Agreement in left ventricular function measured by echocardiography and cardiac magnetic resonance in patients with chronic total occlusion

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Research

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Abstract

Background: To determine the agreement between two-dimensional transthoracic echocardiography (2DTTE) and cardiovascular magnetic resonance (CMR) in left ventricular (LV) function in CTO patients: including end-systolic volume (LVESV), end-diastolic volume (LVEDV), and ejection fraction (LVEF).

Methods: Eighty-eight CTO patients were enrolled in this study. All patients underwent 2DTTE and CMR within one week of each other. The correlation and agreement of LVEF, LVESV and LVEDV as measured by 2DTTE and CMR were assessed using Pearson correlation, Kappa analysis and Bland-Altman method.

Results: The mean age of patients enrolled was 57 ± 10 years. There was a strong correlation (r=0.71, 0.90 and 0.80, respectively, all P<0.001) and a moderately strong agreement (Kappa=0.62, P<0.001) between the two modalities in measurement of LV function. The agreement in patients with EF≧50% was better than in those with an EF <50%. CTO patients without echocardiographic WMA had stronger intermodality correlations (r=0.84, 0.96, and 0.87, respectively) and smaller biases in LV function measurement.

Conclusions: The difference in measurement between 2DTTE and CMR should be noticed in CTO patients with EF<50% or abnormal ventricular motion. CMR should be considered in these conditions.

Trial registration: Retrospectively registered

1. Background

For patients with coronary chronic total occlusion (CTO), left ventricular (LV) function assessment before revascularization has reference value for clinical decision-making and prognosis prediction [1], and may further influence the management and long-term outcome after revascularization. [2][3] LV function can be measured in clinical work by several noninvasive cardiac imaging modalities: including echocardiography, cardiac magnetic resonance (CMR) and cardiac computed tomography. All of these modalities are widely used in clinical work under different conditions. Many studies regarding the comparison among these techniques have been reported. However, most of them enrolled healthy subjects or patients with different cardiac diseases. Data about the agreement in ventricular function determined by these different modalities in CTO patients is still sparse.

The aim of this study was to determine the agreement between two-dimensional transthoracic echocardiography (2DTTE) and CMR, in assessment of LV function in CTO patients with and without segmental wall motion abnormality (WMA): including end-systolic volume (LVESV), end-diastolic volume (LVEDV) and ejection fraction (LVEF).

2. Materials And Methods

2.1 Study population

A total of 137 consecutive CTO patients, diagnosed by coronary angiography (CAG) from May 2015 to June 2017, were enrolled in this study. As shown in Fig. 1, patients were excluded due to the contradictions of CMR (N = 33) or incomplete CMR data (N = 1). The rest of the patients were referred to echocardiography examination, and further excluded due to poor-quality images (N = 5), incomplete 2DTTE data (N = 4), or lack of 2DTTE images (N = 6), leaving 88 patients eligible for the study. All enrolled patients underwent both echocardiography and CMR imaging within the same week. Coronary artery interventions were not performed until both types of imaging were finished.

Inclusion criteria were as follows: occlusion of at least one major coronary artery (vessel size > 2.5 mm) or branch vessel on CAG and CMR with segmented breath-held cine images. Exclusion criteria were as follows: atrial fibrillation, decompensated heart failure, metal device implantation, claustrophobia, and unclear acoustic windows for echocardiographic imaging (defined as unclear image of the entire left ventricle).

2.2 Transthoracic echocardiography

Transthoracic echocardiography was assessed using standard clinical 2-dimensional imaging platforms: 56 patients with IE33 XMatrix (Philips) and 32 patients with Vivid 7 (General Electric Medical Systems). All images were recorded and analyzed by an experienced echocardiologist, who was blinded to clinical data and CMR results. In each subject, assessments of LV volumes and LVEF were performed according to the recommendations of the American Society of Echocardiography [4] following the Modified Simpson's rule. [5] At end-diastole and end-systole stages, in apical four- and two-chamber views, the LV endocardial interface between myocardium and LV cavity was traced contiguously from one side of the mitral annulus to the other side, including papillary muscles as part of the LV cavity. The contour was finished after a straight line connected the two edges of mitral annular ring. LVEF, LVESV and LVEDV were calculated using the biplane Simpson's formula.

