

Left Ventricular Volume and Function Assessment: a Comparison Study between Echocardiography and Ventriculography

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Background: The left ventricular ejection fraction (LVEF) measurement is a common tool for evaluating the LV systolic function. The application of the global longitudinal systolic strain (GLS) parameter in the assessment of the myocardial function has also received special attention recently.

Objectives: This study was aimed at comparing the LVEF and LV volumes obtained by the two methods of catheterization and two-dimensional (2D) echocardiography (available in our institution) and assessing the correlation between the LVEF and the GLS.

Patients and Methods: In this cross-sectional study, 45 patients were recruited from coronary angiography candidates. The patients underwent echocardiography immediately before catheterization. The LVEF and LV volumes were measured via echocardiography using the apical four- and two chamber-views. The GLS was calculated through the automated functional imaging algorithm. Left ventriculography was performed by calculating the LVEF in the right and left oblique views.

Results: The LVEF values obtained by the two methods of ventriculography and echocardiography were not significantly different. The highest correlation regarding the echocardiographic LVEF was obtained in the angiographic right anterior oblique view ($P < 0.001$, $r = 0.95$). There was a good agreement as regards the biplane LVEF between 2D echocardiography and ventriculography (-0.5 ± 13.27 ; CI of 95%). The GLS showed a significant correlation with the estimated EF in both methods, the highest being with the Biplane Simpson method ($r = -0.84$; $P < 0.001$). Linear regression was used to obtain the formula for estimating the 2D LVEF from the GLS [$LVEF = 2.53 (GLS) + 10.48$]. The GLS values ≤ -11.7 and $\geq -21.7\%$ were consistent with normal and severe global LV systolic dysfunction, respectively. The inter- and intra-observer agreement was more evident in the GLS measurement rather than in the LVEF.

Conclusions: Despite the widespread use of 2D LVEF and its good agreement with ventriculography, strain analysis seems to be more reliable as a quantitative tool for ventricular assessment.

Keywords: Ventriculography; Echocardiography; Left Ventricular

1. Background

The evaluation of the left ventricular (LV) systolic function is critical in the appropriate management of patients with different heart diseases. The estimation of the LV ejection fraction (EF) is the most common method for this purpose (1).

Multiple imaging modalities have been used for such assessment, including echocardiography, contrast ventriculography, radionuclide ventriculography, and cardiac magnetic resonance imaging. Tissue Doppler imaging (including deformation indices), three-dimensional (3D) echocardiography, and two-dimensional (2D) speckle-tracking echocardiography (2D-STE) have also been widely utilized in the evaluation of the LV function in recent decades (2, 3). There is, however, a dearth of data on the degree of agreement between the different techniques. Moreover, finding reference values for the normally functioning or dysfunctional ventricle would be a challenging issue.

2. Objectives

The present study sought to compare the reliability of two imaging modalities available in our institution, i.e. noninvasive echocardiography and invasive cine-angiography, with respect to the LV volumes and LVEF. The global longitudinal strain (GLS) (derived by 2D-STE) was also calculated to determine reference values for the severely depressed and the normal systolic functions.

3. Patients and Methods

This cross-sectional study was conducted from March 2011 to 2012 on 54 consecutive patients with stable angina who were candidates for elective coronary angiography according to the American College of Cardiology/American Heart Association (ACC/AHA) guideline (4). Echocardiography was done in all the patients immediately before catheterization.

The exclusion criteria were defined as poor LV endocardial borders (on echocardiography or ventriculography),

heart rate over 110 per minute, multiple ventricular extra systoles, atrial fibrillation, hemodynamic instability or significant aortic or mitral regurgitation, LV thrombus, decompensated heart failure, and extreme elevation of the LV end-diastolic pressure. Forty-five patients met the inclusion criteria and were enrolled in the study for further analysis. This study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and obtained the approval of the Research Ethics Committee of Mashhad University of Medical Sciences (code No:2513339). Informed written consent was obtained from each participant.

