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Evaluation of Left Ventricular Longitudinal, Radial, and Circumferential Strains in Subjects with Normal Variations of Coronary Dominance: A Preliminary Comparative Study

ORIGINAL INVESTIGATION

ABSTRACT

Background: The aim of this study was to evaluate the contractile function of the left ventricular muscles in subjects with normal coronary artery and normal variations of coronary dominance.

Methods: This study was performed on 90 adult subjects with normal results of coronary arteries angiography, echocardiography, and electrocardiography. The participants were categorized into 3 groups of 30 with right-dominant, left-dominant, and codominant variations. Two-dimensional transthoracic echocardiography was performed with apical 2-, 3-, and 4-chamber views and parasternal basal, mid, and apical short-axis views. Then, images were analyzed offline using the velocity vector imaging method. In all studied groups, the mean and standard deviation of left ventricle coronary territorial longitudinal, circumferential, radial strains, and left ventricle global strains were determined. They were compared in 3 layers of sub-endocardial, myocardium, and sub-epicardial.

Results: In terms of longitudinal and circumferential strains, there were significant differences in the most coronary territories and global strain among the right-dominant, left-dominant and codominant groups ($P < .05$). No significant differences in terms of territorial and global radial strains were observed among the study groups ($P > .05$).

Conclusion: Strain level decreased from endocardium to epicardium in all studied groups. Territorial and global contractile functions (longitudinal and circumferential strains) of the left ventricle vary depending on the variations of coronary arteries.

Keywords: Coronary angiography; coronary dominance; echocardiography; velocity vector imaging; cardiac function

INTRODUCTION

Right and left coronary arteries originate from the ascending aorta and Valsalva sinuses. Coronary dominance is determined based on the coronary arteries size, perfusion of cardiac muscles, and anatomy of posterior descending artery (PDA) and right coronary artery (RCA). The RCA distal is divided into PDA and posterolateral branch (PLB) in right coronary dominance (approximately 80%). On the other hand, in 10% of the codominant variation, PDA originates from the RCA, and PLB originates from the left circumflex artery (LCX). In 10% of subjects with left coronary dominance, both PDA and PLB originate from the LCX.[1]

Today, the evaluation of left ventricular function has changed from simple measurements to advanced examinations and techniques, with emphasis on the intrinsic evaluation of myocardial contractilities, such as measurement of myocardial strain and other cardiac mechanical parameters.[2] Strain is a mechanical parameter, which represents the level of tissue deformity (expressed in percentage), and clearly indicates cardiac muscle contraction. Normal strains include longitudinal, radial, and circumferential strains.[3] Velocity vector imaging (VVI) is a relatively new method in echocardiography, which is based on speckle tracking

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echocardiography (STE) technique with advanced edge detection measuring the strain of multilayered cardiac muscles.[4-6]

In this study, we hypothesized that the contractile function of left ventricle (LV) might be affected by variations of coronary dominance. To the best of our knowledge, no studies have been conducted in this area. In the present study, we evaluated and compared the longitudinal, radial, and circumferential strains of the LV separately, in the subendocardial, myocardium, and subepicardial in subjects with normal coronary artery and different coronary dominance, using the VVI method.

METHODS

Study Population

In the current preliminary study, subjects aged 30 years and older were selected from the archive and picture archiving and communication system (PACS). Coronary artery angiography (standard Judkins technique, Siemens Axiom Artis FC and FD platform) had been done for all these patients from October 23, 2017, to January 20, 2018, in Heshmat Remedial Heart Center and Goslar Hospital. All subjects with normal coronary arteries and echocardiographic and electrocardiogram (ECG) findings were enrolled in this study. Patients with the following disorders were excluded: coronary artery disease (CAD), congenital heart disease, moderate to severe valvular heart disease, all types of cardiomyopathies, atrial fibrillation, bigeminy, trigeminy, and frequent premature ventricular contraction in 12-lead ECG or cardiac rhythm in echocardiography, atrial tachycardia, ventricular tachycardia, and accessory pathway, and all types of cardiac blocks.

According to subjects' coronary variation, we divided them into 3 groups of right, left, and codominant. Eventually, we selected 30 subjects from each group randomly and categorized them into 3 study groups with respect to cardiac dominance. Written informed consents were obtained from all participants, and the checklist of demographic characteristics was completed.

The study protocol was approved by the scientific vice chancellor for research and the Ethics Committee of Guilan University of Medical Sciences (IR.GUMS.REC.1396.267); it was confirmed to the ethical guidelines of the 1975 Declaration of Helsinki.

HIGHLIGHTS

- Contractile function of the left ventricle may be affected by different types of coronary dominance or myocardial perfusion.
- Coronary territorial and global longitudinal and circumferential strains were significantly different among the right-dominant, left-dominant, and codominant groups.
- In terms of coronary territorial and global radial strains, comparable results were observed in the study groups.

