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Assessment of Left Ventricular Torsion in Short Axis View between Healthy Subjects and Significant Coronary Artery Disease Patients

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Abstract

Background: Coronary artery disease causes changes in biomechanical parameters and function of myocardial. Recently, torsion angle is one of the most important mechanical parameters. Therefore in this study, torsion angle in healthy subjects and LAD significant coronary artery disease patients, using echo tracking method in short axis view, was evaluated.

Materials and Methods: In cross sectional study, 14 healthy subjects and 10 patients with significant stenosis of LAD were evaluated. Two dimensional echocardiography images were scanned in apical and basal parasternal short axis view were recorded. Successive ultrasonic images were processed by echo tracking under block matching algorithm and peak torsion angle were estimated. Difference between healthy group and patient group were extracted by using peak torsion angle by the confidence level of 95%.

Results: In this study, basal rotation angle, apical rotation angle and torsion angle in short axis view in significant coronary artery disease patients significantly decreased 33%, 44% and 38% relative to healthy subjects, respectively. Also time to reach peak torsion angle in LAD coronary artery stenosis patients increased 19% relative to healthy group.

Conclusion: It seems, torsion angle in short axis view, can diagnose LAD coronary artery stenosis patients reative to healthy subject.

Introduction

Characterized by the unnatural accumulation of lipids and fats on vessel walls, atherosclerosis leads to vessel constriction and reduced blood flow toward the heart's myocardial muscle [1, 2]. The main procedures for the direct examination of coronary vessels are angiographic and CT angiographic imaging which are inappropriate for periodical evaluations of the patient due to their invasive nature and risk of ionizing radiation. Using modern echocardiographic methods, the appropriate physical parameters for the evaluation of the heart's performance based on the extent of the constriction of the coronary area can be determined nowadays [3, 4].

Lower [5] was the first to discover the torsion of the heart. The rotation of the left ventricular cross section around the long axis in basal and apical levels and from the apical view is known as rotation. The main cause leading to rotational movements in the heart is the structure and the type of location of heart fibers in the three layers of the heart and the three-dimensional contraction of spiral myofibers [6, 7]. The heart rotation results in a consistent distribution of stress and shortenings along the fibers. The lack of rotation, on the other hand, leads to higher stress and strain in the internal layers, and thus, increases demand for oxygen and eventually decrease left ventricular systolic function [5, 8, 9]. The potential characteristic of the left ventricular torsion measurements lies in the early, initial detection of damages to the myocardium [8, 10]. Tagging MRI is one of the non-invasive methods for studying heart torsion angle [11].

High spatial resolution and the ability to study angle in various layers of the heart are among the advantages of this method. Its disadvantage, on the other hand, lies in its low time resolution. In order to estimate the torsion angle of the heart with high time resolution, two methods - tissue doppler and speckle tracking- are used [12-14]. The torsion angle is affected by two torques enforced upon internal and external layers in opposite directions. The time required to reach maximum angles is also affected by two parameters heart beat and contractility during the heart's systolic phase [15]. Previous studies have shown that contractility is delayed to the diastolic phase in individuals suffering from ischemia [16, 17]. Studies show that LAD (left anterior descending) coronary artery constriction is of high risk, for it feeds more parts of the myocardium, including the anterior and anteroseptal sections of the left ventricle, as well as two thirds of the frontal inter-ventricular septum wall [18, 19]. In this research, therefore, the procedure for extracting the biomechanical parameter for left ventricular basal and apical segment rotation angles on the short axis view during a cardiac cycle will be presented. In this study, the rate of the left ventricular basal and apical level displacements will be obtained by means of the block matching algorithm, momentary [20]. Then, the ability to diagnose patients with significant LAD coronary artery as compared to healthy arteries will be assesses and evaluated based upon the biomechanical parameter of left ventricular torsion and the time required to reach maximum torsion angle.

Materials and Methods

In this cross-sectional study, 14 males 40-60 years of age with healthy coronary arteries and perfect cardiovascular health were selected as the pilot. These individuals had no history of cardiovascular diseases - such as infarction, surgery, atrial and ventricular arrhythmia, heart failure, nerve conduction block and diabetes- and their electrocardiographic and two dimensional echocardiographic tests indicated normal local and general left ventricular performances. Moreover, clinical and hemodynamic examinations showed their hearts to be healthy; none of them had pacemakers. Furthermore, since it is not feasible to conduct angiographic studies on coronary arteries on this group of individuals, the indices obtained from the Framingham Study [21, 22] -including individuals' gender, age, blood pressure, cigarette consumption, blood cholesterol amount, diabetes, and hypertrophy- were used by means of risk assessment software for cardiac coronary diseases; thus, individuals who entered the healthy group had less than 10% likelihood of getting coronary artery diseases.

