Evaluation of the left ventricular torsion and twist in patients with chronic heart failure using three dimensional speckle tracking echocardiography

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Summary

Objective: To evaluate the left ventricular torsion deformation in patients with chronic heart failure using 3D speckle tracking echocardiography. *Subject and method:* From January 2018 to October 2020, a prospective, cross-sectional study with controls was conducted on 110 chronic heart failure patients and 50 healthy people who were treated as inpatients at the Department of Cardiology, 108 Military Central Hospital. *Result:* The mean age of the group of patients with heart failure was 65.82 ± 11.77, with men accounting for 66.36%, while the mean age of the control group was 65.16 ± 10.24, with men accounting for 68%. The heart failure group's left ventricular torsion parameters were all lower than the control group's: Peak-AR (4.56 ± 2.960 versus 10.41 ± 3.060; p<0.001), Peak-BR (-4.04 ± 2,250 vs -8.97 ± 2.750; p<0.001), Peak-Twist (7.94 ± 4.280 vs 18.99 ± 4.280; p<0.001), and Torsion (1.01 ± 0.560 vs 2.42 ± 0.600; p<0.001) and decreased in both the preserved EF group and the control group: Peak-AR (6.63 ± 2.49 vs 10.41 ± 3.06, p<0.05), Peak-BR (-5.02 ± 3,040 vs -8.97 ± 2.750; p<0.05), Peak-Twist (10.96 ± 4,740 vs 18.99 ± 4,280, p<0.05), Torsion (1.46 ± 0.600 vs 2.42 ± 0.600, p<0.05). The absolute value of left ventricular torsion parameters gradually decreased from heart failure with EF 50% to heart failure with a slight decrease in ejection fraction to heart failure with EF 40%. From the group of heart failure with grade I diastolic dysfunction to the group of heart failure with grade III diastolic dysfunction, the absolute value of the parameters of left ventricular torsion decreased statistically significantly. Apical rotation and left ventricular torsion have a moderate relationship with EF, left ventricular longitudinal strain as measured by 2D speckle tracking echocardiography. On 2D speckle tracking echocardiography, the angle of rotation should be weakly correlated with EF and left ventricular longitudinal strain drived from 2D speckle tracking echocardiography (2D–GLPS). *Conclusion:* Torsional deformation parameters of the left ventricle were lower in heart failure patients compared to controls, and they changed earlier in the group with preserved ejection fraction. Torsion deformation parameters, despite being the last variable parameter, are still quite sensitive in detecting left ventricular dysfunction.

Keywords: Heart failure, tissue marker ultrasound, 3D ultrasound, torsion movement.

1. Background

Heart failure is a complex clinical syndrome that is the end-stage progression of many cardiovascular diseases, with significant consequences for patients' health and quality of life [1]. Heart failure with preserved ejection fraction (EF 50%) has been increasing in recent years, accounting for 50% of the heart failure population [2]. Left ventricular ejection fraction (EF) is an important parameter in the assessment of left ventricular function, cardiovascular risk assessment, and an important prognostic factor in patients with heart failure who have an EF of 40% or higher [3]. However, for

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patients with heart failure who have an EF greater than 40%, the prognostic value of EF is limited, and EF has little value in assessing cardiovascular risk and prognosis for this group of patients. In recent years, 2D speckle tracking echocardiography has emerged as a useful method for detecting changes in left ventricular function early in the disease by assessing myocardial deformities. The heart has a complex structure: the endocardial layers run to the right at a 600-degree angle, the epicardium layers run to the left at a 600-degree angle, and the middle layers run circumferentially. As a result, even when contracting, the heart muscle moves and twists in 3D space. Myocardial contractility must be assessed using 3-D imaging analysis tools. Recently, 3D speckle tracking echocardiography has emerged as a new method for evaluating deformation parameters in 3D space, overcoming the limitations of 2D tissue-marked echocardiography [4]. Currently, there are few national and international studies on this topic. As a result, we conducted this study with the following objectives: *Evaluation of the left ventricular torsion deformation in patients with chronic heart failure using 3D speckle tracking echocardiography.*

2. Subject and method

The study included 110 patients with chronic heart failure and 50 healthy people without heart disease of similar age, gender, height, and weight. From January 2018 to December 2020, all subjects were treated at 108 Military Central Hospital.