Echocardiography

Echocardiograms were obtained within 3 months after coronary angiography by a commercial echocardiographic system (Siemens, model Prime Acuson SC2000, D-80333 Muenchen, Germany) equipped with a phased array multi-frequency (1.5-4 MHz) ultrasonic transducer. The participants were placed in the left lateral decubitus positions, and heart rate monitoring was performed throughout echocardiography. Frame rate was optimized to 60-90 fps. Modified Simpson's method was used to evaluate the left ventricular ejection fraction. To evaluate the regional and global functions of the LV, 2-dimensional imaging was conducted in 2, 3, and 4-chamber apical longitudinal views, as well as parasternal short-axis views at the base, mid, and apex levels of the LV for 3 heartbeats. In order to reduce artifacts, echocardiography was carried out at the end of deep inhalation in each view. All images were saved digitally in cine-loop format for offline analysis.

Strain Analysis

The offline analysis of 2-dimensional images was performed using the VVI method. For analyzing each view, endocardial and epicardial borders of LV were manually traced in the end-systolic frame; subsequently, the software (Syngo VB10E, Ver. 4) traced the borders in the other frames automatically. The velocity vectors of the endocardial and epicardial points were then displayed overlaid onto the B-mode images. The quality of myocardial tracking was assessed visually, and the process was repeated if satisfactory tracking of the myocardium was not obtained (Figure 1). Vector direction, movement direction, and vector dimension represent the velocity magnitude of cardiac segments.

In order to examine the LV strain, longitudinal strain was first analyzed in 18 segments in the apical 2-chamber view (i.e., basal anterior, basal inferior, mid anterior, mid inferior, apical anterior, and apical inferior segments), apical

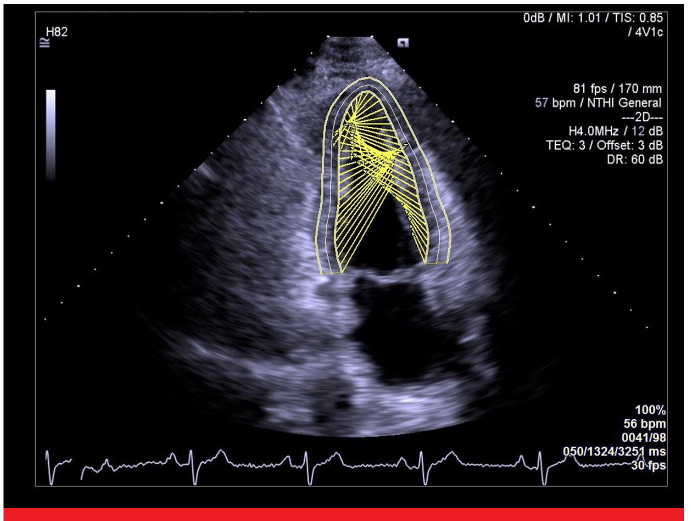

Figure 1. Apical two-chamber view of the LV and VVI. The vector dimensions and orientations represent the movement rate in the left ventricular segments in the systolic phase of the cardiac cycle. LV, left ventricle; VVI, velocity vector imaging.

3-chamber view (i.e., basal anteroseptal, basal inferolateral, mid-anteroseptal, mid-inferolateral, apical anterior, and apical lateral), and apical 4-chamber view (i.e., basal anterolateral, basal inferoseptal, mid-anterolateral, mid-inferoseptal, apical lateral, and apical septal). Moreover, radial and circumferential strains were analyzed in 16 segments of short-axis views in the base and middle segments (i.e., anterior, anteroseptal, anterolateral, inferoseptal, inferolateral, and inferior), and also segments from short-axis views at the apex (i.e., anterior, inferior, septal, and lateral).

Longitudinal strain-time and circumferential strain-time curves of the LV were provided separately for 3 cardiac muscle layers (subendocardial, myocardium, and subepicardial). Moreover, radial strain-time curves of the LV were provided for 3 cardiac cycles; mean of cardiac systolic peaks was also calculated. For example, in Figure 2, the apical 3-chamber view of the heart, as well as endocardial and epicardial borders, is shown on the left, while the longitudinal strain-time curve is shown on the right in the basal inferolateral segment, with a mean strain peak of −27.5%. Figure 3 presents the results related to the middle short axis of the LV in the inferoseptal segment, radial strain-time curve with a mean peak of 56.5%, and circumferential strain-time curve of endocardium with a mean peak of −45.1%.

Coronary Territories

According to the cardiac perfusion of LV different segments, the territorial coronary strain was calculated in 5 groups: (1) segments of basal anterior, basal anteroseptal, mid anterior, mid anteroseptal, apical anterior, and apical, which are assigned to the left anterior descending (LAD) coronary artery distribution, (2) segments of basal inferior, basal inferoseptal, and mid inferior are assigned to the RCA, (3) segments of basal anterolateral, mid anterolateral, and apical lateral are assigned to the LAD or LCX, (4) segments of mid inferoseptal and apical inferior are assigned to the LAD or RCA, and (5) segments of basal inferolateral and mid inferolateral are assigned to the RCA or LCX.[7] Moreover, global longitudinal, radial, and circumferential strains were calculated.

Statistical Analysis

Kolmogorov–Smirnov test was used to analyze the distribution of continuous data, including segmental, territorial, and global strain. Data were presented as mean and standard deviation (SD). Analysis of variance was also performed to compare the means of groups. The least significant difference *post hoc* was applied for multiple comparisons. The analysis was performed twice on the 21 random images (7 subjects for each study group) by 2 independent blinded observers. The statistical reproducibility was calculated as a coefficient of variance percentage and intraclass correlation coefficient. All statistical analyses were managed in Statistical Package for the Social Sciences version 22 (IBM, Armonk, NY, USA), and the statistical significance level was considered as P-value <.05.