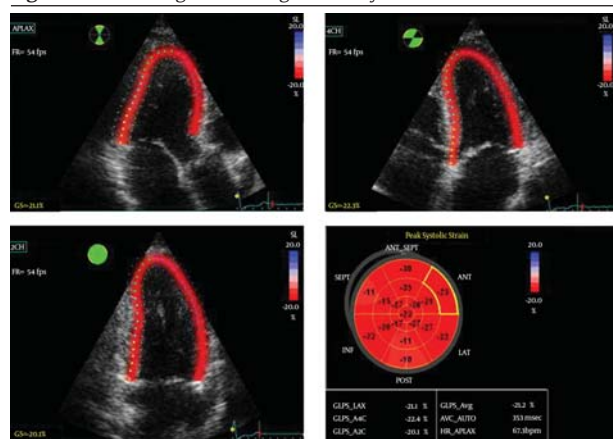
3.1. Echocardiography

Echocardiography was performed using Vivid 7 Dimension (General Electric Vingmed Ultrasound AS, Horten, Norway) through a 4-MHz probe, with the patient in the left lateral decubitus position. The LV end-systolic volume (LVESV), LV end-diastolic volume (LVEDV), and the LVEF were measured in the apical four- and two-chamber views using the Biplane Simpson rule. The LVEFs $\geq 55\%$ and $\leq 30\%$ were considered normal and severely depressed systolic functions, respectively (5).

3.2. Global Left Ventricular Longitudinal Strain

The GLS was assessed by the automated functional imaging method. Three apical views were recorded in each patient (apical long-axis and four- and two-chamber views) in gray scale with a frame rate of at least 50 per second. The mitral annulus and the LV apex were defined in each view. The endocardial, mid-myocardial, and epicardial borders were traced automatically, whereas the region of interest was adjusted manually if necessary (Figure 1). Myocardial motion was evaluated by speckle-tracking in each region of interest.

Figure 1. Measuring Global Longitudinal Systolic Strain



Three apical views in which the endocardial, myocardial, and epicardial layers of the LV are delineated automatically after defining the apex and borders of the mitral annulus; the GLS data are shown in a 17-segment template. The estimated GLS was -21.1% in this patient.

The peak systolic longitudinal strain was calculated in each ventricular segment, and the final data were gathered in a bull's eye template (a 17-segment model). The mean longitudinal strain in all the segments was identified as the average global longitudinal peak systolic strain (GLS Avg) for the whole LV. A larger longitudinal systolic strain was presented by a larger negative value. All the strain analyses were conducted offline.

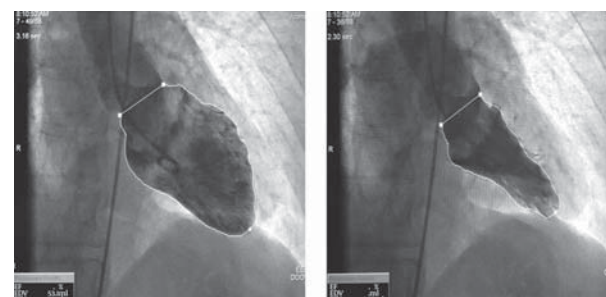
3.3. Catheterization

After undergoing echocardiography, the patients were transferred to the catheterization laboratory. The femoral artery puncture was done, and coronary angiography was conducted. A pigtail catheter was placed in the LV, and the LV end-diastolic pressure was recorded. Next, 25-30cc of the contrast material was injected into the LV with an injector in each of the two subsequent left anterior oblique (LAO) and right anterior oblique (RAO) views at a rate of 10-15 mL/sec. The apex and the basal part of the LV were defined manually in each projection at both end-systolic and end-diastolic phases. The left endocardial borders were traced automatically (Figure 2). The borders could be edited manually if necessary. The software calculated the LVESV and LVEDV. The EF was calculated by the following formula: $LVEF = LVEDV - LVESV / LVEDV$. The echocardiographic and ventriculographic data were analyzed separately by two observers, who were blinded to the result of the measurements.

