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Assessment of the left ventricular systolic function in multi-vessel coronary artery disease with normal wall motion by two-dimensional speckle tracking echocardiography

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Abstract. – OBJECTIVE: To evaluate the clinical value of two-dimensional speckle tracking echocardiography for analyzing the left ventricular systolic function in patients with multi-vessel coronary artery disease with normal wall motion (NWM-MVD).

PATIENTS AND METHODS: Forty-five NWM-MVD patients and thirty-six subjects with low risk of coronary artery disease (control group) were enrolled in this study. Echocardiogram images of the short axis of the left ventricle and apical long axis were obtained. The Q-analysis software was used to analyze the peak systolic strain of the left ventricular segments and the global longitudinal strain (GLS). We calculated the left ventricular global circumferential strain (GCS) and the radial strain (GRS), as well as the longitudinal, radial and circumferential strain of the basal (Bas-GLS, Bas-GCS, Bas-GRS), middle (Mid-GLS, Mid-GCS, Mid-GRS) and apical segments (Ap-GLS, Ap-GCS, Ap-GRS).

RESULTS: (1) The coronary occlusion or subtotal occlusion were visible in 85.71% of the NWM-MVD patients. (2) The heart rate of the NWM-MVD patients was lower than that of the control group [(61.78 ± 6.76) beats/min vs. (66.13 ± 6.24) beats/min, $p < 0.05$]. The conventional ultrasonic measurement indices are similar between the NWM-MVD group and the control group ($p > 0.05$). (3) Compared with the control group, the GLS, Bas-GLS, Mid-GLS, Bas-GCS, Mid-GCS, GRS and Bas-GRS were lower in the NWM-MVD group ($p < 0.05$).

CONCLUSIONS: The longitudinal, circumferential and radial systolic functions of the NWM-MVD patients were impaired at different degrees.

Key Words:
Speckle tracking echocardiography, Ventricular function, Multi-vessel Coronary artery disease.

Introduction

Cases like atherosclerosis involving all major coronary arteries which leads to severe decrease of blood flow are common[1-3]. It is labeled as multi-vessel coronary artery disease (MVD), since the diameter stenosis of the two main coronary arteries or their main branch (lumen) is at 50%[4-6] or greater. Studies have shown that the six-year survival rate after treatment of triple-vessel coronary artery disease patients whose wall motion score is between 16-30 is 63%. However, the rate of patients with normal wall motion is up to 90%, which is both significantly higher that of the drug treatment group. Therefore, early detection of MVD especially changes to the cardiac morphology and function is of great importance for MVD patients[7]. Normal wall motion (NWM) at rest indicates that normal myocardial function is lower than the threshold value of the abnormal wall motion. As traditional echocardiography has certain limitations on the evaluation of myocardial function, this study aims to evaluate 2D-STI technology in early detection of myocardial systolic function changes in NWM-MVD patients.

Patients and Methods

Subject of Study

Forty-five NWM-MVD patients were randomly selected from our hospital. There were 34 male and 11 female patients, aged 44-74. All patients met the following requirements: (1) coronary angiography revealing that the diameter stenosis of the two main coronary arteries or

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their main branch (lumen) is at 70% or greater; (2) at least two experienced echocardiography physicians analyzed patients' wall motion at rest without knowing any prior clinical data to confirm no segmental wall motion abnormality. Patients with acute or obsolete myocardial infarction, severe arrhythmia and severe valvular disease were excluded according to their medical history and relevant examination data.

The control group was made up of randomly selected healthy volunteers whose age and gender matched the patients in the NWM-MVD group. A total of 36 cases, 23 male and 13 female cases, aged 45-81 were selected for the study. Diseases that affect heart function like congenital heart disease, severe valvular disease, severe arrhythmia, myocardial infraction, hyperthyroidism were ruled out according to the patients' medical history. Regular physical examination and relevant auxiliary analyses (echocardiography, electrocardiogram, chest X-ray) were performed.