RESULTS

Study Population and Baseline Characteristics

Out of 1834 subjects, 422 (23%) subjects had normal coronary angiography; of which 313 (74.2%) were right dominant, 63 (14.9%) codominant, and 46 (10.9%) were left dominant. In each of the right, codominant, and left dominant groups and based on the inclusion and exclusion criteria, 30 subjects were randomly selected and enrolled in the study. Table 1 shows the mean and SD of demographic, clinical, and echocardiographic data of the participants according to variations of coronary dominance. In this study, a total of 90 individuals were analyzed, including 53 women (58.90%) and 37 men (41.10%). There were more female subjects in the codominance group as compared with right or left dominance groups. The mean age of the participants was 57.8 ± 9.4 years. There were statistically no significant differences in basic characteristics among the 3 coronary dominance groups.

Territorial Longitudinal Strain

Table 2 shows the territorial longitudinal strains in 3 layers of subendocardial, myocardium, and subepicardial of the LV. In

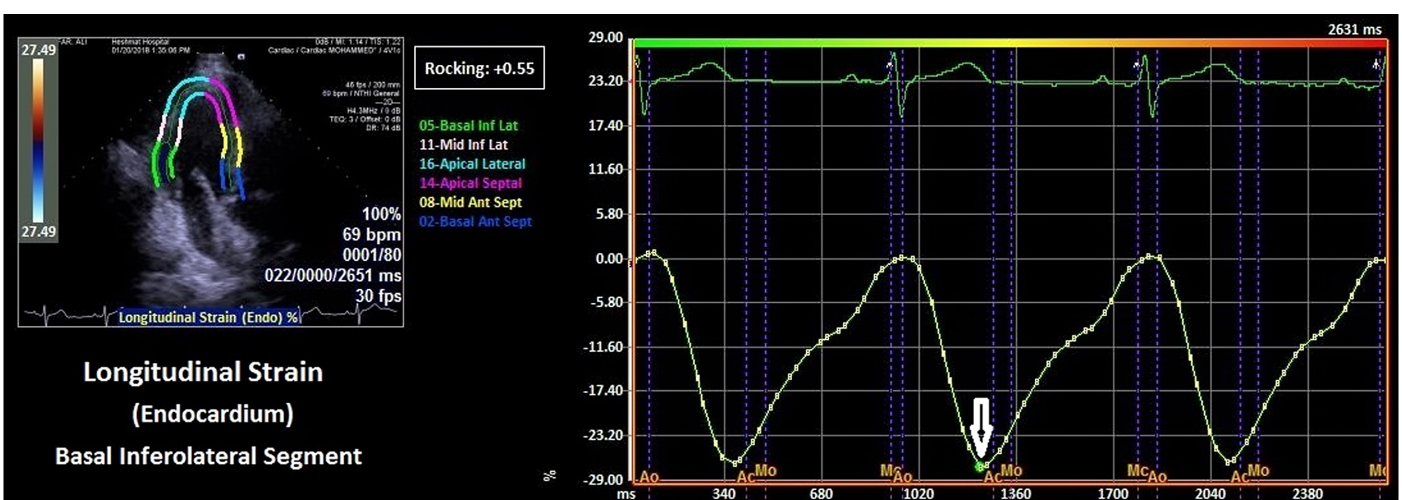

Figure 2. Apical 3-chamber view (left) and longitudinal strain-time curve of the LV in the basal inferolateral segment (right). In the second cardiac cycle, the systolic peak is represented by a white arrow. LV, left ventricle.