3.4. Observer Variability

The inter-observer variability was assessed in 12 randomly selected patients. This was done via an analysis of the echocardiographic and ventriculographic data measured by the two separate observers. The LVEDV, LVESV, and LVEF as well as the GLS were considered for this assessment. The intra-observer agreement was also tested for only the echocardiographic data.

Figure 2. Left Ventriculography in the Right Anterior Oblique Projection



Note the three markers put manually at the level of the annulus and the apex in both end-systolic (A) and end-diastolic (B) phases. The endocardial border is then traced automatically by the software. The end result would be the calculated LV volume, which is shown in the small box in the left lower site of the images.

3.5. Statistical Analysis

The demographic, angiographic, and echocardiographic data of the patients were recorded and analyzed by SPSS 11 for Windows (SPSS Inc., Chicago, Illinois) using the paired t-test, Pearson correlation test, and linear regression test. To measure pair-wise correlation between the raters using a scale that is ordered, the Spearman ρ was used. For method comparison study (agreement between different methods), the Bland-Altman test was carried out. The clinically acceptable mean difference in the values was specified by the investigators at the beginning of the study. The bias and precision results were compared to these priori specifications using the Bland-Altman test. This analysis was done using MedCalc software (version 13.0). A p value less than 0.05 was considered statistically significant.

4. Results

Forty-five patients, at a mean age of 57.45 ± 11.75 years (range: 32-84 years), were studied between the years 2011 and 2012. Ten (22.2%) patients had normal coronary arteries, whereas one had a history of coronary artery bypass graft surgery with patent grafts. Significant coronary ar-

tery stenosis ($> 50\%$) was present in the remaining cases (75.58%) with the involvement of the left anterior descending, left circumflex, and right coronary arteries in 61.9%, 50%, and 47.6% of the patients, respectively. Three patients had a history of previous infarction.

The LVESV, LVEDV, and LVEF, which were recorded during catheterization and echocardiography, are presented in Table 1. The agreement between the two methods (ventriculography and 2D echocardiography) was tested considering the volumetric parameters and the EF (Table 2). There was a good agreement between these two (in both RAO and LAO projections) as regards the measurement of the LVESV and LVEF (considering CI 95%). The LVEDV measured in the LAO view had less agreement with 2D echocardiography compared with the RAO projection. Furthermore, while it seemed that the estimated volumes were larger than the data in 2D echocardiography in the RAO view, in the LAO projection, it was vice versa. The data regarding the ejection fraction were comparable.

There was a significant correlation between the GLS and the EF obtained from catheterism and echocardiography (Table 3), the highest correlation being between the GLS and the Biplane EF ($P < 0.001$, $r = -0.848$) (Figure 3).

Table 1. Measurements in Ventriculography and Echocardiography ^{a, b}

	RAO Projection	LAO Projection	4C View in ECHO	Biplane Method in ECHO
LVEDV, cc	104.64 ± 41.86	90.81 ± 37.53	105.09 ± 45.40	105.72 ± 42.66
LVESV, cc	57.55 ± 38.47	48.04 ± 30.99	58.06 ± 40.03	58.67 ± 42.26
LVEF, %	52.97 ± 13.43	50.11 ± 14.58	49.15 ± 14.32	47.33 ± 13.50

^a Abbreviations: RAO, right anterior oblique; LAO, left anterior oblique; 4C, four-chamber; ECHO, echocardiography; LVESV, left ventricular end-systolic volume; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction.

^b All data are presented as mean ± SD.

Table 2. Correlation between LVEF and GLS in Catheterization and Echocardiography ^{a, b}

	Constant Parameters in Regression Model ^a		r ²	P Value
	a	b		
LVEF (RAO)	-2.581	12.858	0.597	< 0.001
LVEF (LAO)	-2.734	0	0.577	< 0.001
LVEF (Biplane)	-2.533	10.48	0.715	< 0.001
LVEF (4C)	-2.713	0	0.700	< 0.001

^a Constant values are specified according to the different methods.