Selection criteria: The patient was diagnosed with heart failure in accordance with the 2016 European Society of Cardiology recommendation [5].

Exclusion criteria: Patients with atrial fibrillation, atrial flutter, bradycardia less than 50 beats per minute, or tachycardia greater than 100 beats per minute. Congenital heart disease, heart valve disease. Ultrasound cannot be performed on patients who are critically ill. The patient refused to participate in the study. The ultrasound image is blurry and unable to be analyzed.

Deformation parameters evaluation:

All patients were evaluated clinically, and informed consent was obtained for the study. Echocardiography was performed on a Philip EQI 7C ultrasound machine equipped with an X5 matrix probe (Philips Healthcare, the Netherlands): animate recording of basic cross-sections with accompanying electrocardiogram, then transferred to an analysis station equipped with integrated software TOMTEC Arena (Tomtec, Germany). TOMTEC software was used to analyze basic parameters and left ventricular torsion deformation parameters based on a full volume cross section of the entire left ventricle. The following are some of the indicators measured in the study: The EF index is calculated using the Simpson method after measuring the basic ultrasound parameters of the size as recommended by the American Society of Echocardiography. Using 4D analysis software, the full volume analysis of the entire left ventricle automatically provides us with the torsion deformation parameters:

Peak-AR (Apical rotation): Left ventricular apical peak rotation. The degree unit is: (^{0}).

ES-AR (end systolic apical rotation): End-of-systolic rotation of the left ventricular apex. The measurement is in degrees: (^{0}).

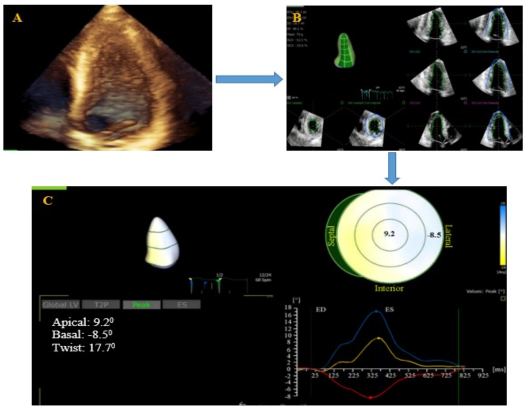
Peak-BR (Basal rotation): Left ventricular base peak rotation. The measurement is in degrees: (^{0}).

ES-BR (end systolic basal rotation): The rotation of the left ventricular base at the end of systole. The degree unit is used: (^{0}).

Peak-Twist: Left ventricular rotation peak angle. The measurement is in degrees (^{0}). The difference between the peak torsion of the base and the peak torsion of the left ventricular apex is calculated.

ES-Twist: At the end of systole, the left ventricle rotates. The measurement is in degrees (^{0}).

T (Torsion): Torsion of the left ventricle. The unit is ^{0}/m. Calculated by dividing the left ventricular torsion angle by the length of the left ventricle from base to apex.



Assessment of left ventricular torsion

Data analysis:

We process data using SPSS 22.0 software; quantitative variables are expressed as mean ± SD, and qualitative variables are expressed as percentages (%). The t-Student test was used to compare quantitative variables, and the chi-squared algorithm was used to compare qualitative variables. A $p<0.05$ value was considered statistically significant.