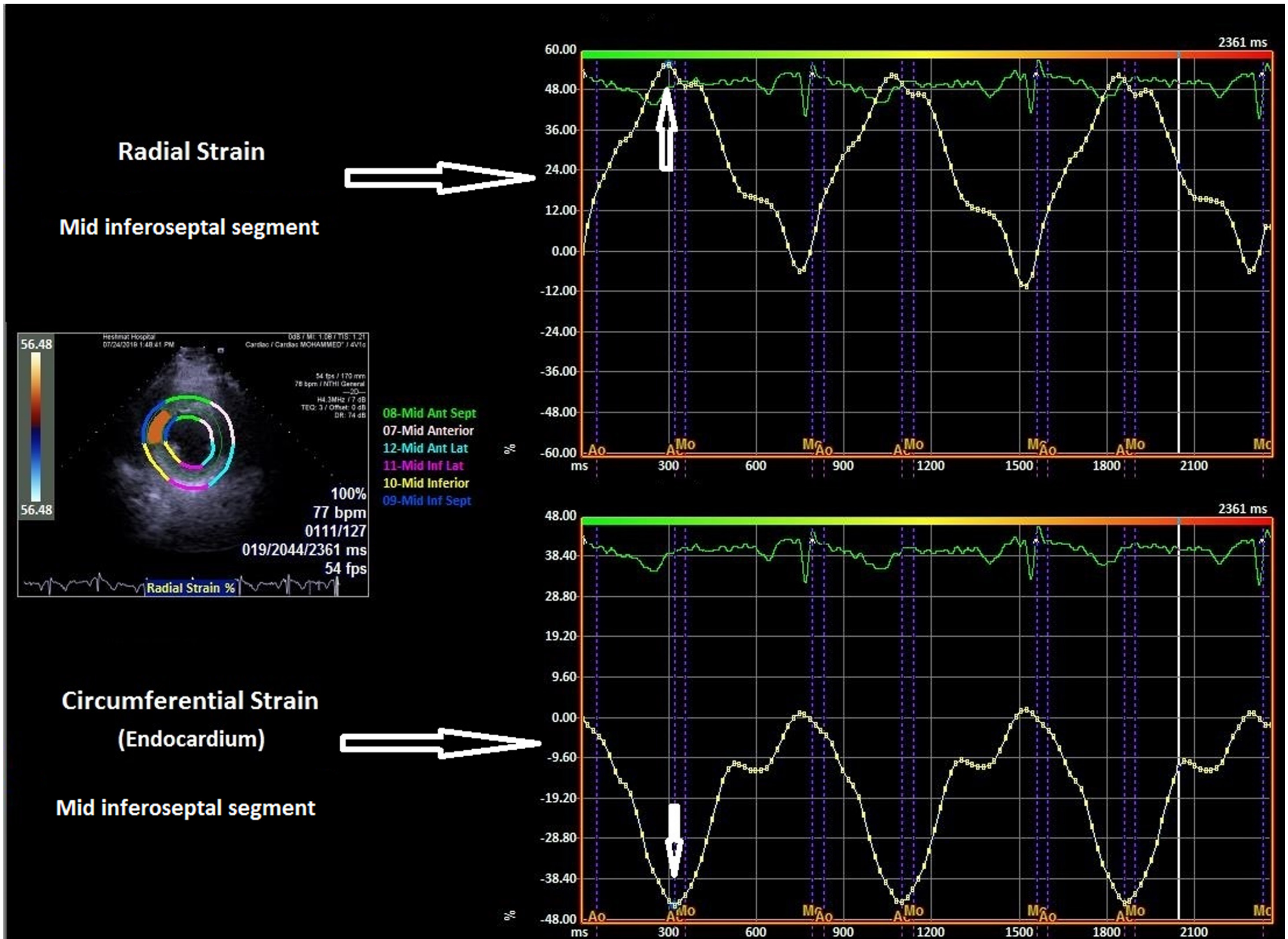

Figure 3. Short-axis view of the middle segment of the LV (left), radial strain-time curve (top right), and circumferential strain-time (endocardium) curve of the LV (bottom right) in the mid inferoseptal segment. The systolic peak is represented by a white arrow in the first cardiac cycle. LV, left ventricle.

Table 1. Baseline Characteristics of the Study Population According to Coronary Dominance

		Dominance			
Variables	**Total**	**Left Dominant**	**Codominant**	**Right Dominant**	***P***
Sex (male/female)	37/53	15/15	10/20	12/18	.418
Age (years)	57.8 ± 9.4	59.7 ± 7.5	56.2 ± 10.1	57.6 ± 10.4	.35
Height (m)	1.62 ± 0.10	1.61 ± 0.10	1.62 ± 0.09	1.63 ± 0.10	.82
Weight (kg)	76.4 ± 12.9	76.1 ± 14.4	79.9 ± 12.6	74.2 ± 11.2	.182
BMI (kg/m^2)	28.9 ± 4.7	28.67 ± 5.2	30.33 ± 4.4	27.84 ± 4.2	.11
BSA (m^2)	1.77 ± 0.13	1.77 ± 0.16	1.76 ± 0.14	1.78 ± 0.10	.729
Heart rate (bpm)	72.5 ± 4.9	71.9 ± 4.7	72.8 ± 5.9	73.00 ± 3.9	.658
SBP (mm Hg)	121.8 ± 8.6	122.2 ± 8.7	121.9 ± 9.0	121.7 ± 7.9	.941
DBP (mm Hg)	79.1 ± 4.9	78.8 ± 5.7	79.8 ± 4.2	79.2 ± 4.3	.871
LVEF (median, %) (Q1, Q3)	57 (54, 60)	57 (54, 61)	58 (54, 62)	57 (53, 60)	-

*Numerical values are expressed as mean ± standard deviation and the statistical significance level was considered as *P*-value <.05. Blood pressure evaluated by consecutive blood pressure measurements
BMI, body mass index; BSA, body surface area; DBP, diastolic blood pressure; LVEF, left ventricular ejection fraction; SBP, systolic blood pressure; Q1, 25% lower quartile; Q3, 75% upper quartile.