2.3 Cardiac magnetic resonance imaging

CMR imaging was performed using a 3T whole-body scanner (Siemens, Germany) with a 32-element matrix coil. Images were obtained using steady-state and breath-hold cines in three long-axis planes and sequential short-axis slices extending from the mitral valve plane to just below the LV apex. End-diastolic and end-systolic volumes were obtained by manual delineation of the endocardial borders. Short-axis slices with ≧ 50% of the LV circumference surrounded by the myocardium were included in the process of volume calculation. [6] The basal and apical slices were ensured on long-axis views. In every short-axis slice, the endocardial contour was traced at end-diastole and end-systole stages, with inclusion of papillary muscle and trabeculae as part of the LV cavity. Imaging analysis was performed by an experienced radiologist, who was blinded to the study. LVEF, LVESV and LVEDV were calculated with commercially available software (CVI42 version5.9.1, Circle Cardiovascular Imaging, Canada). CMR was used as the reference standard for comparing with echocardiography.

2.4 Statistical analysis

All analyses were performed using SPSS (Version 20.0, IBM Corporation, USA). For continuous variables, a Shapiro-Wilk test was used for normal distribution tests. Normally distributed values were expressed as means ± standard deviation (SD) and compared using Student's t-test. Non-normally distributed ones were expressed as a median with interquartile range (IQR) and compared using the Mann-Whitney U test. Categorical variables were expressed as percentages and compared using the chi-squared test. The intermodality correlation and agreement were tested, respectively, using Pearson correlation, Kappa analysis, and Bland–Altman method. Bias and limits of agreement (LOA) were expressed as the mean and 95% confidence interval of the differences in normally distributed values, and as median and 2.5th -97.5th percentiles of the differences in non-normally distributed values. All statistical tests were two-sided and statistical significance was defined as P value < 0.05.

3. Results

3.1 Patient characteristics

A total of 88 patients (mean age 57 ± 10 years, 83% male) were included in this study. Most patients had unstable angina pectoris (77.3%) and more than half of them had a history of hypertension (55.7%) and smoking (53.4%). Further clinical data and LV functions (LVEF, LVESV and LVEDV) are presented in Table 1.

Table 1
Baseline Characteristics

	All Patients N=88
Age (years)	57 ± 10
Male	73 (83.0)
Clinical presentations	
Stable angina pectoris	8 (9.1)
Unstable angina pectoris	68 (77.3)
Myocardial infarction	5 (5.7)
Follow-up	7 (8.0)
Hypertension	49 (55.7)
Diabetes	18 (20.5)
Dyslipidemia	32 (36.4)
Prior myocardial infarction	24 (27.3)
Prior PCI	31 (35.2)
Smoking	47 (53.4)
Echocardiography	
EF (%)	60.0 (54.3-63.9)
ESV (ml)	38.9 (32.0-53.8)
EDV (ml)	100.3 (82.5-123.9)
CMR	
EF (%)	58.4 (50.3-66.5)
ESV (ml)	45.0 (28.8-56.8)
EDV (ml)	106.7 (83.3-130.3)

Data are expressed as mean ± standard deviation or median with interquartile range

PCI, percutaneous coronary intervention; EF, ejection fraction; ESV, end-systolic volume; EDV, end-diastolic volume; CMR, cardiac magnetic resonance

3.2 Correlation and agreement in 2DTTE and CMR measurements of LV function

In all 88 patients, correlation coefficients between 2DTTE and CMR for LVEF, LVESV and LVEDV were 0.71, 0.90 and 0.80, respectively ($p < 0.001$ for all). (Fig. 2 and Table 2) The Bland-Altman analysis, bias and 95% LOA between two modalities (with CMR as reference standard) were + 2.0 (-16.7, 20.6) % for LVEF, -4.2 (-65.2, 22.8) mL for LVESV, and − 6.4 (-57.9, 45.2) mL for LVEDV. (Fig. 3 and Table 2)