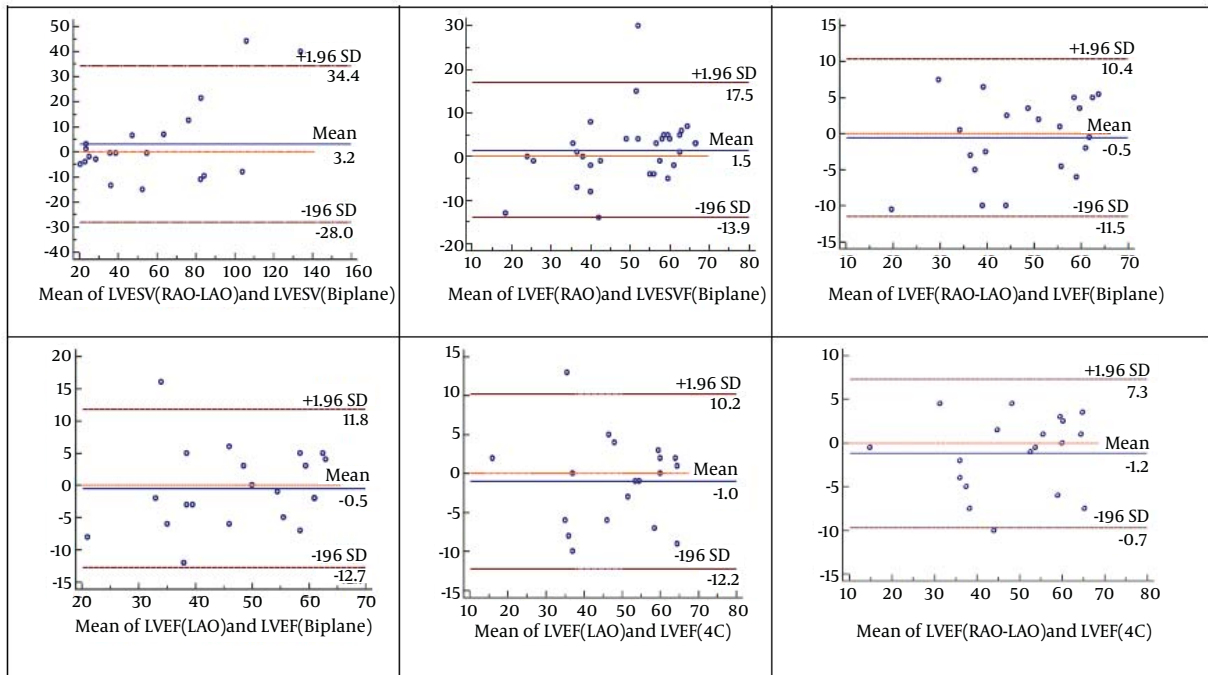
^b Abbreviations: LVEF, left ventricular ejection fraction; RAO, right anterior oblique; LAO, left anterior oblique; 4C, four-chamber.

Table 3. Inter- and intra-Observer Agreement in Echocardiography (n = 12) with the Correlation and Mean Difference between the Measurements^a

	Intra-Observer			Inter-Observer		
	Correlation	P Value	Mean Difference	Correlation	P Value	Mean Difference
LVEDV	P = 0.88	< 0.001	-1.25 ± 13.26	P = 0.78	< 0.01	-4.50 ± 17.75
LVESV	P = 0.84	< 0.001	-5.25 ± 9.74	P = 0.69	< 0.05	-4.33 ± 12.48
LVEF	P = 0.87	< 0.001	4.67 ± 5.77	P = 0.67	< 0.05	2.17 ± 8.30
GLS	P = 0.96	< 0.001	-0.16 ± 1.04	P = 0.92	< 0.001	-0.67 ± 1.50

^a Abbreviations: LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; LVEF, left ventricular ejection fraction; GLS, global longitudinal systolic strain.