Table 2. Territorial Longitudinal LV Strains (Subendocardial, Myocardium, and Subepicardial) According to Coronary Dominance

			Dominance			
Territorial Strain (%)	Coronary Territories	Total	Left Dominant (Mean ± SD)	Codominant (Mean ± SD)	Right Dominant (Mean ± SD)	P
Longitudinal (sub-endocardial)	LAD	−21.63 ± 4.63*	−20.91 ± 5.16$^{\alpha}$	−22.49 ± 4.16$^{\gamma}$	−21.51 ± 4.37	.005
	LAD or RCA	−22.50 ± 4.33*	−21.25 ± 3.96$^{\alpha}$	−23.52 ± 4.15	−22.73 ± 4.62	.014
	LAD or LCX	−21.68 ± 4.36	−21.14 ± 4.80	−21.95 ± 4.42	−21.94 ± 3.82	.363
	RCA or LCX	−20.92 ± 4.06	−20.43 ± 3.93	−21.95 ± 4.31	−20.38 ± 3.77	.054
	RCA	−21.22 ± 4.25*	−20.10 ± 3.79$^{\alpha}$	−22.41 ± 4.01$^{\gamma}$	−21.14 ± 4.62	.001
Longitudinal (myocardium)	LAD	−19.25 ± 4.31*	−18.09 ± 3.28$^{\beta,\alpha}$	−20.62 ± 4.59$^{\gamma}$	−19.05 ± 4.57	<.001
	LAD or RCA	−19.87 ± 4.01*	−17.96 ± 3.25$^{\beta,\alpha}$	−21.39 ± 4.46	−20.26 ± 3.48	<.001
	LAD or LCX	−18.95 ± 3.80*	−17.88 ± 3.53$^{\beta,\alpha}$	−19.24 ± 4.22	−19.74 ± 3.40	.003
	RCA or LCX	−19.16 ± 5.11	−18.84 ± 4.15	−20.12 ± 7.00	−18.53 ± 3.40	.193
	RCA	−18.97 ± 3.46*	−17.80 ± 2.71$^{\alpha}$	−20.41 ± 3.85$^{\gamma}$	−18.72 ± 3.22	<.001
Longitudinal (sub−epicardial)	LAD	−17.57 ± 4.06*	−16.70 ± 3.00$^{\beta,\alpha}$	−18.31 ± 4.28	−17.72 ± 4.57	.001
	LAD or RCA	−18.62 ± 4.01*	−17.24 ± 3.50$^{\beta,\alpha}$	−19.50 ± 4.41	−19.12 ± 3.76	.004
	LAD or LCX	−17.71 ± 3.53*	−16.68 ± 3.70$^{\beta}$	−17.51 ± 3.69$^{\gamma}$	−18.94 ± 2.78	<.001
	RCA or LCX	−17.48 ± 4.47	−16.93 ± 3.98	−18.38 ± 5.78	−17.13 ± 3.19	.158
	RCA	−17.98 ± 4.08*	−17.00 ± 3.39$^{\alpha}$	−19.09 ± 3.55$^{\gamma}$	−17.85 ± 4.91	.002

*All values are expressed as mean ± standard deviation and the statistical significance level was considered as *P*-value <.05. $^{\alpha}$Significant difference between left and codominant; $^{\beta}$Significant difference between left and right dominant; $^{\gamma}$Significant difference between right and codominant. LAD, left anterior descending artery; LCX, left circumflex; RCA, right coronary artery; SD, standard deviation; LV, left ventricle.

all groups, the strain decreased from the subendocardial to the subepicardial. For example, the LAD coronary territories longitudinal strain was decreased from −22.49 ± 4.16% to −18.31 ± 4.28% in codominant subjects.

There were significant differences among the right dominant, left dominant, and codominant groups in most subepicardial, myocardial, and subendocardial territories. However, there were no significant differences among RCA or LCX territory in the subepicardial (−16.93 ± 3.98% for left dominant, −18.38 ± 5.78% for codominant, and −17.13 ± 3.19% for right dominant) and myocardium (−18.84 ± 4.15% for left dominant, −20.12 ± 7.00% for codominant, and −18.53 ± 3.40% for right dominant), the subendocardial RCA or LCX territory, and LAD or LCX territory (−21.14 ± 4.80% for left dominant, −21.95 ± 4.42% for codominant, and −21.94 ± 3.82% for right dominant).

Territorial Radial and Circumferential Strains

Tables 3 and 4 compare the results of territorial circumferential strains in 3 layers of subendocardial, myocardium, and subepicardial of the LV, as well as territorial radial strains in the 3 cardiac dominance groups. In all groups, the strain decreased from the subendocardial to the subepicardial. For example, the LAD coronary territories circumferential strain was decreased from −33.18 ± 9.01% to −21.79 ± 6.09% in codominant subjects. Comparisons showed no significant difference in the subendocardial strain of all territories except LAD or LCX (−29.92 ± 8.61% for left dominant, −34.03 ± 8.23% for codominant, and −30.47 ± 10.04% for right dominant) and strains of RCA or LCX (−25.04 ± 6.53% for left dominant, −27.72 ± 6.90% for codominant, and −24.79 ± 5.87% for right dominant) and LAD (−23.56 ± 6.67% for left dominant, −26.25 ± 7.47% for codominant, and −25.64 ± 7.48% for right dominant) in the myocardium. There were significant differences for subepicardial strain of all territories except RCA or LCX (−22.60 ± 7.40% for left dominant, −24.35 ± 6.51% for codominant, and −22.97 ± 6.01% for right dominant). No significant difference in territorial radial strain was observed among the study groups ($P > .05$).

Global Longitudinal Strain

Table 5 shows the global longitudinal strain of the LV in the cardiac dominance groups. In all groups, the global longitudinal strain decreased from subendocardial to subepicardial. In all layers, the longitudinal strain was at the highest in the codominant group and at the lowest in the left-dominant group (Figure 4).

