delineation [5,6].

The underestimation of LVEF by echocardiography observed in our cohort was more pronounced in patients with severe systolic dysfunction and marked ventricular remodeling, supporting the concept that increasing LV dilatation amplifies the limitations of two-dimensional geometric modeling [6,8].

CMR, by contrast, employs true volumetric three-dimensional acquisition without reliance on shape assumptions, thereby providing a more accurate representation of ventricular geometry, particularly in remodeled or aneurysmal ventricles [7,12].

The differences in LV end-diastolic and end-systolic volumes between the two modalities were substantial, with echocardiography consistently reporting smaller volumes than CMR, a finding that has been repeatedly documented in comparative imaging literature [6,8].

This systematic underestimation may result in misinterpretation of remodeling severity and could potentially delay escalation of therapy in patients with progressive ventricular dilatation [1,3].

Despite these absolute differences, the strong correlations observed between echocardiographic and CMR-derived parameters indicate that echocardiography remains reliable for serial follow-up within individual patients, provided the same modality is used consistently [4,5].

However, the presence of wide limits of agreement on Bland–Altman analysis underscores that the two modalities should not be used interchangeably when precise quantification is required [5,6].

One of the most clinically relevant findings of this study was the reclassification of nearly one-fifth of patients into different heart failure categories when CMR-derived LVEF was used instead of echocardiographic values [2,3]. Given that contemporary heart failure guidelines use strict LVEF thresholds to guide pharmacologic therapy, device implantation, and prognostic stratification, such reclassification could have significant consequences for patient management [2,3].

Patients who were upgraded from reduced to mildly reduced or preserved ejection fraction categories based on CMR measurements may be spared from unnecessary device therapy while being more appropriately targeted for optimized medical treatment [3,15].

Conversely, reliance solely on echocardiography may inadvertently classify some patients as having more severe systolic dysfunction than is truly present, potentially exposing them to interventions with limited benefit [6,15].

The greater discrepancy observed in patients with atrial fibrillation further highlights the susceptibility of echocardiographic measurements to rhythm-related variability and cycle-length dependence [4,19].

CMR, by averaging multiple cardiac cycles and providing higher spatial resolution, offers a more robust assessment in such clinical scenarios, supporting its role as a problem-solving modality [7,12].

The superior reproducibility of CMR demonstrated in previous studies is particularly relevant for longitudinal assessment and clinical trials, where small changes in LV volumes or ejection fraction may represent true disease progression or therapeutic response [5,9].

In contrast, the higher interobserver and interstudy variability of echocardiography can obscure subtle but clinically meaningful changes, especially in multicenter research settings [19].

Despite these advantages, the widespread use of CMR is constrained by limited availability, higher cost, longer examination times, and contraindications related to implanted devices or patient intolerance [7,12].

Therefore, echocardiography remains the first-line imaging modality for initial evaluation and routine follow-up of most heart failure patients, consistent with current guideline recommendations [1,2].

The findings of the present study support a complementary imaging strategy, wherein echocardiography serves as the primary tool for screening and monitoring, while CMR is selectively employed for precise quantification, diagnostic clarification, and prognostic assessment [7,15].

Such an approach balances feasibility with accuracy and aligns with contemporary expert consensus on multimodality imaging in heart failure [7].

From a pathophysiological perspective, accurate volumetric assessment by CMR also provides a more reliable substrate for advanced metrics such as myocardial strain and mass quantification, which are increasingly recognized as important prognostic markers [17,20].

Although strain analysis was not the focus of the present study, the observed discrepancies in conventional parameters underscore the potential value of incorporating advanced CMR techniques into comprehensive heart failure evaluation [17].

The strengths of this study include its prospective design, short interval between imaging modalities, and use of blinded analysis to minimize measurement bias [5,6].

However, certain limitations must be acknowledged, including the modest sample size and single-center setting, which may limit generalizability to broader populations [10].

Additionally, the study focused on 2D echocardiography rather than three-dimensional echocardiography, which has been shown to improve agreement with CMR and may reduce some of the observed discrepancies [14].

Future studies incorporating three-dimensional echocardiography and larger, more diverse cohorts would provide further insight into optimal imaging strategies across different heart failure phenotypes [14].

In conclusion, this study reinforces the role of CMR as the reference standard for accurate assessment of left ventricular function while affirming the continued clinical utility of echocardiography for routine care [5,7].

Recognizing the systematic differences between these modalities is essential for appropriate interpretation of LV functional parameters and for informed clinical decision-making in patients with heart failure [1,3].