The patients' group was male subjects with significant left anterior descending coronary artery (LAD) stenosis in the proximal portion, who are 40-60 years of age and were referred to the echocardiographic section of Dey Hospital's cardiovascular center. It is to be noted that patients included in the preliminary selection for echocardiographic test examination in this research were candidates for coronary artery angiography and echocardiography; when their angiographic reports confirmed over 70%LAD coronary artery stenosis.

Volunteers submitted written consent for participation in the study. Also, the executive protocol of the research was approved by the Medical Ethics Committee of Tarbiat Modares University. At first, echocardiographic images of the apex and base levels of the left ventricle from the short axis view are extracted and recorded. Assuming that the apical and the basal levels are circular in shape (on the short axis view), and having determined the coordinates for the center of this circle, the interventricular septum wall apical and basal levels rotation angle can be estimated by means of the displacement vectors and the rotation center. The images from the short axis view have been obtained using the American Society of Echocardiography protocol [23]. It is to be noted that in this view, the base segment is located where the mitral valve is clearly visible (Fig. 1A), whereas the apex segment (Fig. 1B) is recorded on the last part of the papillary muscles, so that the muscles cannot be seen [24]. Having transferred consecutive ultrasound images to a personal computer, tracking techniques are used through the block matching algorithm [18-20]. Block matching involves the selection of a window (or block) in the first frame as the reference block and finding the most similar block to it in the next frames. In the block matching method, it is assumed that the blocks remain constant in size during the whole movement period. In this study, the movement of the tissue along consecutive frames was estimated by means of grayscale data from two dimensional echocardiographic images through the block matching algorithm. Vertical movement is defined along the lateral direction (along the matrix columns in the image) and horizontal movement is defined along the axial direction. In order to implement the block matching algorithm, the cine loop format must first be converted into consecutive frames. To do so, a program is written and executed in MATLAB medium. This program is capable of converting cine loop format with DICOM, AVI and WMV formats into consecutive frames. In order to examine the maximum movement of the left ventricular muscle, and subsequently the rotation of the base and apex levels, the location of the block in the frame for the initial cardiac systolic phase concerned with the myocardial wall is determined manually (based on the electrocardiogram). Having executed the echo tracking algorithm, the amount of basal and apical level displacements along the two axes -X and Y- is extracted during a cardiac cycle. In this step, momentary variations of the total left ventricular displacements for the two segments studied are recorded. Figure 2 has displayed a sample of momentary variations in left ventricular septum wall segment displacements on the short axis view with 16 ms time resolution. The reliability of the algorithm and the motion estimation program has been evaluated in our previous research [20-25].

Having implemented the block matching algorithm on consecutive frames, the amount of septum wall displacement along the horizontal axis (X in Cartesian coordinates) and the vertical axis (Y in Cartesian coordinates) us extracted in the systolic phase. Assuming a circular shape for the left ventricular basal and apical levels on the short axis view, the coordinates for base and apex level centers for the end systolic phase (based on the electrocardiogram) was obtained along the axes X (X_{center}) and Y (Y_{center}) (Fig. 3).

To estimate the amount of heart segment movements (Fig. 2), coordinates for the base and apex segments at the end-diastolic phase (Y_{ED} and X_{ED}) as well as the coordinates for the segments at the end-systolic phase (Y_{ES} and X_{ES}) are obtained. Assuming a circular shape for the left ventricular basal and apical cross sections of the heart on the short axis view, the coordinates for base and apex segment centers for the end-diastolic phase (based on the electrocardiogram) was obtained along the axes X (X_{center}) and Y (Y_{center}) (Fig. 3). To estimate the rate of heart segment movements (Fig. 2), based on the coordinates for these segments at the end-diastolic phase (Y_{ED} and X_{ED}) as well as the coordinates for the base and apex segments at the end-systolic phase (Y_{ES} and X_{ES}), the rate of the rotation angle (Θ) for the left ventricular apical and basal levels can be estimated using equation 1:

$$\Theta = (Arc\tan(\frac{X_{ES} - X_{center}}{Y_{ES} - Y_{center}}) - Arc\tan(\frac{X_{ED} - X_{center}}{Y_{ED} - Y_{center}}))$$