Global Radial and Circumferential Strain

Table 5 presents the global radial and circumferential strains of the LV in all 3 groups. In all groups, the global circumferential strain decreased from the subendocardial to the subepicardial. In all layers of the subendocardial, myocardium, and subepicardial, the global circumferential strain was at the highest in the codominant group; it was at the lowest in the left-dominant group. No significant difference was observed in global radial strain among the studied groups ($P = .318$), Figure 4.

Reproducibility

The intra-observer variables for global longitudinal, circumferential, and radial strain were 2.97%, 2.69%, and 2.46%, respectively. Intra-observer agreement intraclass correlation coefficient was 0.93-0.96 (95% CI, 0.83-0.98; $P < .001$) for all examined parameters. The inter-observer variabilities for global longitudinal, circumferential, and radial strain were also 3.49%, 3.05%, and 2.19%, respectively. The intra-observer

Table 3. Territorial Circumferential LV Strains (Subendocardial, Myocardium, and Subepicardial) According to Coronary Dominance

Territorial Strain (%)	Coronary Territories	Total	Dominance: Left Dominant (Mean ± SD)	Codominant (Mean ± SD)	Right Dominant (Mean ± SD)	*P*
Circumferential (subendocardial)	LAD	−32.09 ± 9.43	−30.92 ± 9.61	−33.18 ± 9.01	−32.18 ± 9.59	.075
	LAD or RCA	−36.11 ± 10.05	−34.86 ± 9.75	−36.57± 10.15	−36.91 ± 10.29	.49
	LAD or LCX	−31.47 ± 9.14*	−29.92 ± 8.61$^{\alpha}$	−34.03 ± 8.23$^{\gamma}$	−30.47 ± 10.04	.004
	RCA or LCX	−30.71 ± 9.34	−29.15 ± 9.84	−32.17 ± 8.66	−30.80 ± 9.38	.208
	RCA	−28.41 ± 8.90	−28.18 ± 9.23	−28.25 ± 8.63	−28.79 ± 8.91	.881
Circumferential (myocardium)	LAD	−25.15 ± 7.30*	−23.56 ± 6.67$^{\beta,\alpha}$	−26.25 ± 7.47	−25.64 ± 7.48	.001
	LAD or RCA	−25.99 ± 7.28	−24.58 ± 7.38	−27.15 ± 7.14	−26.23 ± 7.21	.147
	LAD or LCX	−25.53 ± 7.58	−24.61 ± 7.31	−26.42 ± 7.73	−25.56 ± 7.69	.275
	RCA or LCX	−25.85 ± 6.55*	−25.04 ± 6.53$^{\alpha}$	−27.72 ± 6.90$^{\gamma}$	−24.79 ± 5.87	.024
	RCA	−23.69 ± 6.51	−24.28 ± 6.40	−22.88 ± 5.76	−23.91 ± 7.26	.329
Circumferential (subepicardial)	LAD	−20.95 ± 5.57*	−19.87 ± 5.67$^{\beta,\alpha}$	−21.79 ± 6.09	−21.20 ± 4.71	.004
	LAD or RCA	−23.48 ± 5.40*	−22.90 ± 6.23$^{\alpha}$	−24.94 ± 4.50$^{\gamma}$	−22.59 ± 5.12	.034
	LAD or LCX	−22.22 ± 6.47*	−20.64 ± 5.70$^{\beta,\alpha}$	−23.29 ± 6.88	−22.73 ± 6.53	.015
	RCA or LCX	−23.30 ± 6.67	−22.60 ± 7.40	−24.35 ± 6.51	−22.97 ± 6.01	.322
	RCA	−21.46 ± 5.62*	−20.02 ± 4.10$^{\beta,\alpha}$	−22.57 ± 6.86	−21.79 ± 5.30	.007

*All values are expressed as mean ± standard deviation and the statistical significance level was considered as *P*-value <.05. $^{\alpha}$Significant difference between left and codominant; $^{\beta}$Significant difference between left and right dominant; $^{\gamma}$Significant difference between right and codominant.
LAD, left anterior descending artery; LCX, left circumflex; RCA, right coronary artery; SD, standard deviation; LV, left ventricle.

agreement intraclass correlation coefficient was also 0.90-0.94 (95% CI, 0.81-0.96; $P < .001$) for all examined parameters.

DISCUSSION

To the best of our knowledge, there are no studies on the LV contractile function in individuals with different types of coronary dominance. We aimed to determine and compare the mean longitudinal, radial, and circumferential strains in the subepicardial, myocardium, and subendocardial of the LV in subjects with normal coronary artery and normal variations of coronary dominance. Our results showed that myocardial contractile function was significantly different among the left dominant, right dominant, and codominant groups. Although all the participants had normal coronary arteries, cardiac contractile function varied due to coronary variations.