3. Result

Table 1. General characteristics of the patient group

Characteristics	Heart failure group (n = 110)	Control group (n = 50)	p
Average age (years)	65.82 ± 11.77	65.16 ± 10.24	>0.05
Male, n (%)	73 (66.36%)	34 (68.0%)	>0.05
Female, n (%)	37 (33.64%)	16 (32.0%)	>0.05
Weight (kg)	58.29 ± 10.67	59.46 ± 9.34	>0.05
Height (kg)	1.60 ± 0.07	1.62 ± 0.06	>0.05
BMI (kg/m^2)	22.7 ± 3.53	22.7 ± 3.07	>0.05
NT-pro BNP (pg/ml)	3467.06 ± 6669.69		

There were no differences in age, gender, height, or weight between the heart failure and control groups.

Table 2. Prevalence of diastolic dysfunction in heart failure group

Diastolic dysfunction	Heart failure group (n = 110)	
	n	Percentage %
Grade I	64	58.2
Grade II	28	25.4
Grade III	18	16.4
Total	***110***	***100.0***

Table 3. The comorbidities disease prevalence in the heart failure group

Background diseases	Heart failure group n = 110		Heart failure group with EF Simpson's ≥ 50% (n = 30)	
	n	Percentage %	n	Percentage %
Coronary artery disease	54	49.1	22	73.3
Hypertension	82	74.5	27	90.0
Type 2 diabetes mellitus	37	33.6	13	40.0

Table 4. Characteristics of left ventricular torsion motor parameters in heart failure patients

Parameters	Heart failure group (n = 110)	Control group (n = 50)	p
Peak-AR (^{0})	4.56 ± 2.96	10.41 ± 3.06	<0.001
ES-AR (^{0})	3.82 ± 2.94	9.24 ± 3.09	<0.001
Peak-BR (^{0})	-4.04 ± 2.25	-8.97 ± 2.75	<0.001
ES-BR (^{0})	-3.16 ± 2.22	-7.66 ± 2.64	<0.001
Peak-Twist (^{0})	7.94 ± 4.28	18.99 ± 4.28	<0.001
ES-Twist (^{0})	6.16 ± 4.63	16.84 ± 4.21	<0.001
Torsion (^{0})	1.01 ± 0.56	2.42 ± 0.60	<0.001

When compared to the control group, the absolute values of left ventricular rotation parameters were lower in the heart failure group. The time parameters AR-time, BR-time, and T-time of the two groups did not differ statistically.

Table 5. Characteristics of left ventricular torsion motor parameters in the heart failure group with EF (Simpson's) ≥ 50% compared to the control group

Parameters	Heart failure group EF (Simpson's) ≥ 50% (n = 30)	Control group (n = 50)	p
Peak-AR (^{0})	6.63 ± 2.49	10.41 ± 3.06	<0.05
ES-AR (^{0})	5.42 ± 2.93	9.24 ± 3.09	<0.05
Peak–BR (^{0})	-5.02 ± 3.04	-8.97 ± 2.75	<0.05
ES-BR (^{0})	-4.54 ± 2.59	-7.66 ± 2.64	<0.05
Peak-Twist (^{0})	10.96 ± 4.74	18.99 ± 4.28	<0.05
ES-Twist (^{0})	9.39 ± 4.97	16.84 ± 4.21	<0.05
Torsion (^{0})	1.46 ± 0.60	2.42 ± 0.60	<0.05

The absolute values of left ventricular torsion deformatoin parameters were ≥ 50% lower in the EF Simpson's heart failure group than in the control group.

Table 6. Characteristics of left ventricular torsion deformation in heart failure patients

	EF < 40% (n = 50)	40%≤EF≤49% (n = 30)	EF ≥ 50% (n = 30)	p
Peak-AR (^{0})	2.95 ± 2.11	5.19 ± 3.16	6.63 ± 2.49	<0.05
ES-AR (^{0})	2.87 ± 2.13	3.83 ± 3.46	5.42 ± 2.93	<005
Peak–BR (^{0})	-3.46 ± 1.69	-4.04 ± 1.84	-5.02 ± 3.04	<0.05
ES-BR (^{0})	-2.47 ± 1.58	-2.94 ± 2.16	-4.54 ± 2.59	<0.05
Peak-Twist (^{0})	5.89 ± 2.79	8.34 ± 4.05	10.96 ± 4.74	<0.05
ES-Twist (^{0})	4.25 ± 2.96	6.13 ± 4.88	9.39 ± 4.97	<0.05
Torsion (^{0})	0.72 ± 0.35	1.05 ± 0.51	1.46 ± 0.60	<0.05

**ANOVA analysis revealed group differences.*

The absolute value of left ventricular torsion parameters gradually decreased from heart failure with EF ≥ 50% to heart failure with a slight decrease in ejection fraction to heart failure with EF < 40%.

