Am J Transl Res 2023;15(7):4779-4787
www.ajtr.org /ISSN:1943-8141/AJTR0150939

Original Article

The relationship between CTA performances and cardiac function indicators in myocardial bridge and mural coronary artery

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Received April 27, 2023; Accepted June 26, 2023; Epub July 15, 2023; Published July 30, 2023

Abstract: Objective: To investigate the relationship between computed tomography angiography (CTA) performances and cardiac function indicators in patients with myocardial bridge and mural coronary artery (MB-MCA). Methods: The clinical data of 60 patients with MB-MCA receiving CTA in the First Hospital of Zhangjiakou from January 2021 to February 2022 were analyzed retrospectively. The patients were divided into different groups based on CTA performances, including the degree of stenosis of the left anterior descending (LAD) MCA, whether there was atherosclerosis in the anterior segment of MB of LAD branch, the MB thickness, and the degree of stenosis of the LAD branch. The correlation between these TCA performances and cardiac function indicators including end-systolic volume (ESV), end-diastolic volume (EDV), stroke volume (SV), cardiac output (CO), and left ventricular ejection fraction (LVEF) was analyzed. Besides, the receiver operating characteristic (ROC) curve was used to analyze the predictive performance of cardiac function indicators for the severity of MB-MCA. Results: ESV, EDV, SV, CO and LVEF were statistically different between the moderate stenosis group and mild stenosis group (all $P < 0.05$). EDV, SV, CO, and LVEF were statistically different between the atherosclerosis group and non-atherosclerosis group (all $P < 0.05$). SV, CO, LVEF in the deep group were lower than that in the superficial group (all $P < 0.05$). EDV, CO, LVEF were different between the LAD moderate stenosis group and LAD mild stenosis group (all $P < 0.05$). The AUC (areas under the curve) of combined detection of ESV, EDV, SV, CO, and LVEF in predicting the severity of MB-MCA was 0.907, which was higher than the single indicator predictive effect. Conclusions: Cardiac function indicators, mainly CO and LVEF are correlated with the CTA performance of MB-MCA patients. The combination of cardiac function indicators has a good effect in predicting the severity of MB-MCA.

Keywords: CTA performances, cardiac function indicators, myocardial bridge and mural coronary artery

Introduction

Coronary heart disease (CHD) is a disease endangering human life and health in the world today [1]. The incidence of CHD in China is also on the rise [2]. The etiology of CHD refers to cardiac dysfunction and/or organic lesions. Myocardial bridge (MB) is one of the important causes of coronary artery stenosis and myocardial ischemia [3]. A segment of the coronary artery or its branches is covered by shallow myocardial tissue and runs within the myocardium. This segment of the coronary artery is called the MCA (mural coronary artery), and the myocardium covering this segment of the coronary artery is called MB [4]. MB-MCA is commonly referred to as "MB" in clinical practice. For a long time, MB-MCA has been considered a benign variant that does not affect myocardial blood supply. However, in recent years, with the increasing number of serious cases, such as angina, there is an urgent need to accurately and objectively determine whether MB-MCA causes myocardial ischemia in clinical practice, in order to further understand the pathological and physiological changes of MB-MCA [5]. MB mainly occurs in the middle and far segments of the anterior descending branch. Autopsy, pathological and clinical imaging studies suggest that myocardial bridges have a tendency to cause or accelerate atherosclerosis in the proximal coronary artery [6]. It can be seen that it is very important to detect MB early.

