Assessment of left ventricular longitudinal deformation, rotation and twisting, using two-dimensional strain.

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Introduction.

The heart muscle is consisted by 90% of fluid and is composed by myocyte bundles involved by interstitial tissue sheath called perimysium (formed mainly by collagen and elastin). This heterogeneous tissue has elastic properties that determine its deformation when it is applied an effort [1]. These properties are: a) incompressibility: the cardiac muscle change its form, but not its volume; b) anisotropism: the elastic properties vary with the direction in which the force is applied; c) no uniformity: the components of myocardium have different physical properties, so the deformation is not the same in all regions; d) viscous-elasticity: the effort causes different degrees of deformation as the applied velocity varies.

The cardiac muscle is formed by a single muscular band enrolled over it, reflected in the interventricular septum and anchored at its ends in aortic and pulmonary rings [2]. This disposition gives the muscle a twisting motion, such as twisting a towel to dry water. This peculiar anatomy gives the heart great mechanical efficiency [3].

The myofibril bundle direction changes gradually along the ventricular wall thickness, with mainly right-handed pitch direction in the subendocardial region and left-handed pitch direction in the subepicardial region [4].

This architecture, associated with the physical properties described above, provides complex variations of parietal deformation.

Early analysis of myocardial strain was started by hemodynamic methods, with radio-opaque markers inserted into the heart muscle [5]. Nuclear magnetic resonance imaging uses highly ionized markers called "tags" [6]. Doppler echocardiography, through the tissue Doppler, allows deformation measuring velocity gradient between two closer points to the wall [7]. This methodology is, however, highly dependent on the Doppler angle, which limits its application, particularly for apical regions of the left ventricle [8]. The use of speckle tracking method, allowing the identification and tracking points of two-dimensional images during the cardiac cycle, removes this limitation [9]. The trajectory of the points is represented by vectors that indicate the velocity and direction of movement, resulting in deformation (strain).

The deformation of the heart muscle can be decomposed in several directions [10]: longitudinal, radial and circumferential, all perpendiculars between them.

Apical approach is used to determine longitudinal strain, actually it is considered an important parameter of left ventricular function. Short axis views at the base of the left ventricle, at papillary muscles level and apical region level are used to measure circumferential strain and rotational movement.

Objective.

The aim of this work is to assess the myocardial deformation and rotation in individuals with no echocardiographic cardiac disease.

Material.

We studied, with two-dimensional strain, 250 individuals with no evidence of cardiac disease, 95 males, 155 females, and mean age of 40.4 years, standard deviation of 15.0 years, with range of 14 to 63 years. All subjects were in agreement of the Consent and Terms standardized in our Institution for echocardiographic studies.

Methods.

Were selected individuals with no echocardiographic evidence of heart disease, with normal systolic and diastolic functions and without valve or pericardial disease, using the analytical criteria of the ASE (11).

In classical echocardiographic approach (apical four chambers, apical two chambers, apical long axis view and short axis views across the mitral valve, papillary muscles and apical region), we studied the longitudinal deformation of 17 myocardial segments, the circumferential deformation and the basal and apical rotation. The endocardial and epicardial border are generated automatically by the system, but can be repositioned manually by the edit function, if necessary.

Longitudinal and circumferential strain generates negative curves (Figure 1), basal rotation clockwise curves (negative) and apical rotation counter clockwise curves (positive) (Figure 2). The data were compared with those of recent publications.

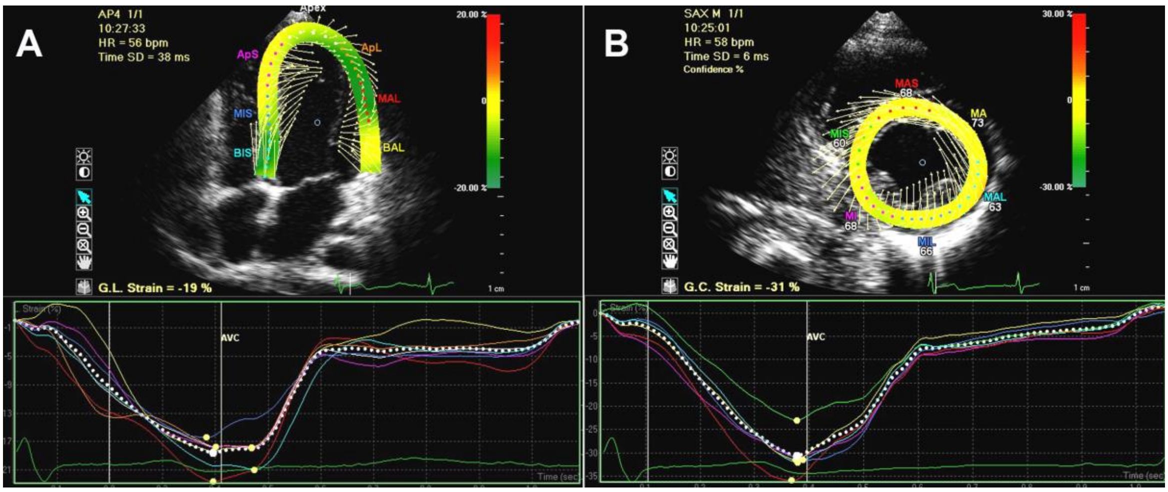

Figure 1 - A: longitudinal strain of the LV obtained from the apical approach. At the top, velocity vectors and parametric representation of the myocardial walls. At the bottom, curves of deformation of the various segments. B: LV circumferential strain obtained from the short axis view at papillary muscle level with parametric and vectorial representation and deformation curves.