Normally, LAD, LCX, and RCA supply 50%, 25%, and 25% of blood circulation to the LV myocardium, respectively.[8] Blood supply to cardiac muscles by coronary arteries varies in different types of dominance. In the right-dominant variation, RCA supplies blood to the right atrium, a large part of the right ventricle, diaphragmatic surface of the LV, posterior 1/3 of the interventricular septum, sinoatrial node (SAN) in nearly 60% of individuals and atrioventricular node (AVN) in nearly 80% of individuals. Moreover, the left main coronary artery (LMCA) supplies blood to the left atrium, a large part of the LV, partly of the right ventricle, posterior 2/3 of the interventricular septum, atrioventricular fiber bundles in the connective tissues through septal branches and SAN in nearly 40% of individuals.[9-11]

In the left-dominant variation, RCA is small and non-dominant; it only supplies the right ventricle and atriums. In this group, the LV is supplied by the LMCA.[12] On the other hand, in the codominant variation, the posterior interventricular septum wall is jointly supplied by RCA and circumflex artery. "The relatively low prevalence of left and codominance may reflect a small biologic disadvantage, which is related to right dominance."[13]

Table 4. Territorial Radial LV Strains According to Coronary Dominance

Territorial Strain (%)	Coronary Territories	Total	Dominance: Left Dominant (Mean ± SD)	Codominant (Mean ± SD)	Right Dominant (Mean ± SD)	*P*
Radial	LAD	37.20 ± 9.19	37.35 ± 9.62	37.05 ± 9.66	37.21 ± 8.27	.955
	LAD or RCA	35.79 ± 8.74	36.80 ± 8.99	34.26 ± 7.91	36.30 ± 9.19	.242
	LAD or LCX	38.62 ± 8.65	39.69 ± 9.31	38.59 ± 8.68	37.59 ± 7.87	.267
	RCA or LCX	37.41 ± 9.02	37.92 ± 9.50	36.74 ± 8.37	37.56 ± 9.27	.765
	RCA	37.59 ± 8.04	37.82 ± 8.23	37.63 ± 8.54	37.32 ± 7.37	.915

*All values are expressed as mean ± standard deviation and the statistical significance level was considered as *P*-value <.05.
LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; SD, standard deviation; LV, left ventricle.

Table 5. Global Longitudinal, Circumferential, and Radial LV Strains According to Coronary Dominance

			Dominance			
Global Strain (%)	**Index**	**Total**	**Left Dominant (Mean ± SD)**	**Codominant (Mean ± SD)**	**Right Dominant (Mean ± SD)**	***P***
Longitudinal	Subendocardial	−21.58 ± 4.42*	−20.78 ± 4.57$^{\beta,\alpha}$	−22.43 ±4.22$^{\gamma}$	−21.53 ± 4.31	<.001
	Myocardium	−19.21 ± 4.15*	−18.07 ± 3.35$^{\beta,\alpha}$	−20.36 ± 4.77$^{\gamma}$	−19.20 ± 3.89	<.001
	Subepicardial	−17.79 ± 4.03*	−16.85 ± 3.40$^{\beta,\alpha}$	−18.46 ± 4.31	−18.07 ± 4.14	<.001
Circumferential	Subendocardial	−31.62 ± 9.58*	−30.49 ± 9.57$^{\alpha}$	−32.71 ± 9.20	−31.64 ± 9.86	.002
	Myocardium	−25.14 ± 7.15*	−24.20 ± 6.81$^{\beta,\alpha}$	−25.95 ± 7.26	−25.27 ± 7.27	.001
	Subepicardial	−21.89 ± 5.95*	−20.76 ± 5.84$^{\beta,\alpha}$	−22.93 ± 6.36$^{\gamma}$	−21.99 ± 5.44	<.001
Radial	–	37.39 ± 8.83*	37.88 ± 9.23	37.06 ± 8.96	37.23 ± 8.26	.318

*All values are expressed as mean ± standard deviation and the statistical significance level was considered as *P*-value <.05. $^{\alpha}$Significant difference between left and codominant, $^{\beta}$Significant difference between left and right dominant; $^{\gamma}$Significant difference between right and codominant.

Myocardial muscle fibers are not in the same direction, subendocardial and subepicardial fibers are arranged longitudinally, and mid-wall fibers are circular in normal systolic function. Longitudinal fibers are shortened, resulting in the proximity of the left ventricular base to the cardiac apex and shortened circular fibers. The quality and quantity of these movements are measured by calculating the strain.[14,15] Strain as a mechanical parameter can express the contraction characteristics and represents tissue deformity in percentage.[16]

In the present study, we used the VVI technique, which is not angle-dependent; it uses edge detection to integrate images for analysis in longitudinal, radial, and circumferential strains for each layer of the endocardium, myocardium, and epicardium. Velocity vector imaging technique for evaluating the regional and general cardiac muscle function has been approved in previous studies. This technique is helpful to assess systolic and diastolic functions of cardiac ventricles.[16-22] In many studies, different results have been reported regarding the contractile function of the LV in healthy individuals. Some of the most important factors are described below:

Individual's Age

Normal reference levels of the LV strain have been reported in infants,[23,24] children,[25] and adults.[26-33] Studies showed that strain is age-dependent and follows a decreasing trend with age. In this study, we only examined adults with a mean age of 57.8 ± 9.4 years old.