During the contraction and relaxation of the cardiac cycle, the myocardial bridge is also constantly contracting and expanding, while the underlying wall coronary artery is constantly squeezed, especially in the systolic period of the heart; thus, coronary blood flow increases, and rapid blood flow repeatedly washes the vascular wall [7], causing vascular endothelial damage. In this circumstance, platelets easily accumulate, leading to thrombosis, which can cause coronary artery spasm, so that the proximal end of the MCA is in a high pressure state for a long time and there are hemodynamic disorders, thus causing tunica intima damage and secondary atherosclerosis [8]. Related pathological studies have found that atherosclerosis degree in the proximal segment of MB can reach as high as 86%. Therefore, a simple and non-invasive examination method is urgently needed in clinical practice to screen coronary MB [9]. The MB patients without atherosclerosis or asymptomatic MB patients should actively change their bad living habits to prevent the occurrence of coronary atherosclerosis. It's also very important to take early treatment and intervention for patients with atherosclerosis to prevent adverse events such as myocardial ischemia, myocardial infarction and acute coronary syndrome [10]. In the past, coronary angiography (CAG) was believed to be the "gold standard" for diagnosing MB-MCA [11]. However, CAG cannot directly display MB, but indirectly diagnose it through the dynamic narrowing and dilation of the coronary artery diameter [12]. The diagnostic criteria: the presence of typical transient stenosis (linear, beaded, or occlusion-like changes) of the coronary artery in systolic period in at least two projection locations, while the diseased segment completely or partially returns to normal in diastolic period. The typical signs are "milking like performance" or "sucking like change". Therefore, myocardial bridges with mild "milking" effect or even without cannot be displayed and diagnosed. This is related to many factors such as the length and thickness of the myocardial bridge, the positional relationship between the myocardium and the corresponding wall coronary artery, the tissue structure around the coronary artery, imaging techniques, projection position, and observer experience [13]. Therefore, CAG can only detect myocardial bridges that have a significant impact on coronary blood flow. In addition, the examination is invasive with high cost and cannot visually display the presence of myocardial bridges, which is generally not used as routine screening.

Due to certain limitations in the detection of myocardial bridges, a large portion of MB cannot be detected. Many scholars believe that myocardial bridges belong to congenital malformation and do not have certain clinical significance. However, with the rapid development of science and technology, the popularity and application of multi-slice spiral CT (MSCT) have significantly improved the success rate and image quality of coronary artery CT imaging [14]. In recent years, there has been a gradual increase in literature on the use of computed tomography angiography (CTA) to study myocardial bridges. The angina, tachycardia, arrhythmia, acute coronary syndrome, and even sudden cardiac death caused by myocardial bridges have been gradually confirmed [15]. The purpose of this study was to investigate the relationship between CTA performances and cardiac function indicators in the MB-MCA patients.

Materials and methods

General data

Clinical data of 60 patients with MB-MCA receiving CTA in the First Hospital of Zhangjiakou from January 2021 to February 2022 were analyzed retrospectively. Inclusion criteria: (1) Patients with complete clinical data; (2) Patients with an age > 18; (3) Patients with no previous history of allergy to contrast media; (4) Patients with diagnosed MB-MCA [15]; (5) Patients who had received CTA examination. Exclusion criteria: (1) Patients with a history of iodine allergy; (2) Patients with a history of pacemaker replacement, artificial valve replacement, coronary artery bypass grafting, or coronary stent implantation; (3) Patients with a history of old myocardial infarction, myocardial or cardiac valve disease; (4) Patients with congenital heart disease; (5) Patients with arrhythmias; (6) Patients with a history of hypertension of grade 3 or above; (7) Patients with a history of hyperthyroidism and malignant tumors; (8) Poor image quality affected the observation of coronary stenosis, or the endocardial, epicardial and interventricular septum couldn't be clearly delineated. This study was approved by the Ethics Committee of the First Hospital of Zhangjiakou.

Grouping of the patients

Based on the degree of stenosis of the left anterior descending (LAD) MCA, 30 patients with stenosis degree greater than 50% were grouped into the moderate stenosis group, and 30 patients with stenosis degree ≤ 50% were grouped into the mild stenosis group.

Based on whether there is atherosclerosis in the anterior segment of MB of LAD branch, 27 patients were grouped to the atherosclerosis group, and the other 33 patients were grouped to the non-atherosclerosis group.

Based on the MB thickness, 23 patients with MB thickness ≥ 2 mm were grouped into the deep group, and the other 37 patients with MB thickness less than 2 mm were regarded as the superficial group.

Based on the degree of stenosis of the LAD branch, 27 patients with stenosis degree greater than 50% were classified into the moderate LAD stenosis group, and the other 33 patients with stenosis degree ≤ 50% were classified into the mild LAD stenosis group.