The ventricular torsion angle (θ) is extracted from the gradients for the rotation angles of the apex (Θ_{apex}) and base (Θ_{base}) segments (equation 2):

$$\theta = \Theta_{apex} - \Theta_{base}$$

During the cardiac systolic phase, the apex has a counterclockwise movement shown with a positive sign, whereas the basal level has a clockwise movement represented with a negative sign. Therefore, the maximum torsion angle is equal to the sum of the absolute amounts of the maximum rotation angles for the base and the apex levels. To determine the time required to reach maximum torsion angles on the short axis view, the frame in which maximum and minimum movement occurs was first found. Then, based on the number of frames between the maximum and the minimum as well as the heartbeat, the time required to reach maximum torsion angles on two short axis views was determined. It is to be noted that in the block matching algorithm, the frames in which maximum and minimum septum wall movement has taken place are regarded as the end of the cardiac diastole phase and the end of the cardiac systole phase respectively, which is also confirmed by the ECG signal recorded at the lower part of the image.

Data analysis was conducted using SPSS-13 software (SPSS Inc. Chicago, IL, USA). The results obtained from the parameters measured during local heart performance examinations on the individuals studied including horizontal and vertical movements, maximum rotation angle, the time required to reach maximum angles, and the maximum torsion angle were analyzed; the results were subsequently presented as means and standard deviations. A sample estimate was made based on the parameter of maximum rotation in basal and apical levels. Means and standard deviations were calculated according to the pilot study for 14 healthy individuals and 10 patients. Seven samples were estimated for each group based on the independent samples *t*-test with 95% confidence level. To decrease errors in measurements, parameters were extracted for four cardiac cycles. The KS (Kolmogorov-Smirnov) test was used to examine the normality of the distribution of the groups. Also, the Independent samples *t*-test with 95% confidence level was used to assess the differentiation between the two groups ($p<0.05$).

Results

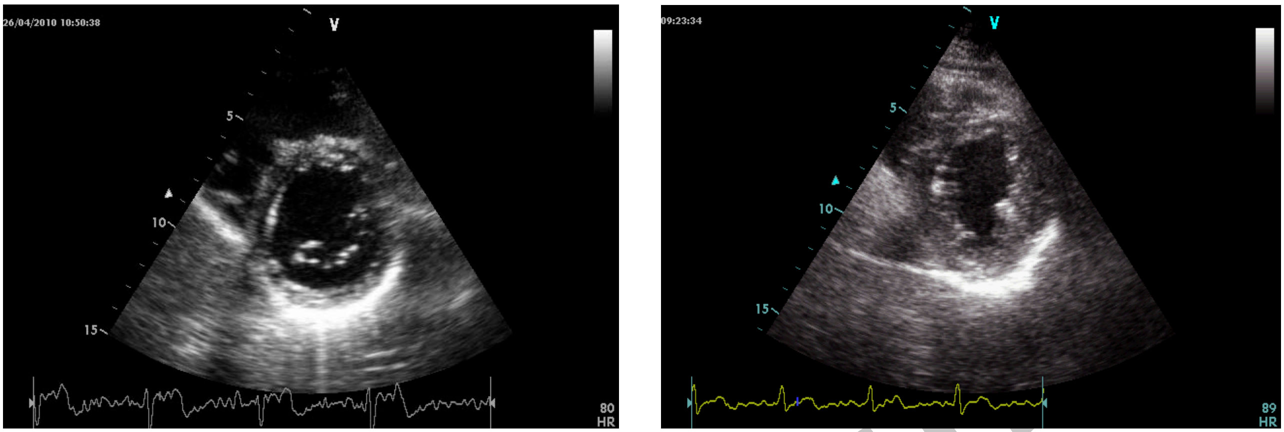
The means and standard deviations for the physical, hemodynamic and echocardiographic features of the individuals studied have been displayed in table 1. By means of the independent samples *t*-test, there are no significant difference in the age, body mass indices, posterior wall thickness, end-diastolic inter-ventricular septum wall thickness and left ventricular ejection fraction between the healthy individuals and the significant left anterior descending coronary artery (LAD) stenosis (>70%). There are, however, a significant difference between the two groups studied in systolic and diastolic blood pressures of radial artery and the end-diastolic and systolic left ventricular diameters.