Sex Difference

The results of World Alliance Societies of Echocardiography Normal Values Study showed that the LV global peak longitudinal myocardial strain was higher in absolute value for female subjects (−18 to −26% vs. −17 to −24%; *P* < .0001).[34] In studies by Park et al[31], Andree et al[27], and Dalen et al[29], higher absolute values of LV global longitudinal strain have also been reported in female subjects (−21.2 ± 2.2% vs. −19.5 ± 1.9%; *P* < .001, −20.4 ± 3.1% vs. −22.9 ± 2.7%; *P* < .05, and

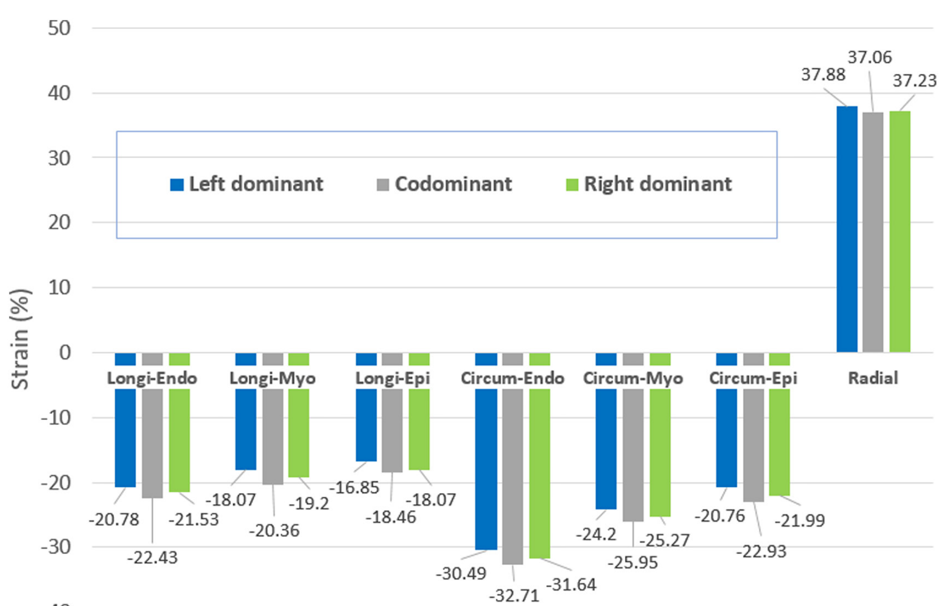

Figure 4. Global longitudinal, circumferential, and radial strain. Longi, longitudinal; Endo, endocardium; Myo, myocardium; Epi, epicardium, Circum, circumferential.

−17.4 ± 2.3% vs. −15.9 ± 2.3%; P <.0001, respectively). It was also reported that the circumferential strain was higher in absolute value in female subjects (−22.2 ± 3.2% vs. −20.4 ± 3.3%; $P < .05$), whereas the radial strain was lower resulting values (34.8 ± 8.9% vs. 37.9 ± 8.2%; $P < .05$).[27] Although in our study, participants were not examined in terms of sex, no significant sex-related differences were observed among the study groups.

Echocardiographic System, Techniques, and Software

Takigiku et al[35] aimed to determine the reference levels in healthy individuals using 3 different speckle tracking echocardiography vendors (V1, Vivid 7 or Vivid E9, GE Healthcare; V2, iE33, Philips Medical Systems; V3, Artida or Aplio, Toshiba Medical Systems). The results indicated that global and segmental longitudinal, radial, and circumferential strains vary among the 3 vendors. Therefore, the type of system and software can be influential factors. Most previous studies have used GE Echo PAC software to measure strain, while fewer studies have utilized tissue Doppler imaging (TDI) and VVI.[33] In the present study, all 3 groups with left, right, and codominant variations were analyzed by the same echocardiography system and software. Therefore, the results of comparison among the groups are reliable.

Anatomical Position

In many previous studies, segmental and global contractile functions were reported in the LV myocardium,[26,27,29,36] while many studies have not examined the territorial longitudinal strain.[36,37] Strain is at its highest in the subendocardial layer and at the lowest in the subepicardial layer. In the present study, in addition to myocardium, the endocardium and epicardium were also examined. Moreover, territorial and global strains were determined and compared in longitudinal, radial, and circumferential directions, separately for every 3 cardiac layers in 3 groups with different coronary dominance variations.

Study Limitations

The present study had several limitations. It was a preliminary study with a small data set. More research should be carried out to confirm our findings. Because our study was retrospective (we used PACS angiographic data and no further evaluation was possible for non-obstructive CAD), we could not exclude microvascular dysfunction and vasospastic CAD. This study was only conducted in the resting position; therefore, further biomechanical analysis of exercise stress is recommended in both genders and different age groups.

CONCLUSION

Contractile function of the LV muscles, including longitudinal and circumferential strains (but not radial strain), was significantly different among the left, right, and codominant groups. Left ventricle longitudinal and circumferential strains were at the highest degree in the codominant variation and at the lowest in the left-dominant variation. The findings of the present study can be important to select the control group in different cardiac studies.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Guilan University of Medical Sciences (approval No: IR.GUMS.REC.1396.267).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: MRA, HM, EN, MH, MAR: conception and design of the work; MRA, HM, EN: supervision of the project; MRA, HM: funding; MRA, MH, MAR: materials; MH, HM, EN: data collection and processing; HM: acquisition, analysis, and interpretation of data; EN, HM, MH, MAR: literature review; MH, HM: drafting the manuscript and revising it critically for important intellectual content; HM, MRA, MH, EN, MAR: final approval of the version to be published. All authors read and approved the final manuscript.

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