Table 7. Characteristics of left ventricular strain parameters based on diastolic dysfunction

Parameters	Diastolic dysfunction			p
	Grade I (n = 64)	Grade II (n = 28)	Grade III (n = 18)	
Peak-GLS (%)	-12.18 ± 4.05	-9.79 ± 2.63	-8.77 ± 2.99	<0.001
ES-GLS (%)	-11.73 ± 419	-9.24 ± 2.57	-8.11 ± 2.83	<0.001
Peak-GRS (%)	24.52 ± 8.53	19.12 ± 6.56	16.97 ± 6.70	<0.001
ES-GRS (%)	24.09 ± 8.49	18.71 ± 6.41	16.54 ± 6.61	<0.001
Peak-GCS (%)	-17.46 ± 6.89	-13.24 ± 5.73	-11.87 ± 5.81	<0.01
ES-GCS (%)	-16.90 ± 6.86	-13.03 ± 5.75	-11.61 ± 5.74	<0.01
Peak-GAS (%)	-21.19 ± 7.22	-16.20 ± 5.86	-14.48 ± 5.85	<0.001
ES-GAS (%)	-20.97 ± 7.25	-16.03 ± 5.89	-14.22 ± 5.84	<0.001

**ANOVA analysis revealed group differences.*

From the group of heart failure with grade I diastolic disorder to the group of heart failure with grade III diastolic disorder, the absolute value of the parameters of left ventricular strain decreased statistically significantly.

Table 8. Correlation between left ventricular torsion parameters and Simpson's EF in the heart failure group

Parameters (n = 110)	r	p	Regression equation
Peak-AR (^{0})	0.59	<0.05	Peak-AR = -2.27 + 0.121*EF
ES-AR (^{0})	0.45	<0.05	ES-AR = 0.215 - 0.091*EF
Peak-BR (^{0})	-0.31	<0.05	Peak-BR = -2.11 - 0.048*EF
ES-BR (^{0})	-0.39	<0.05	ES-BR = -0.79 - 0.059*EF
Peak-Twist (^{0})	0.56	<0.05	Peak-Twist = 1.28 + 0.166*EF
ES-Twist (^{0})	0.54	<0.05	ES-Twist = 0.65 + 0.17*EF
Torsion (^{0})	0.62	<0.05	Torsion = 0.049 + 0.024*EF

Torsrion and EF had a strong positive correlation (r = 0.62; p<0.05). Peak-AR (r = 0.59; p<0.05) and Peak-Twist (r = 0.56; p<0.05) had a moderately positive correlation with ejection fraction. Peak-BR had a weak negative correlation with ejection fraction EF (r = -0.31; p<0.05).

Table 9. Correlation between left ventricular torsion parameters and 2D-GLPS in heart failure patients

Parameters (n=110)	r	p	Regression equation
Peak-AR (^{0})	-0.52	<005	Peak-AR = 0.24-0.42*GLPS
ES-AR (^{0})	-0.41	<0.05	ES-AR = 0.47-0.32*GLPS
Peak-BR (^{0})	0.21	<0.05	Peak-BR = -2.75+0.13*GLPS
ES-BR (^{0})	0.36	<0.05	ES-BR = -0.94+0.22*GLPS
Peak-Twist (^{0})	-0.48	<0.05	Peak-Twist = 2.24–0.55*GLPS
ES-Twist (^{0})	-0.48	<0.05	ES-Twist = -0.01-0.60*GLPS
Torsion (^{0})	-0.51	<0.05	Torsion = -0.20–0.08*GLPS

Peak-AR (r = -0.52; p<0.05), Twist (r = -0.48; p<0.05), and Torsion (r = -0.51; p<0.05) had a moderate negative correlation with *GLPS*. Peak-BR had a weak positive correlation with *GLPS* (r = 0.21; p<0.05).