The echocardiograms were performed in basal conditions, left lateral decubitus, expiratory apnea, with equipment HD15, IE33 or CX50 (Philips Healthcare, Andover, MA) with digital image storage system. The examinations were reviewed offline with Qlab 9.1™ software.

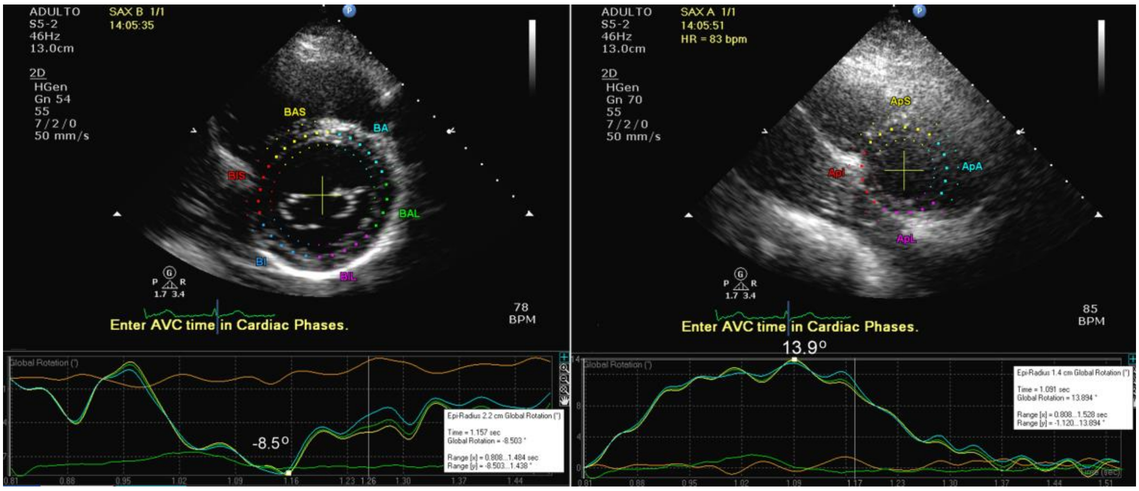

Figure 2 – Curve of basal LV rotation (left), clockwise, with the curves shown below baseline. Apical LV rotation (right), counterclockwise, with curves above the baseline. The angular difference between the basal and apical rotation is twisting.

Values were expressed in mean and standard deviation. One Way Analysis of Variance performed statistical analysis, complemented with Student-Newman-Keuls test for significance between individual segments. Inter-observer variability and reproducibility was analyzed by correlation coefficient. Comparison with literature data was analyzed with unpaired Student's "t" test using mean and standard deviation values.

Results.

Left ventricular apical approach.

Longitudinal strain increases slightly toward the apex. The values of the regional strain were -22.06 ± 2.07% at basal segments, -23.51 ± 2.37% at medial segments and -24.30 ±2.75% at apical segments. Table 1 shows all strain values. Analysis of Variance demonstrate significant difference between base and apex on ventricular segments with $p<0.05$.

Table 1 – Longitudinal strain in seventeen segments.

		Strain (%)		
		Basal	**Medial**	**Apical**
Anterior	**X**	-21.52	-27.00	-19.42
	sX	6.78	9.61	9.79
Anterior-septal	**X**	-20.96	-25.27	-
	sX	7.72	5.18	
Inferior-septal	**X**	-18.96	-23.04	-25.12
	sX	4.13	6.06	5.17
Inferior	**X**	-22.65	-21.46	-26.65
	sX	6.83	5.28	6.67
Inferior-lateral	**X**	-24.88	-21.39	-19.80
	sX	7.90	6.37	4.26
Anterior-lateral	**X**	-23.50	-21.48	-
	sX	6.95	5.85	
Apex	**X**	-	-	-20.23
	sX			4.42
All segments	**X**	**-22.06**	**-23.51**	**-24.30**
	sX	**2.07**	**2.37**	**2.75**

Left ventricular short axis approach.

In short axis view circumferential strain increases towards the apex. The regional values of circunferential strain were -22.8 ± 3.99% in basal segments, -24.51 ± 4.04% in medial segments and -24.70 ± 5.93% in apical segments. Table 2 shows the values of all segments. Analysis of Variance demonstrates significant difference between mitral valve level and apical level with $p<0.05$.

Table 2 – Circumferential strain.