In this research, having recorded echocardiographic images of basal and apical segments on the short axis view, the maximum vertical and horizontal movement of the septum wall of the myocardial muscle during the cardiac systole phase was examined in healthy individuals and in patients. The results obtained from studying the maximum vertical and horizontal movement (mm) in the cardiac systole phase in basal and apical segments on the short axis view have been displayed in table 2.

The normality of the distribution of the data was examined using the KS statistical test with 95% confidence level. The results of the KS test indicate a normal distribution in the vertical and horizontal movements on the short axis view in apical and basal segments in healthy individuals and in patients. With the normal distribution of the data, the independent sample *t*-test pointed out a significant difference between horizontal apical movements on the short axis view in healthy individuals and patients. Nonetheless, no significant difference was observed between the vertical movements in basal and apical segments as well as the horizontal movements in basal segments on the short axis view in healthy individuals and patients.

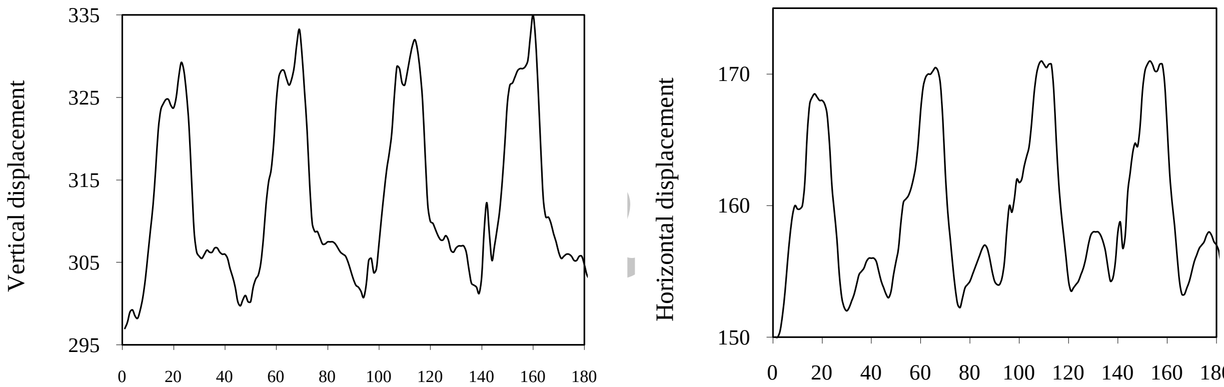
By considering the momentary displacements of the inter-ventricular septum wall on the short axis view during a cardiac cycle in the basal and apical segments, and also having located the centers in the segments concerned on the short axis view and in the end-diastolic frame, the rotation angle rate for healthy individuals and patients was obtained. Figure 4A displays the results for the rotation angle rate in basal and apical levels on the short axis view during a cardiac cycle for one healthy individual and one patient as a sample. Figure 4B displays the results for the rate of torsion angles based on the rotation angle gradient for basal and apical segments on the short axis view during a heart cycle for one healthy individual and one patient as a sample for the sake of comparison.

A study of figure 4 leads to clear differences between momentary changes of basal and apical segment rotation angles and the momentary changes of torsion angles in healthy and the significant LAD coronary artery stenosis individuals. Having extracted the inter-ventricular septum wall maximum movement during a cardiac cycle for the basal and apical segments, and also having located the center in the concerned segments on the short axis view and at the end of the diastolic phase, the maximum apical and basal segment rotation angle on the short axis view for one cardiac cycle in healthy individuals and patients was obtained by using equation 1. Based on the angle gradient for the basal and apical rotation, the left ventricular torsion angle was estimated. The results obtained for the extraction of basal segment and apical segment rotation angles during three cardiac cycles and also the maximum left ventricular torsion angles in degrees have been displayed as means and standard deviations in table 3. As the disease progresses (Table 3), the maximum rotation angle of apical and basal segments decreased 44% and 80% and so the maximum left ventricular torsion angle decreased 39% compared to the healthy group. The time to reach maximum torsion angles also proves to be 19% higher than that of the healthy group.



(A) (B)

Figure 1. The echocardiographic images of the left ventricular myocardium; A) the basal, and B) the apical level



(A) (B)

Figure 2. Momentary changes for; A) horizontal and, B) vertical left ventricular apical levels on the short axis view extracted using the block matching algorithm. Time resolutions are 16 ms.