Figure 3. Agreement between Echocardiography and Ventriculography in Measuring the Left Ventricular Volume and Ejection Fraction



The Bland-Altman plots are given; 95% limits of agreement are defined. RAO, Right anterior oblique; LAO, Left anterior oblique; Biplane, Biplane Simpson's method in echocardiography; 4C, Four-chamber view in echocardiography; 2C, Two-chamber view in echocardiography; LVEF, Left ventricular ejection fraction

The relationship between the GLS and the LVEF in the catheterization and echocardiography methods was studied by the linear regression test, separately. An appropriate and meaningful association was found between the constant coefficients (a) and the constant values (b) for each variable. According to the r square test and the significance of the constant values, a meaningful linear relationship can be defined by the following formula:

$$LVEF = a (GLS) + b$$

The values which stand for constant parameters (a and b) are presented in Table 3. They somehow differed based on the selected method (LVEF in catheterization in the RAO and LAO views versus LVEF in echocardiography in the four-chamber view or by the modified biplane Simpson method). Strain imaging (GLS) was used for estimating the severity of the LV systolic dysfunction. The reference values for the GLS in the LVEF estimation were -11.7% for severe LV systolic dysfunction and -21.7% for the normal systolic function.

4.1. Inter- and intra-Observer Variability

There was a high inter- and intra-observer agreement with respect to the measurement of the GLS ($P = 0.96$, -0.16 ± 1.04 and $P = 0.92$, -0.67 ± 1.50 , respectively) (Table 3). The intra-observer variability was more evident for the volumetric parameters and the EF. The inter-observer agreement was also better while assessing the GLS (P

$= 0.96$ and $P < 0.001$) in comparison with the LVESV ($P = 0.84$ and $P = 0.001$), LVEDV ($P = 0.88$ and $P < 0.001$), and LVEF ($P = 0.87$ and $P < 0.001$) in echocardiography.

The inter-observer differences were also defined for the LVEDV ($P = 0.86$, -2.03 ± 16.07 , $P < 0.05$), LVESV ($P = 0.87$, 0.64 ± 12.44 , $P < 0.001$), and LVEF ($P = 0.79$, -0.01 ± 4.60 , $P < 0.05$) in ventriculography (Figure 4).

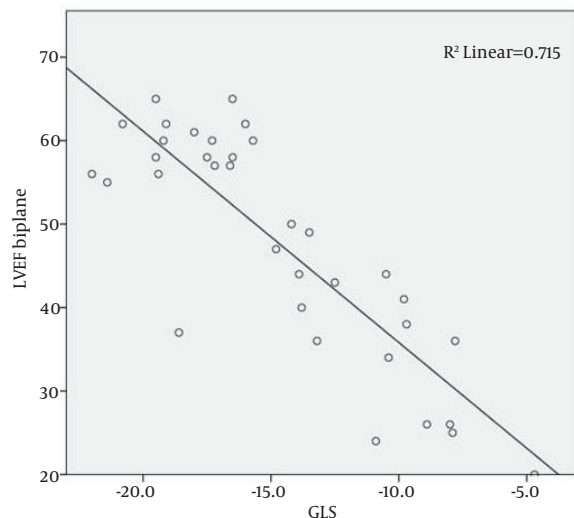


Figure 4. Correlation between the Global Longitudinal Strain and the Biplane Ejection Fraction in Echocardiography

5. Discussion

The LVEF assessment has a critical role in the diagnosis, management, and prognosis of patients with different cardiovascular diseases. Echocardiography by itself plays a pivotal role in assessing the LV systolic function, mainly by calculating the LVEF, and is as such deemed the most widely employed method. Cardiac catheterism and radionuclide ventriculography have been accepted as diagnostic methods, but they have such limitations as invasiveness, high cost, and high radiation exposure (6). There are conflicting data on the assessment of the LV volumes by conventional 2D echocardiography. In the study of Thomson HL et al. (6), 2D quantification was likely to underestimate the non-opacified LVEDV by 30-40%.