4. Discussion

Lichard Lower discovered in 1669 that left ventricular torsion motion resembles the image of a squeegee; the basic mechanism for the formation of this torsion motion is due to the complex architecture of the myocardium, which Steeter and Geenbaum anatomically described [6]. The authors discovered that endocardial muscle fibers rotated to the left by 60 degrees, while epicardial muscle fibers rotated to the right by 60 degrees. As a result, when the heart muscle contracts, it not only shortens along the longitudinal axis and thickens along the horizontal axis, but it also twists and turns around its axis. Torsional locomotion is critical to the mechanical efficiency of the heart, with only 15% contraction of the muscle fibers resulting in a 60% reduction in left ventricular volume [7]. The authors discovered that if the EF is simply muscle contraction, the EF is only 15-28%, but the average person's true EF is 60-70% due to the contribution of torsion motion [8]. Because the heart muscle has a complex structure, when it contracts, it will move in different directions in 3D space, so evaluating on the 2D plane will be inaccurate because some elements will move out of the plane 2D, resulting in skewed results. These disadvantages of 2D STE ultrasound are overcome by 3D STE ultrasound, which allows assessment of myocardial deformations in different directions in 3D space. Many studies have shown that 3D STE is more accurate, time efficient, and effective than 2D STE [9].

Using 3D STE to assess torsional deformation in heart failure patients, we discovered that torsion deformation parameters such as apex rotation, base rotation, left ventricular rotation angle, and left ventricular torsion were significantly lower in the heart failure group compared to the control group. When we examined left ventricular torsion motor parameters in the heart failure group with EF ≥ 50%, we discovered that they were lower than in the control group. Peak apical rotation angle (6.63 ± 2.49^0 vs. 10.41 ± 3.06^0; p<0.05), top apical rotation angle (-5.02 ± 3.04^0 vs -8.97 ± 2,75^0; p<0,05), peak left ventricular rotation (10.96 ± 4.74^0 vs. 18.99 ± 4.28^0; p<0.05), left ventricular torsion (1.46 ± 0.60^0 vs 2.42 ± 0.60^0; p<0.05).

Yip et al. discovered that torsion angle and left ventricular torsion were reduced in both heart failure groups compared to controls using 2D STE ultrasound in 112 patients with heart failure with preserved ejection fraction and 175 patients with heart failure with reduced ejection fraction compared to 63 healthy subjects [10]. Wang et al. compared 50 heart failure patients (20 with preserved ejection fraction and 30 with reduced ejection fraction) to 17 patients using 2D STE. Normally, in the heart failure group, left ventricular strain and torsion decreased while the ejection fraction decreased, but in the heart failure group, the ejection fraction was preserved while only longitudinal strain and radial strain decreased. When compared to healthy controls, there was no difference in left ventricular circumference or torsion [11]. This difference is due to the study subjects; our heart failure group was older on average than the author Wang group (65.82 ± 11.77 vs. 58 ± 16). Furthermore, Wang's study subjects had no age group similarity, with the heart failure group having a higher mean age than the control group (58 ± 16 versus 42 ± 11). Our heart failure group's mean EF ≥ 50% is lower than that of the author Wang group (57.93 ± 7.47 vs. 63 ± 6). In our study group, the prevalence of coronary artery disease and hypertension was high, and the combined incidence of hypertension, diabetes, and coronary artery disease was also high. Our group of heart failure EF ≥ 50% patients had a relatively high rate of coronary artery disease (73.3%), hypertension (90%) and diabetes (40.0%), with two co-morbidities. Patients with hypertension, diabetes, and coronary artery disease account for 76.7% (Table 3), and up to 100% of patients have diastolic dysfunction from grade I, indicating that there are significant risks. It is possible that our study group had myocardium damage in the deep layers. Furthermore, our study using 3D STE to evaluate left ventricular torsion motor has more advantages than 2D STE, providing more accurate values. Because when using 2D STE to evaluate torsion motion, we must use cross-sectional and apical views of the left ventricle, which necessitates a good and standard cross-section, especially for transaortic views when the transducer is in place. Different locations will yield different results, and when analyzing the 2D STE measurement results, structures that move out of the plane may cause the results to be inaccurate [12].