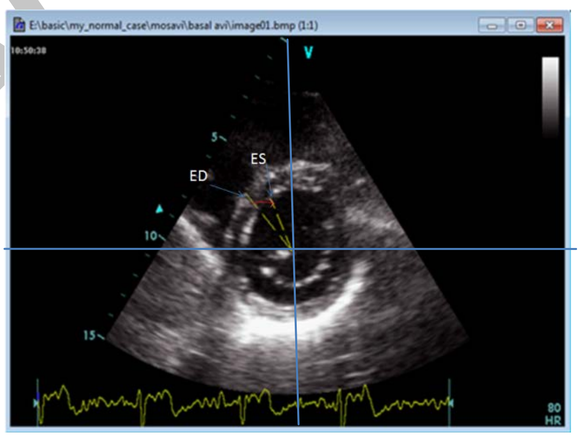


Figure 3. The left ventricular apical level rotation from the cardiac end diastolic phase (ED) to the end systolic phase (ES) on the short axis view of the echocardiography. These images are the result of the overlapping of frames at two phases-end systolic and end diastolic phases. The concerned maximum segment rotation angle is then calculated according to the coordinates of the rotation center. This image displays the electrocardiogram signal.

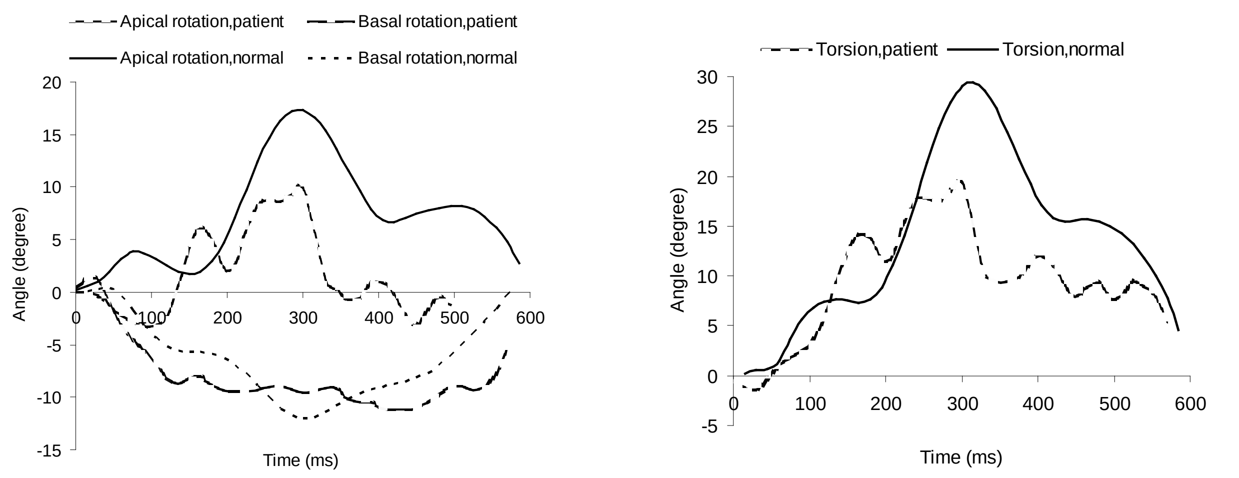


Figure 4. A) The rate of rotation angles for base and apex segments (degree), and B) the rate of torsion angles (degree) during a cardiac cycle for a sample healthy individual and a patient. Studies have been conducted at temporal resolution of 16 ms

Table 1. Means and standard deviations for the physical, hemodynamic and echocardiographic features of the healthy and the significant LAD coronary artery stenosis

Parameter	Healthy (Mean±SD)	Significant stenosis>70% (Mean±SD)	*p*-Value
Age (yr)	46±5	47±7	0.796
Body mass index (kg/m^2)	25±2	24±3	0.983
Radial systolic blood pressure (mmHg)	113±10	133±9	0.000
Radial diastolic blood pressure (mmHg)	80±10	79±5	0.010
End diastolic left ventricular diameter (mm)	49.8±3.9	45.6±3.7	0.025
Peak systolic left ventricular diameter (mm)	31.4±4.2	31.1±5.5	0.762
Posterior wall thickness (mm)	11.1±1.1	10.0±0.0	0.948
End-diastolic inter-ventricular septum wall thickness (mm)	11.9±0.8	10.5±0.7	0.330
Left ventricular ejection fraction (percent)	58±2	50±16	0.066