Instruments and Methods

The GE Vivid 7 Dimension diasonograph, M3S probe (1.5-4.0 MHz) was used to record the heart rate. The left ventricular end-diastolic diameter (LVEDD) and left atrial end-systolic diameter (LAD) were measured by the parasternal long axis view of the left heart. The left ventricular ejection fraction (LVEF) was captured by M type echocardiography and the E peak velocities (E) and A peak velocities (A) of the mitral valve flow by apical four chamber view and the E/A value were calculated. Early and late peak motion rate of the ventricular septum basal segment e and a was measured by Tissue Doppler and the e/a value was calculated. The left ventricular isovolumic relaxation time (IVRT), left ventricular ejection fraction was measured using the biplane Simpson method (Simpson's LVEF).

Stable two-dimensional dynamic gray scale images of the three cardiac cycles from the mitral valve, papillary muscle and apical levels of the left ventricular parasternal short axis, apical four chamber, long axis of the left heart and apical two-chamber were taken. The images were imported to the Echo PAC workstation and were divided into 18 segments using the Q-analysis software. The image phase was adjusted to outline the endocardial border in the end-systole manually. Two-dimensional speckle tracking software captured the strain curve of the myocardial segments, and the longitudinal, radial, circumferential systolic strain and left ventricular global longitudinal strain (GLS) were recorded. We calculated the left ventricular global circumferential strain (GCS, the average of circumferential strain of 18 segments), radial strain (GRS, the average of radial strain of 18 segments), and the longitudinal, radial and circumferential strain of the basal (Bas-GLS, Bas-GCS, Bas-GRS), middle (Mid-GLS, Mid-GCS, Mid-GRS) and apical segments (Ap-GLS, Ap-GCS, Ap-GRS) (the average of longitudinal, radial and circumferential strain of six basal, middle and apical segments).

Statistical Analysis

Statistical analysis software PASW Statistics 18.0 was used for the analysis. All measurement data is represented by average ± standard deviation (± s). Comparison between the NWM-MVD group and the control group was performed using the independent sample *t*-test. Count data rate indicates the comparison between the two groups by chi-square test. A $p < 0.05$ values signifies that the difference is statistically significant.

Results

Results of Coronary Angiography

Among the 45 patients in the NWM-MVD group, there are 29 patients with triple vessel lesions (Figure 1), 16 patients with two-vessel lesions. Of which, 21 patients had primary lesions in the right coronary artery, 24 patients had primary lesions in the left coronary artery. Of the 45 patients in the NWM-MVD group, 21 patients had coronary occlusion or subtotal occlusion, 14 patients had right coronary occlusion, 5 patients with anterior descending artery occlusion, 2 patients with circumflex coronary occlusion.

General Clinical data

Compared with control group, there are more patients in the NWM-MVD group whose BMI ≥ 24 kg/m^2. Their heart rate is significantly slower [(62.00 ± 6.69) beats/min *vs.* (65.74 ± 6.28) beats/min, $p < 0.05$] and the sinus bradycardia is more prevalent (16/45 *vs.* 5/36, $p < 0.05$). There is no remarkable difference of age and gender between the two groups. Results are shown in Table I.

Conventional Ultrasonic Measurement Index

There is no significant difference ($p > 0.05$) between the NWM-MVD group and the control