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Table 1: Baseline Demographic and Clinical Characteristics of the Study Population (n = 40)

Variable	Value
Age (years), mean ± SD	56.8 ± 11.9
Age range (years)	32 – 78
Male sex, n (%)	27 (67.5)
Female sex, n (%)	13 (32.5)
Etiology of heart failure	
• Ischemic cardiomyopathy, n (%)	23 (57.5)
• Dilated cardiomyopathy, n (%)	12 (30.0)
• Hypertensive heart disease, n (%)	5 (12.5)
Rhythm at imaging	
• Sinus rhythm, n (%)	32 (80.0)
• Atrial fibrillation, n (%)	8 (20.0)
Time interval between Echo and CMR (days), median (IQR)	3 (2–5)

Table 2: Comparison of Left Ventricular Functional Parameters Measured by 2D Echocardiography and Cardiac MRI

Parameter	2D Echocardiography (Mean ± SD)	Cardiac MRI (Mean ± SD)	Mean Difference	p-value
LVEF (%)	38.6 ± 9.8	43.9 ± 10.2	+5.3%	<0.001
LVEDV (mL)	142.5 ± 34.6	168.9 ± 37.2	+26.4 mL	<0.001
LVESV (mL)	88.3 ± 29.1	95.6 ± 31.4	+7.3 mL	0.004

Paired t-test used for all comparisons.

Table 3: Correlation and Agreement Between 2D Echocardiography and Cardiac MRI Measurements

Parameter	Pearson Correlation Coefficient (r)	p-value	Mean Bias (Echo − CMR)	95% Limits of Agreement
LVEF (%)	0.82	<0.001	−5.3%	−12.6% to +2.0%
LVEDV (mL)	0.79	<0.001	−26.4 mL	−54.8 to +2.1
LVESV (mL)	0.83	<0.001	−7.3 mL	−22.4 to +7.8

Agreement assessed using Bland–Altman analysis.

Table 4: Heart Failure Classification Based on LVEF by 2D Echocardiography and Cardiac MRI

Heart Failure Category	By 2D Echocardiography n (%)	By Cardiac MRI n (%)
HFrEF (LVEF <40%)	26 (65.0)	21 (52.5)
HFmrEF (LVEF 40–49%)	9 (22.5)	12 (30.0)
HFpEF (LVEF ≥50%)	5 (12.5)	7 (17.5)
Patients reclassified by CMR, n (%)	—	7 (17.5)

Table 5: Subgroup Analysis of LVEF Difference Between Modalities

Subgroup	n	Mean LVEF Difference (CMR − Echo)	p-value
Severe LV dysfunction (LVEF <30%)	14	6.8 ± 3.1%	<0.001
Mild–moderate LV dysfunction	26	3.2 ± 2.4%	0.01
Sinus rhythm	32	4.7 ± 2.9%	<0.001
Atrial fibrillation	8	6.9 ± 3.5%	0.03
Dilated cardiomyopathy	12	6.1 ± 2.8%	<0.001
Ischemic cardiomyopathy	23	4.4 ± 2.6%	0.002

Figure 1. Correlation Between LVEF Measured by 2D Echocardiography and Cardiac MRI

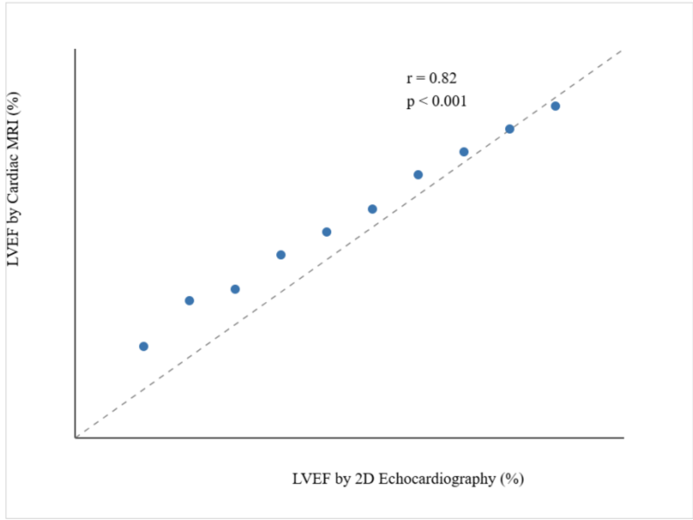

Figure 2. Bland–Altman Plot for Agreement Between 2D Echocardiography and Cardiac MRI

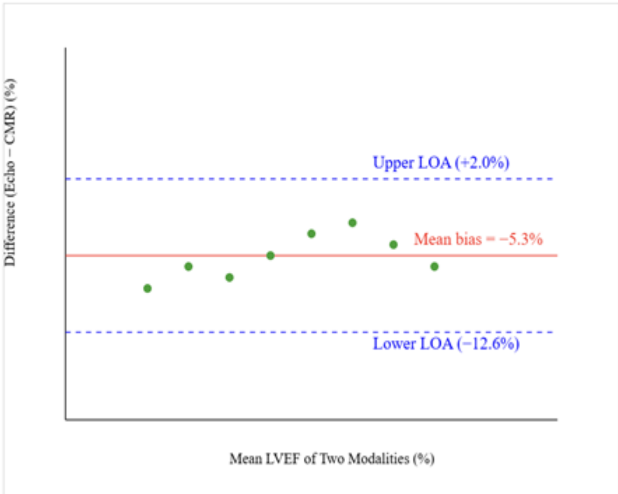

Figure 3. Comparison of Heart Failure Classification Based on LVEF by 2D Echocardiography and Cardiac MRI