Table 2. Means and standard deviations for maximum vertical and horizontal movements in basal and apical segments of inter-ventricular septum wall (mm) in the healthy and the significant LAD coronary artery stenosis on the short axis view

Parameter		Healthy (Mean±SD)	Significant stenosis>70% (Mean±SD)	*p*-Value
Horizontal displacement (mm)	Basal	5.71±1.45	4.50±2.42	0.170
	Apical	8.33±2.21	5.50±2.33	0.007
Vertical displacement (mm)	Basal	3.15±1.12	2.32±1.03	0.080
	Apical	3.93±1.23	3.45±1.53	0.411

Table 3. Means and standard deviations for maximum basal and apical rotation angles (degree) during three cardiac cycles and also maximum left ventricular torsion angles (degree) on the short axis view and so the time required to reach the maximum torsion angle (ms) in the healthy and the significant LAD coronary artery stenosis (>70%)

Mechanical parameter	Healthy	Significant stenosis>70%	*p*-Value
Basal rotation angle (degree)	9.49±1.71	5.35±0.84	0.000
Apical rotation angle (degree)	7.96±1.57	5.30±1.20	0.000
LV torsion angle (degree)	17.45±2.17	10.65±1.32	0.000
Time to reach LV torsion angle (ms)	290±24	344±41	0.010

A statistical analysis of the study of maximum rotation angles on the short axis view indicates a significant difference between the healthy group and the patients with the significant LAD coronary artery stenosis (p=0.001). A statistical analysis of the difference between the two groups based on the time to reach maximum left ventricular torsion angles also indicates a significant difference between two groups mentioned above with 95% confidence level (p=0.010).

Discussion

The present research endeavored to estimate the torsion angle for the heart in the short axis view; it was shown that the left ventricular torsion angle in the short axis view in patients with the significant LAD coronary artery stenosis (>70%) has a significant decrease compared to healthy individuals. Furthermore, this research showed, with 95% confidence level, a significant difference between the time to reach maximum torsion on the short axis view between healthy individuals and patients; in the latter, the time had shown to increase. The time required to reach the maximum angle of torsion is affected by two parameters the heartbeat and contractility. It seems, therefore, that the only effective factor here is the contractility of the myocardial wall. Furthermore, since contractility has decreased in individuals the significant LAD coronary artery stenosis compared to healthy individuals, these results are to be expected.

The most common measurements used in clinical echocardiography in order to quantify heart muscle performance are based upon ejection fraction. In many pathological conditions of the heart, however, the disease appears in the form of local changes in myocardium performance [26]. The progression of coronary artery disease results in movement disorders in the segments of the cardiac walls. Therefore, ultrasound techniques can be used to evaluate the local performance of the myocardial wall due to their capability to study movement [27]. Ledesma-Carbayo et al. [28] estimated the extent of the vertical and horizontal movement of the middle and basal septum walls on the long axis view of ultrasound images in healthy individuals and also in those suffering from ischemia by means of the optical flow algorithm. In their studies on individuals whose septal-basal walls suffered from ischemia (the restriction of blood supply), these researchers pointed out that the extent of movement had decreased vertically and horizontally. On the other hand, our results, obtained by studying the movement of the basal segment of the septum wall in patients showed no significant difference between the extent of vertical and horizontal movement along the short axis view between healthy individuals and patients. In patients with the significant LAD coronary artery stenosis, the septum wall in the base segment is not supplied with blood by the LAD artery; therefore, the results mentioned above seem to be logical. It is to be noted that the apical part of the septum wall is supplied with blood by the LAD artery; since our results on the extraction of vertical movement on the long axis view between healthy individuals and patients with the significant LAD coronary artery stenosis indicated a significant difference, it seems that these results are to be expected due to the biomechanical change in the apex area which is supplied with blood by the LAD coronary arteries and the lack of blood supply in this area.