Table 2
Correlation and agreement analysis for 2DTTE and CMR

	Pearson r *	Linear Regression Equation	Bias**	limits of agreement***
EF	0.71	y = 0.47 x + 31.85	2.0%	(-16.7, 20.6) %
ESV	0.90	y = 0.65 x + 12.18	-4.2 ml	(-65.2, 22.8) ml
EDV	0.80	y = 0.68 x + 29.21	-6.4 ml	(-57.9, 45.2) ml
Abbreviations as in Fig. 1				
*All P values were < 0.001				
** Bias in EF and EDV were expressed as the mean of the differences, as median of the differences in ESV.				
*** Limits of agreement in EF and EDV were expressed as the 95% confidence interval of the differences, as 2.5th-97.5th percentiles of the differences in ESV.				

According to the heart failure guidelines [7], an LVEF of 50% was chosen as the threshold when assessing the agreement between 2DTTE and CMR. The intermodality agreement was moderately strong ($k = 0.62$, $P < 0.001$). In detail, 78 patients had the same classification when measured by 2DTTE and CMR, and 67 of them (85.9%) had an EF ≧ 50%. 2DTTE reclassified 10 of the total 88 patients (11.4%). Furthermore, in 9 of the 10 instances (90.0%) of reclassification, CMR derived that patients had an EF<50% and 2DTTE values were overestimated. (Table 3)

Table 3
Patients assessed by echocardiography and CMR at EF 50% threshold

		CMR EF		
		≥ 50%	< 50%	Total
Echocardiographic EF	≥ 50%	67	9	76
	< 50%	1	11	12
Total		68	20	88
Kappa = 0.62, P < 0.001				

3.3 Agreement of measurement for LV functions in patients with and without segmental wall motion abnormality

According to whether existing echocardiographic WMA was present or not, patients were divided into two groups: WMA group and non-WMA group. Compared with WMA group, non-WMA group had significantly higher CMR derived EF (59.0 ± 10.4% vs. 54.9 ± 16.1%) (Table 4) and higher intermodality correlations for LVEF, LVESV and LVEDV (0.84 vs. 0.66, 0.96 vs. 0.87 and 0.87 vs. 0.75, respectively). Additionally, bias in LVEF, LVESV and LVEDV were all greater in WMA group (8.2% vs. 4.8%, -7.3 ml vs. -3.3 ml and − 12.3 ml vs. -10.6 ml, respectively).

Table 4
Comparison of patients with and without segmental wall motion abnormality detected by 2DTTE

	WMA N = 40	**non-WMA N = 48**	**P Value**
Age (years)	57 ± 10	56 ± 10	0.742
Male	33 (82.5)	40 (83.3)	0.918
Hypertension	25 (62.5)	24 (50.0)	0.240
Diabetes	7 (17.5)	11 (22.9)	0.530
Dyslipidemia	15 (37.5)	17 (35.4)	0.840
Prior myocardial infarction	11 (27.5)	13 (27.1)	0.965
Prior PCI	14 (35.0)	17 (35.4)	0.968
Smoking	20 (50.0)	27 (56.2)	0.588
Echocardiography			
EF (%)	58.7 ± 8.8	58.6 ± 9.3	0.901
ESV (ml)	38.7 (31.0-57.5)	39.0 (32.5–52.4)	0.782
EDV (ml)	109.1 ± 38.3	104.1 ± 37.0	0.890
CMR			
EF (%)	54.9 ± 16.1	59.0 ± 10.4	0.007
ESV (ml)	43.8 (28.1–58.0)	45.3 (28.8–56.5)	0.802
EDV (ml)	105.6 (79.2-123.6)	108.5 (85.0-135.3)	0.379
Data are expressed as mean ± standard deviation or median with interquartile range			
Abbreviations as in Table 1			

Table 5
Correlation and agreement analysis for 2DTTE and CMR in patients with and without segmental wall motion abnormality