		Strain (%)		
		Basal	Medial	Apical
Anterior	X	-21.33	-22.91	-24.72
	sX	7.54	7.72	8.06
Anterior-septal	X	-27.73	-29.42	-23.68
	sX	7.51	7.51	5.46
Inferior-septal	X	-24.42	-25.24	
	sX	6.29	7.60	
Inferior	X	-20.04	-24.74	-23.19
	sX	5.30	7.23	8.33
Inferior-lateral	X	-20.32	-20.52	-23.81
	sX	6.51	6.25	8.35
Anterior-lateral	X	-21.74	-24.04	
	sX	6.25	6.82	
All segments	X	**-22.80**	**-24.51**	**-24.70**
	sX	**3.99**	**4.04**	**5.93**

Rotation is clockwise in basal segments and counter clockwise in apical segments. Values of rotation was -5.9º ± 3.7º at mitral valve segments and 10.39º ± 4.03º at apical segments. Angular difference between basal and apical rotation, called twisting, was 16.29º ± 5.19º.

System acuracy.

To test the feasibility of the method was evaluated by capturing and tracking of each point, considering not available the segment corresponding to the point that had not caught correctly after three attempts to measure.

The percentage of segments correctly assessed in apical projections was 95.7%. In short axis views, at mitral level, 94.2% of the segments have been feasible. At papillary muscles level, 92.3% of segments have been feasible. At apical level, 98.1% of segments were feasible. The overall percentage of segments that weren't evaluated was 4.7%.

In 90 individuals (36% of the sample) was held inter-observer variability for longitudinal and circumferential strain, giving a Pearson correlation of 0.97.

Comparison with literature.

Longitudinal and circumferential strain showed no statistically significant difference with the values obtained by Yingchongcharoen et al [12]. Rotational values showed no statistical difference with the values obtained by Kaku et al [13].

Discussion.

Analysis of myocardial deformation measured by speckle tracking method seems to explain anatomical observations described by Torrent-Guasp [2] and Greenbaum [14], among others, indicating a helicoidal morphology and laminar distribution of the myocardial layers, with predominance of circular fibers in basal region and longitudinal fibers in apical region of the heart.

The apical increase in longitudinal and circumferential strain could be related to the prevalence of longitudinal fibers at apical level. This anatomical feature is responsible for the torsion and shortening of the left ventricular cavity, caused mainly by the

sequential depolarization of the apical bands, agonist and antagonist, responsible for the ventricular ejection [15].
In myocardial deformation analysis, the interventricular septum deserves more attention because of the impact suffered by right ventricular contraction that tends to change the wall deformation. In the cases studied here, however, did not detect any significant change in the deformation and velocity of left endocardial region of the septum with respect to adjacent walls. The analysis of the right side of the interventricular septum, although not analyzed in this study, seems to show no significant differences [16, 17].
The evaluation of apical torsion shows major changes with age, observed a progressive decrease in basal rotation and increase in apical rotation, with the consequent increase in the twisting. This observation is called apical hyper rotation [18].
The comparison with literature, despite small differences probably due to methodology, allows inferring the consistency with the values found in this work. Validation with magnetic resonance, considered gold standard, was not performed, having been tested by several authors [19-21].
Analysis of feasibility seems clear that good quality of digitalized clips analyzed off-line should be very important.
We noted that most walls not properly evaluated are at the short-axis views at basal and medial levels, probably due to the lower lateral resolution of ultrasound equipment for walls that are more oblique in relation to the ultrasonic beam and lateralized on the image sector. Apical level image is more centralized in the sector, improving lateral resolution.
Among the apical positions, the most incorrect assessment was made on the apical two-chamber view, probably due to the difficulty in obtaining good quality images of the anterior wall of the left ventricle.
The point positioning by the operator does not appear to be key factor to error increase, when followed by the recommendations for the inclusion of these points [22]. The repositioning of the epicardial points, automatically generated by the system, in general is not necessary, but the position of these points outside the sector's image is the major cause of errors, since their capture and tracking does not occur in such conditions. Because the majority of endocardial borders are automatically generated by the equipment, after the placement of three points in the endocardium, the inter-observer variability is very low.
As a practical application of myocardial deformation, we can mention the evaluation of cardiac synchrony [22], which has shown good results, the assessment of regional contractility in coronary artery disease [23], in myocardial hypertrophy [24], in early detection of myocardial disease [25] and identification of diastolic dysfunction [26], among others.
The global representation of deformation can be viewed through the parametric images, which display, simultaneously and in function of time, changes in deformation and velocities along the myocardial wall in real time [28].

Limitations.
Two-dimensional methodology for evaluation of myocardial strain has some limitations: depends on the quality of echocardiographic images, which depends on the operator qualification and conditions of the patient thorax. It has low temporal resolution and difficulties in resolving lateral resolution in short axis and apical two-chamber views. Furthermore, the use of two-dimensional echocardiography limits the monitoring of acoustic markers to two plans, which should be eliminated with the use of

three-dimensional echocardiography. Optimization of algorithms of analysis should also contribute to reducing these limitations.

Conclusion.

The impact of new imaging methods in understanding the heart mechanics is very important, mainly because it knowledge implies on the comprehension of various pathological mechanisms. The speckle tracking, as any novel methodology, needs acquisition of benchmarks consisting in normal and pathological studies. Thus we believe, with this work, to be contributing to the accuracy of the method.

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