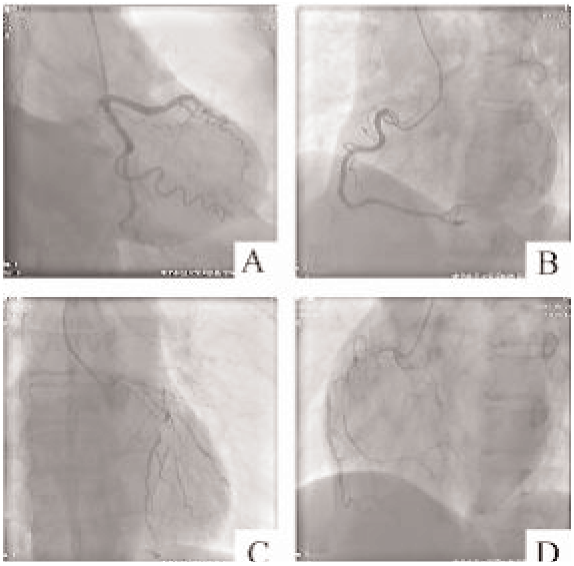

Figure 1. Coronary angiography imaging of control group *(A-B)* and NWM-MVD group *(C-D)*. A and B show respectively left coronary angiography imaging of control group and NWM-MVD group; B and D show respectively right coronary angiography imaging of control group and NWM-MVD group.

group in the left atrial end-systolic diameter (LAD) and the left ventricular end-diastolic diameter (LVEDD). The left ventricular systolic function pump index-M type ultrasonic measurement of the left ventricular ejection fraction (LVEF) and the Simpson's LVEF measured by Simpson method are both normal (EF > 50%). The wall motion score of each segment is one point and there's no significant difference between the two groups ($p > 0.05$). There is no statistically significant difference between the two groups in terms of measurement indices of the left ventricular diastolic function—-E/A, e/a and IVRT. The results are shown in Table II.

Measurement of Left Ventricular Systolic Peak Strain by Two-Dimensional Speckle Tracking Imaging

The comparison of the left ventricular systolic peak strain between the NWM-MVD group and the control group shows that the strains of the NWM-MVD group are lower than that of the control group except for the Ap-GCS (Figure 2). The differences of GLS, GRS, Bas-GLS, Bas-GCS, Bas-GRS, Mid-GLS, Mid-GCS between the two groups have statistical significance ($p < 0.05$). Results are shown in Table III.

Discussion

Traditional echocardiography is a method of assessing wall motion by observing the systolic endocardial motion range and wall thickening rate[8-10]. However, wall thickening rates only reflect myocardial radial motion and cannot fully reflect the myocardial function. Only 46.7% (21/45) of the NWM-MVD patients have coronary occlusion or subtotal occlusion. However, the left ventricular end-diastolic diameter, left ventricular ejection fraction and wall motion score are similar to that of the control group[11,12].

Measurement of the longitudinal, radial and circumferential strain of the myocardium by speckle tracking imaging (STI) technology can avoid the influence of subjective factors and heart motion, and evaluate local and overall systolic function of the left ventricle from multiple angles. A study by Liang et al[13-15] has shown that when the coronary heart disease patients are at rest, the myocardial systolic peak strain rate of the coronary blood-supply segments of which the stenosis is more than at 70%, is much lower than that of other normal segments. A study by Li Yan et al[16-18] has shown that when coronary stenosis is at 70% or less, the longitudinal strain of the blood-supply segments de-

Table I. Comparison of the clinical data between NWM-MVD group and control group.

Parameter	Control group	NWM-MVD group	*p*-value
Age (year)	60.25±9.45	60.91 ± 7.39	0.732
Male ratio (number, %)	23 (63.9%)	34 (75.6%)	0.253
BMI24 ≥ 24 kg/m^2	7 (19.4%)	19 (42.2%)*	0.029
Heart rate (beats/min)	65.74 ± 6.28	62.00 ± 6.69*	0.014
Bradycardia (number)	5 (13.9%)	16 (35.6%)*	0.027

BMI: Body Mass Index; *means that there is statistically significant differences between NWM-MVD group and control group.

Table II. Comparison of conventional ultrasonic measurement index between NWM-MVD group and control group.