		Pearson r *	Linear Regression Equation	Bias**	Limits of agreement***
	EF	0.66	y = 0.39 x + 39.37	8.2%	(-20.1, 23.5) %
WMA	ESV	0.87	y = 0.55 x + 16.98	-7.3 ml	(-79.1, 24.5) ml
	EDV	0.75	y = 0.60 x + 42.68	-12.3 ml	(-53.5, 28.9) ml
	EF	0.84	y = 0.75 x + 14.08	4.8%	(-19.3, 28.8) %
Without WMA	ESV	0.96	y = 0.80 x + 5.61	-3.3 ml	(-39.0, 16.7) ml
	EDV	0.87	y = 0.79 x + 13.89	-10.6 ml	(-50.1, 29.0) ml
*All P values were < 0.001					
** Bias in EF and EDV were expressed as the mean of the differences, as median of the differences in ESV.					
*** Limits of agreement in EF and EDV were expressed as the 95% confidence interval of the differences, as 2.5th-97.5th percentiles of the differences in ESV.					

4. Discussion

In this study, the results suggested that (1) there were strong correlations between 2DTTE and CMR for LV volume measurement in CTO patients; (2) for CTO patients with LVEF < 50%, the strength of intermodality agreement might be lower and the EF was overestimated by 2DTTE; (3) CTO patients with WMA had lower intermodality correlation and greater bias in LV evaluation.

In clinical practice, both echocardiography and CMR are important noninvasive cardiac techniques for accurate and practical cardiac function assessment. Due to its greater availability, lower cost, and lower radiation exposure, echocardiography is the most widely used cardiac imaging for the evaluation of ventricular function. [8] In regards to accuracy, CMR is considered as the gold standard for volumetric and EF assessment, with better tissue characterization and endocardium definition. [9] Previous studies had shown a strong correlation and agreement between 2DTTE and CMR in LV measurement [10], which was further confirmed in this study. However, the strength of intermodality correlation for LVEF (r = 0.71) was found to be lower than that in prior studies. [11][12] Bland-Altman analysis also showed a small bias in LV measurements, but with a large range of agreement. These findings might result from worse ventricular functions in enrolled subjects. Due to long-term ischemic impairment, minimal infarction and restructure in local myocardium are more common in CTO patients, leading to abnormalities in cardiac structure and function[13], and affect the myocardium mapping during measurement.

Accurate, consistent LVEF measurement is important for decision-making in clinical work, including indications for implantable cardioverter defibrillator (LVEF ≤ 35%) [14][15], and for classification for heart failure patients with EF ≥ 50%, 40–49% and < 40%. [16] In a previous study investigating the agreement between 2DTTE and CMR, 11 of 25 (44%) patients differed in LVEF classification (≤ 35%, 35–50%, > 50%) when comparing the two modalities. [17] Another study including patients with ST-elevation myocardial infarction showed low sensitivity (52%) and positive predictive values (54%) to detect LVEF < 50% using 2DTTE. [18] In our study, an LVEF of 50% was chosen as the threshold when assessing intermodality agreement. In patients with the same classification detected by 2DTTE and CMR, the majority had an EF ≥ 50%, while most of patients who were reclassified by 2DTTE had a CMR-derived EF < 50%. Although a small sample size, this suggested that the intermodality agreement might be better when EF ≥ 50%. This also reflected the differing results between echocardiography and CMR measurement in the lower range of EF and the necessity of CMR for further accurate assessment of LV function in these patients.

In the comparison of patients with and without segmental wall motion abnormalities, no significant difference in the history of myocardial infarction was found. This suggested that the judgment of myocardial infarction and necrosis could not exclusively rely on echocardiographic detected segmental wall motion abnormalities, especially in regards to the existence of unrecognized myocardial infarction in clinical work. These patients could present with unequivocal evidence of cardiac ischemia, or they could present with none of the typical symptoms. In recent years, late gadolinium enhancement (LGE) has become a reliable, widely used technique that analyzes the extent of myocardial infarction and shows good correlation with pathological specimens. [19] LGE may provide more reliable evidence for the judgment of myocardial infarction and provide additional prognostic information to medical staffs.