Left ventricle torsion deformation is dependent on abnormalities in the myocardial structure, or the ability of the heart muscle to contract, in addition to factors such as heart burden, age, and gender. Myocardial hypertrophy in hypertensive patients increases the difference in endothelial and pericardial radii. As a result, the endocardium's antagonism with the pericardial layer's kinetic moments is reduced, resulting in increased torsion angle and left ventricular torsion at an early stage [12]. For cardiovascular risk factors such as diabetes, hypertension, obesity, lipid metabolism disorders, and so on, which cause collagen cell degeneration, myocardial fibrosis, and endothelial damage., microvascular ischemia initiates damage to the endothelium, reducing endocardium contractility and thus reducing antagonism between the endocardium and the pericardium, resulting in increased left ventricular torsion. The goal of this compensation is to keep the left ventricular ejection fraction within normal limits. Detorsion, on the other hand, is always affected, reduced, and prolonged [13]. The progression of left ventricular diastolic dysfunction is represented by untwisting. As the disease progresses, the middle layer and muscle pericardium are gradually damaged, reducing the torsion movement of the left ventricle. Our study discovered a reduction in torsional motor parameters in the heart failure group with a lower ejection fraction, which may also be seen in the heart failure group with an EF ≥ 50%. Torsional motor parameters gradually decreased from heart failure with EF ≥ 50% to heart failure with intermediate ejection fraction and finally to heart failure with reduced ejection fraction with EF < 40%. As a result, our heart failure group had damage to the deeper layer of the myocardium. In addition, we discovered that left ventricular torsion motor parameters were moderately correlated with left ventricular ejection fraction, as measured by 3D speckle tracking echocardiography. The researchers also discovered that left ventricular torsion and rotation angle were indicators of left ventricular function. Kim et al discovered a correlation between left ventricular torsion deformation and EF: peak-AR ($r=0.47$, $p<0.05$), peak-BR ($r=-0.14$, $p<0.05$), and Torsion ($r=0.56$, $p<0.05$) [15]. Thus, ejection fraction is strongly correlated with apical rotation, rotation, and left ventricular torsion. Furthermore, the peak basal rotation angle has a weak negative correlation with EF. Many studies have demonstrated that axial tension measured on 2D speckle tracking echocardiography is a highly sensitive parameter for assessing left ventricular function. Peak-AR ($r = -0.52$; $p<0.05$), Twist ($r=-0.48$; $p<0.05$), and Torsion ($r = -0.51$; $p<0.05$) have moderate inverse correlations with global longitudinal peak strain measuring 2D speckle tracking echocardiography, while Peak-BR ($r=0.21$; $p<0.05$) has a weak positive correlation with 2D GLPS.

As a result, while the left ventricular torsion parameters determined by the disease process are the final parameters of damage, they are also quite sensitive parameters in detecting left ventricular dysfunction even in the early stages of the disease when the ejection fraction remains normal.

5. Conclusion

3D speckle tracking echocardiography is a safe and effective method for assessing left ventricular torsion deformation in chronic heart failure patients.

Torsional deformation parameters of the left ventricle were lower in heart failure patients compared to controls, and they changed earlier in the group with preserved ejection fraction. Torsion deformation parameters, despite being the last variable parameter, are still quite sensitive in detecting left ventricular dysfunction.

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