Parameter	Control group	NWM-MVD group	*p*-value
LAD (mm)	33.91 ± 3.12	35.07 ± 3.70	0.143
LVEDD (mm)	46.26 ± 2.27	47.16 ± 2.36	0.090
LVEF (%)	65.26 ± 4.74	65.53 ± 4.12	0.781
Simpson's LVEF (%)	65.28 ± 3.55	65.51 ± 3.55	0.770
E/A <1	19 (52.8%)	31 (68.9%)	0.138
e/a <1	24 (66.7%)	35 (77.8)	0.264
IVRT (ms)	75.43 ± 24.02	79.97 ± 17.32	0.386

LAD: left atrial diameter; LVEED: left ventricular end-diastolic diameter; LVEF: M type ultrasonic measurement of left ventricular ejection fraction; Simpson's LVEF: left ventricular ejection fraction by biplane Simpson method; E/A: mitral valve early-diastolic flow velocity/late-diastolic flow velocity; e/a: ventricular septum basal segment early-diastolic motion rate/late-diastolic motion rate; *means that there is statistically significant difference between NWM-MVD group and control group.

creases. When coronary stenosis is above 70%, the longitudinal, circumferential and radial strain decrease. Results of this study show that the GLS, GRS, Bas-GLS, Bas-GRS, Bas-GCS, Mid-GLS, Mid-GCS of the NWM-MVD group are lower than the control group ($p < 0.05$), indicating that myocardial systolic function of the NWM-MVD patients is impaired at various degrees.

Severe impairment of the longitudinal systolic function may be related to myocardial fiber arrangement and perfusion characteristics. The blood vessels that supply the left ventricular subendocardial myocardium are the main branches, flowing vertically into the myocardium from the epicardial coronary arteries[19-21]. As most branches of coronary blood vessels are deep in the myocardium, the heart exerts oppression on the blood vessels when contracting, and influence on deep coronary blood flow is much more visible, causing significant increase of blood-supply resistance of subendocardial myocardium[22]. Left ventricular longitudinal motion is produced by the contraction of the longitudinal myocardial fibers under the endocardium. Thus, the endocardial myocardium is the most vulnerable when coronary blood flow decreases[23].

The reason behind severe myocardial ischemia of the basal segment than apical and middle segments may be because the proximal coronary artery is closer to the ventricle and bears maximum systolic pressure. Thus, it is exposed more easily to atherosclerotic plaque. When coronary artery disease progresses to a certain degree (> 50%), the small arteries of which distal stenosis is at less than 300 um start compensatory dilatation reducing capillary resistance, and increasing coronary blood flow[24,25]. Also, another reason is that cases of collateral branches are mostly formed by blockage or subtotal blockage of the coronary distal end.

Table III. Comparison of the strain parameters between the NWM-MVD group and control group.

Strain (%)	Control group	NWM-MVD group	*p*-value
GLS	-21.650 5 ± 1.718 6	-20.050 6 ± 2.054 8*	0.000
Bas-GLS	-20.106 5 ± 2.109 3	-17.921 0 ± 1.866 1*	0.000
Mid-GLS	-21.239 0 ± 1.708 2	-19.852 6 ± 1.730 1*	0.001
Ap-GLS	-24.690 4 ± 3.475 2	-24.344 8 ± 4.393 6	0.701
GCS	-24.051 7 ± 3.479 7	-23.114 0 ± 3.029 7	0.202
Bas-GCS	-21.915 3 ± 3.423 6	-19.320 2 ± 3.227 6*	0.001
Mid-GCS	-22.817 8 ± 3.831 9	-19.565 6 ± 2.495 2*	0.000
Ap-GCS	-27.161 0 ± 5.818 1	-29.736 9 ± 6.884 0	0.077
GRS	50.744 0 ± 12.427 6	44.008 1 ± 11.425 7*	0.014
Bas-GRS	52.329 5 ± 14.822 5	45.776 6 ± 14.002 4*	0.046
Mid-GRS	58.286 2 ± 17.965 6	52.879 4 ± 19.703 6	0.206
Ap-GRS	41.758 4 ± 22.905 6	32.722 9 ± 20.025 0	0.064

* There is a statistically significant difference between the NWM-MVD group and the control group