In addition, lower strength of intermodality correlations for LV measurements and more significant bias in LVEF were observed in the WMA group in comparison with the non-WMA group. The defect in the mechanism of echocardiography measurement was the main reason for this result. In clinical work, the biplane approach is a commonly used 2D echocardiography for LV assessment and EF calculation (i.e., the “modified Simpson’s rule”). In this method, the interface between myocardium and ventricular cavity should be mapped, cautiously, at the end-diastole and end-systole stages in apical four and two-chamber views. The LV model is then made into a bullet shape and becomes the basis for measurements of volumetric values and EF calculation. [4] During the process, concise mapping may avoid the potential error in model-making and measurement. However, in patients with WMA, asymmetry of the LV cavity and irregular myocardial motion added difficulties in mapping the ventricular interface and is therefore more likely to add inaccuracies in echocardiography measurements. Thus, for patients with WMA, further CMR should be considered regardless of pre-existing echocardiographic data, offering the improvement of ventricular assessment and providing more accurate risk stratification.

Several limitations of this study need to be addressed. First, this was a single center study with a small number of patients. Second, we only enrolled CTO patients who underwent 2DTTE and CMR. It may be better to expand this study to newly emerging modalities, including 3D echocardiography and cardiac computed tomography. Previous studies have confirmed that 3D echocardiography was superior to the

2D method when it comes to LV function assessment [20], especially in patients with abnormal LV dilating motion or distortedly shaped LV.

5. Conclusions

In conclusion, there was a good correlation and agreement between 2DTTE and CMR for LV assessment in CTO patients, but the intermodality difference before revascularization should be noticed, especially in patients with EF < 50% or with abnormal ventricular motion. In these conditions, CMR should be considered for LV function assessment in order to improve assessment before revascularization.

Abbreviations

CTO
chronic total occlusion
LV
left ventricular
CMR
cardiac magnetic resonance
ESV
end-systolic volume
EDV
end-diastolic volume
EF
ejection fraction
WMA
wall motion abnormality
CAG
coronary angiography
LOA
limits of agreement

Declarations

Ethics approval and consent to participate

The study was approved by the ethical committee. Informed consent was obtained from all patients.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XYY and YH collected the patient data. JHL, LJZ and LYW analyzed data and were major contributors in writing the manuscript. HJZ,RCH,YH took the revision of the manuscript. All authors read and approved the final manuscript.