During the systolic phase, the myocardial wall undergoes longitudinal, radial and circumferential shortening. Such a contractive behavior by the myocardial tissue leads to torsion in the heart. The torsion angle of the heart is one of the heart's important mechanical parameters, and has come to extensive attention nowadays. The main reason of torsion in the heart is the structure and the type of location of the myocardial fibers in its three layers and the three-dimensional contraction of spiral myofibers [5]. During the systole phase, apical rotation occurs counter-clockwise, whereas basal rotation is clockwise. This torsional deformation is the main factor leading to the thickening of the left ventricle wall. Studies on maximum the torsion angle as an important parameter in the assessment of systolic myocardial performance has recently come to attention. Due to the high significance of the torsion angle of the heart, many studies have been done in this field on animals such as mice, dogs, pigs, and also humans [29, 30]. Using the speckle tracking method based on the block matching algorithm, Notomi et al. [14] and Helle-Valle et al. [31] assessed the maximum left ventricular torsion angle on the short axis view in healthy individuals. This research has used the echo tracking method and the block matching algorithm to evaluate the time rhythm of left ventricular torsion angle on the short axis view as well as the maximum rotation angle in base and apex segments and also the maximum left ventricular angle of torsion in healthy individuals and patients with the significant LAD coronary artery stenosis.

According to the studies conducted by Dong et al. [32], the maximum torsion angle was pointed out to be affected by three parameters preload, afterload and contractility myocardial upon the myocardial wall. The results of their study showed that the impact of the contractility of myocardial leads to changes in torsion due to the effect it has upon the force on the wall, without affecting the volume. In general, any factor leading to changes in volume and the power of the heart also affects torsion. In this research, it was pointed out that phenomena such as ischemia result in decreased heart contractility and, in turn, lower heart torsion.

In our study also, the results obtained from the comparison of maximum rotation angles in basal and apical segments as well as maximum rotation angles on the short axis view indicated, with 95% confidence level, a significant decrease between the healthy group and the group with the significant LAD coronary artery stenosis. The reason for lower maximum torsion angles in basal and apical segments in the patients can be due to the increased stiffness of the internal fibers and also the decreased distance between the myofibers. The geometric changes resulted by variations in the Contractile function of cardiac muscle also lead to lower torsion during the systole and suction phases; therefore, in these circumstances, the patient requires oxygen as well as undergoing higher stress upon the walls.

In this research, it was observed that the angle of rotation on the short axis view had decreased despite the lack of blood supply to the basal segment of the septum wall by the LAD artery. Apparently, this is due to impact of the lateral segment (anteroseptal), which is supplied blood by the LAD artery. Moladoust et al. [33] indicated in patients with the significant LAD coronary artery stenosis, biomechanical parameters of stress and elasticity upon the walls increased. Wei [34] pointed out higher stress upon the walls as one of the causes of lower maximum rotation angles in patients with the significant LAD coronary artery stenosis; therefore, the reason for reduced maximum segment torsion angles in this research seems to be increased stress upon and also higher elasticity coefficients of the walls. Studies on the extent of basal segment movement from the septum wall pointed out lower average movement on horizontal and vertical axes of the heart walls in patients with the significant LAD coronary artery stenosis compared to the healthy group. Although no significant difference was observed, possibly due to the different geometry in various individuals, higher numbers of samples seem to be able to yield definite results.

The torsion angle of the heart is proportionate to myocardial movements; therefore, even the slightest change in the extent of movement leads to large differences in the angle of torsion even though the results obtained by our research indicated that the maximum torsion angle of the segments studied and the maximum ventricular rotation angle compared to the variations in movement may have higher capabilities in predicting potential damages to the muscle.

During a cardiac cycle, the heart goes through a three-dimensional motion, whereas the speckle tracking method examines this three-dimensional movement in two dimensions -one of the limitations of this research. Interfacial movements- or, in other words, movement on the long axis of the ventricular shows to be higher (especially about 4 mm in the basal segment of the septum wall [12, 26, 30], whereas the short axis plane concerned is about 2 to 3 mm thick); therefore, while imaging at rates of 60-70 frames per second, the segment studied will be caused to move out of the short axis, and the echo pattern tracked will fall outside the area studied, in turn resulting in errors in the estimation of the amount of the speckle model displacement, eventually bringing about errors in the estimation of torsion angle from the short axis view during a cardiac cycle by the motion estimation method.

Considering the inefficiency of common echocardio graphic systems in the examination of coronary arteries, this study concluded that the biomechanical behavior of the heart changes with the progression of LAD stenosis; thus, through the non-invasive extraction of cardiac rotation by means of processing consecutive echocardiographic images, the two groups can be distinguished without angiographic studies.

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Authors' Contributions
All authors had equal role in design, work, statistical analysis and manuscript writing.

Conflict of Interest
The authors declare no conflict of interest.

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