The agreement between the angiographic LVEDV and echocardiographic data was more apparent when comparing the RAO projection with the LAO view. The results (mean difference with 2D echocardiography) for the LVESV or the LVEF were comparable between the angiographic projections. This stands in contrast with the Habash-Bseiso et al. (7) study, in which the echocardiographic LVEF was lower than that determined by angiography ($49\% \pm 1.0\%$ vs. $54\% \pm 1.0\%$; $P < 0.0001$). That study also reported a significant correlation between the angiographic LVEF and the echocardiographic LVEF ($r = 0.70$, $P < 0.0001$). The geometric assumptions or angiographic magnification could be the source of errors in estimating the volumes by ventriculography (8).

Tissue Doppler-derived strain and strain rate imaging were introduced several years ago as a tool for the quantification of the myocardial mechanical function (9). Nonetheless, their angle dependency, noise interference, and substantial intra-observer and inter-observer variability resulted in a great tendency toward using the newer technique of 2D-STE (10).

2D-STE allows the evaluation of the regional strain values from all the LV segments, which can be averaged to global strain. Global strain is a relatively new parameter for the assessment of the LV function and has been introduced as the best echocardiographic parameter to predict the global infarct mass, which is superior to the more traditional echocardiographic parameters such as the LVEF and the wall motion score index (11, 12). The existing literature, however, contains few reports on the LVEF estimation via the GLS (13), and there is a paucity of information on a reference normal range for the LVEF. The values of -18.6% (with 0.1% of the limits of agreement) (14), $-20.6\% \pm 2.6\%$ (15), and $21.3 \pm 2.1\%$ (16) have been proposed as the normal range by three studies in which the GE system was used for assessment. In our study, -21.7% was considered the reference value for the normal group, which chimes in with the latter two studies. Takigiku et al. (16) reported that 2D image tracking ability in each ultrasound system was different, though less in longitudinal strain analysis compared with the radial or circumferential one.

In one study on patients with coronary artery diseases, the GLS assessed by the automated functional imaging algorithm was linearly related to the biplane LVEF ($r = 0.83$; $P < 0.001$), whereas the correlation was less in patients with myocardial infarction or heart failure ($r = 0.42$ and $r = 0.62$, both $P_s < 0.001$) (17). In another study on patients with previous infarction, the LVEF was measured by magnetic resonance imaging (MRI) and 2D and 3D echocardiography. The GLS was also determined. In regard to the EF, the correlation between the GLS and the MRI was significant and better than that of 2D echocardiography and MRI (13).

Infraction or heart failure cases were not specified in our study. There was a significant linear correlation between the LVEF estimated by both methods and the GLS in the overall study population. On the other hand, the inter- and intra-observer variability was less with the GLS than that with 2D echocardiography regarding the LVEF. The GLS can be used interchangeably with great confidence for evaluating the LV systolic function, especially in patients who need close surveillance and monitoring for changes in the ventricular function. Assuming that the endocardial borders could be well defined, the GLS would be a more reliable method inasmuch as it is less operator-dependent than 2D echocardiography when measuring the LVEF. The volumetric parameters and the EF obtained from noninvasive 2D echocardiography and invasive cine-angiography showed a desirable agreement with no significant difference. The RAO projection would be the preferred view for such assessment. The GLS parameter yielded a favorable correlation with the LVEF; accordingly, it can be suggested as a reliable method for the LV function assessment in routine practice, especially in patients monitored or tracked for the changes in the function.

5.1. Study Limitations

An accurate calculation of the LV volumes and LVEF requires the use of both conventional echocardiography and ventriculography so that the endocardial borders can be precisely defined. Poor image quality or ventricular foreshortening could affect the result. Also, despite the considerable quality of the images, errors could happen in the manual tracing of the LV cavity because of the different perceptions in the definition of the endocardial border. With manual techniques, defining the true end-diastole and end-systole would be another source of error (18). This is also true with the GLS, which needs a clear definition of the borders.

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