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Figures

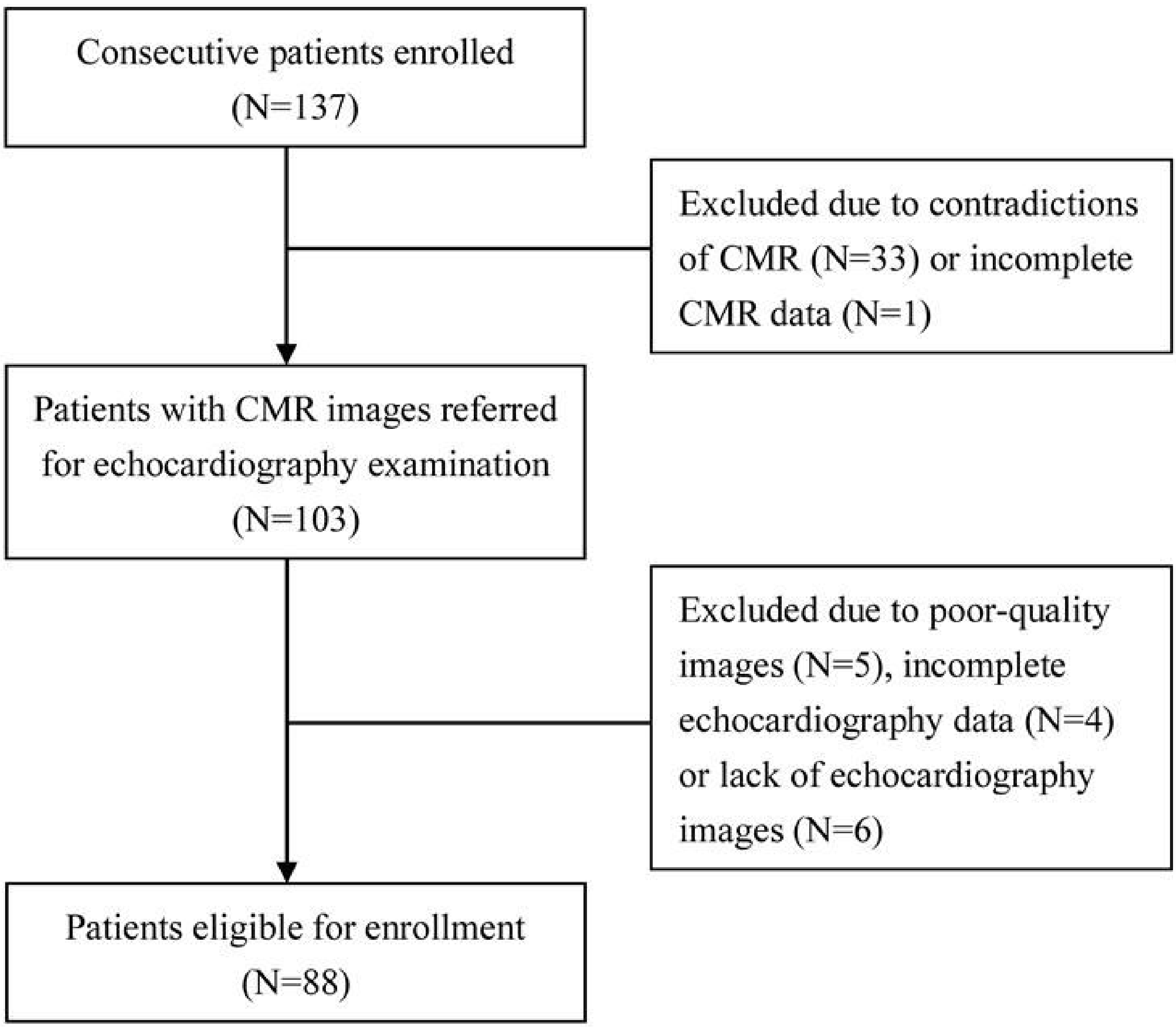

Figure 1

Flow chart of the study

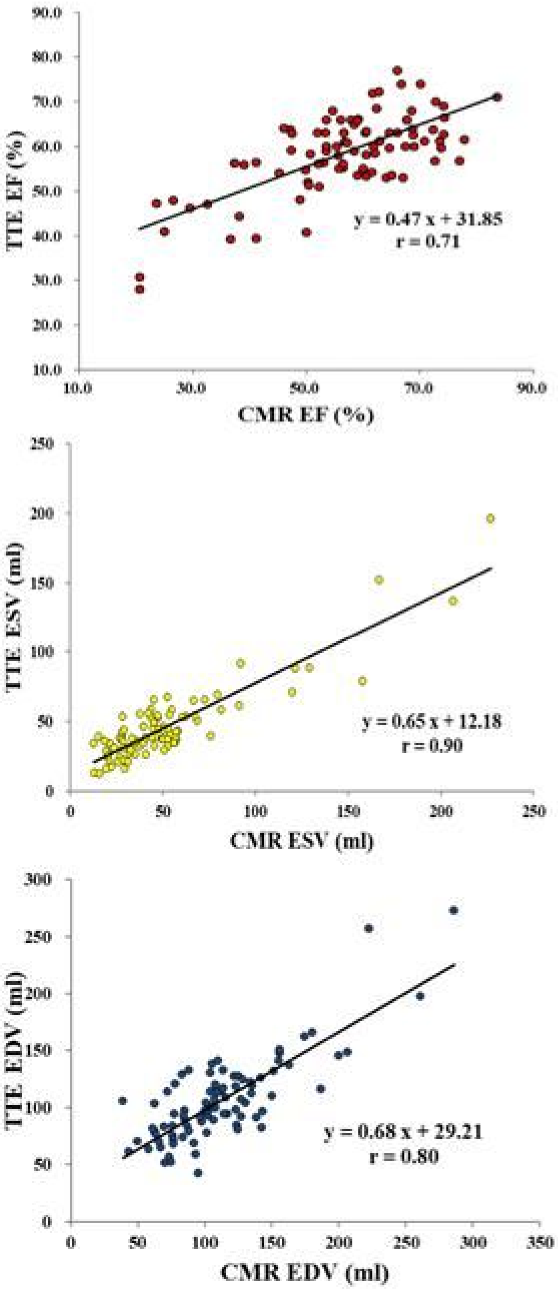

Figure 2

Linear regression analysis for left ventricular functions between echocardiography and CMR (reference standard). EF, ejection fraction; ESV, end-systolic volume; EDV, end-diastolic volume; CMR, cardiovascular magnetic resonance;