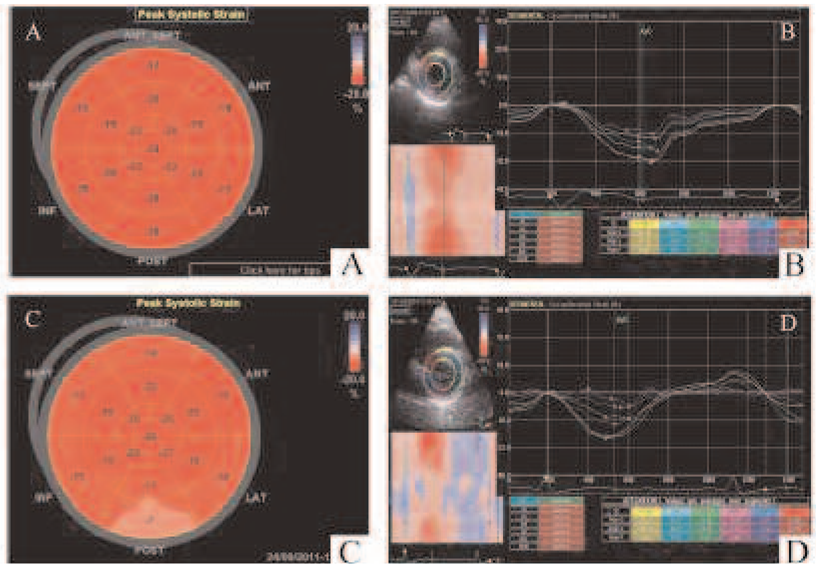

Figure 2. Bovine eye strain diagram and strain curve of control group *(A-B)* and NWM-MVD group *(C-D)*.

Chan et al[26] showed that the radial strain will significantly reduce when the transmural myocardial infarction range is more than 75%. In this study, left ventricular global radial strain (GRS) and radial strain of the basal segment (Bas-GRS) of the NWM-MVD group are lower than that of the control group ($p < 0.05$), indicating that the long-term myocardial blood perfusion has caused local myocardium fibrosis, leading to severe damage of the systolic function.

The study also finds that compared with the control group, the heart rate of patients in NWM-MVD group is significantly slower [(62.00 ± 6.69) beats/min vs. (65.74 ± 6.28) beats/min, $p < 0.05$] and that sinus bradycardia is more common in NWM-MVD group (16/45 *vs.* 5/36, $p < 0.05$). Animal experimental models have confirmed that sinus bradycardia is a good model for coronary arteries. Slower heart rate extends the diastole and increases vascular tangent shear as well as coronary blood flow. These mechanical factors can induce vascular proliferation[27]. Patel et al[28] proved that patients with sinus bradycardia have better collateral development compared with the control group (97% *vs.* 55%, $p < 0.0005$). Moreover, myocardial oxygen consumption is related to left ventricular wall pressure, heart rate and myocardial contractility. Slower heart rate can reduce myocardial oxygen consumption and improve the myocardial tolerance to hypoxia. Therefore, slower heart rate and bradycardia in NWM-MVD patients can be regarded as a kind of compensatory mechanism.

Also, there are more patients in the NWM-MVD group whose BMI ≥ 24 kg/m^2 than the control group (19/45 *vs.* 7/36, $p < 0.05$). This is consistent with some scholars' finding that a BMI ≥ 24 kg/m^2 is a risk factor for high blood pressure, coronary heart disease and diabetes mellitus.

As the sample size is limited, there is no grouping of multi-vessel lesions in this study, such as the presence of collateral circulation, two vessel lesions or triple vessel lesions, which are two vessel lesions and so on; there's no grouping of the stenosis degree of coronary arteries. Moreaver, load test is not carried out in this study. As load test can increase myocardial oxygen consumption, the ischemia detection rate should be higher when combing speckle tracking imaging with load test. STI technology requires clear, high frame frequency two-dimensional ultrasound images. The evaluation of myocardial function in patients with poor acoustic window such as obesity is insufficient.

Conclusions

(1) Visible coronary collaterals in the NWM-MVD patients through coronary angiography can indicate coronary occlusion or subtotal occlusion. (2) Myocardial systolic function of the NWM-MVD patients is impaired at varying degrees, especially for basal systolic function and longitudinal systolic function.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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