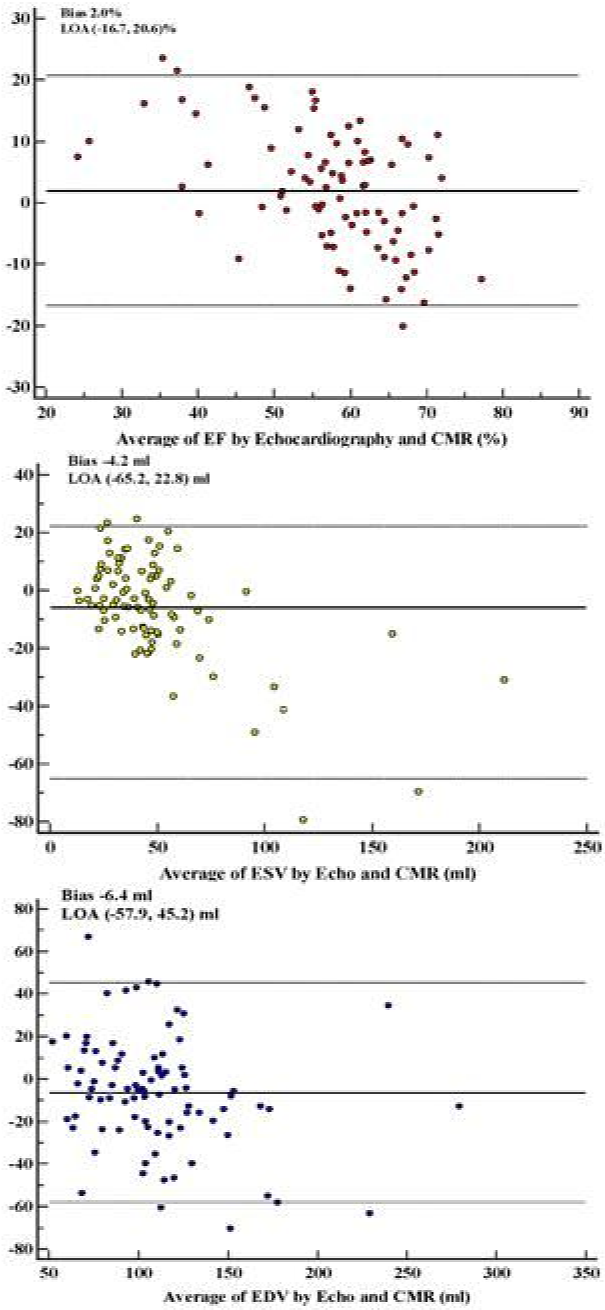

Figure 3

Bland-Altman analysis for left ventricular functions between echocardiography and CMR. Bias and 95%LOA were expressed as the mean and 95% confidence interval of the differences in normally distributed values (i.e. EF and EDV), as median and 2.5th-97.5th percentiles of the differences in non-normally distributed values (i.e. ESV).