CTA examination

CT scanning equipment: Discovery CT750 HD gemstone CT produced by GE company.

CT workstation: GE ADW4.4 image post-processing station.

Scanning protocol: To avoid the impact of rapid heart rate on image quality, patients were instructed to take betaloc 25-75 mg under the guidance of a cardiologist to control their heart rate (prohibited for patients with conduction block). It is best to control the heart rate between 50-70 beats per minute. The patient should arrive at the examination room in advance and rest for at least 15 minutes to ensure a stable heart rate. The patient was told to hold their breath as indicated. Firstly, the scanning of the positioning image was performed to determine the scanning position and scanning range, which typically ranges from the tracheal eminence to 1-2 cm below the septum. The peak enhancement time was determined by pre-scanning, and the scanning delay time was determined based on the time density curve. Enhanced scanning was performed according to the determined scanning range, with a contrast agent dosage of 1-1.5 cm/kg and a speed of 4-6 ml/s. Then, 20-40 mL of physiological saline was added, and the scanning was completed with one breath hold.

Image post-processing

After the completion of scanning, data reconstruction was carried out by the scanning workstation, from 0% to 90% full time phase reconstruction, with an interval of 10%, to obtain 10 sets of data (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%). After the reconstruction, the image was transmitted to the ADW4.4 post-processing workstation for image post-processing. Firstly, the phase of the cardiac cycle that displays the blood vessels most clearly was determined, and then image post-processing was performed. The cardiac functional analysis software and vascular analysis software were used to analyze the MB-MCA and anterior descending artery stenosis, and a number of cardiac function indicators were obtained.

Data of cardiac function

The 10 groups of reconstructed data were imported into the post-processing workstation, and the left ventricular function was analyzed with the AutoEjection Fraction software in the Cardiac software package. The Simpson calculation method was used, and the software automatically detected and delineated the contour edge of the left ventricular endocardium. The blood pool image includes the left Ventricular outflow tract but does not include the larger ventricular papillary muscles. For those with larger deviation in the delineated range, the scope was manually delineated layer by layer. Then, we obtained various index values of cardiac function through software processing, including left ventricular end systolic volume (ESV), left ventricular end diastolic volume (EDV), and stroke volume (SV), cardiac output (CO), and left ventricular ejection fraction (LVEF).

Data confirmation

The analysis of myocardial bridge location, thickness, left coronary artery stenosis loca-

Table 1. The general information in moderate stenosis group and mild stenosis group

Index	Moderate stenosis group (n=30)	Mild stenosis group (n=30)	t/χ^2	P
Age	55.23±4.77	54.63±4.51	0.501	0.618
Gender (male, %)	16 (53.33%)	14 (46.67%)	0.267	0.606
BMI	24.09±0.97	23.82±0.87	1.123	0.266
Course of disease	9.97±2.76	9.83±1.82	0.221	0.826

Note: BMI, body mass index.

Table 2. The general information in atherosclerosis group and non-atherosclerosis group

Index	Atherosclerosis group (n=27)	Non-atherosclerosis group (n=33)	t/χ^2	P
Age	55.44±4.48	54.52±4.74	0.774	0.442
Gender	17 (62.96%)	13 (39.40%)	3.300	0.069
BMI	24.02±0.83	23.91±0.87	0.467	0.642
Course of disease	10.22±2.69	9.64±1.97	0.973	0.335

Note: BMI, body mass index.

Table 3. The general information in deep group and superficial group

Index	Deep group (n=23)	Superficial group (n=37)	t/χ^2	P
Age	54.57±4.74	55.16±4.58	-0.485	0.630
Gender	11 (47.83%)	19 (51.35%)	0.071	0.791
BMI	23.73±0.83	24.10±0.96	-1.515	0.135
Course of disease	9.65±2.74	10.05±2.04	-0.649	0.519

Note: BMI, body mass index.

tion and related data by the above vascular analysis software was completed by two radiologists (Guo and Yan). The diagnosis was determined after consensus, and any disagreement was solved after consulting a higher-level doctor.

Statistical analysis

The left ventricular function data of each group of patients were represented by mean ± standard deviation (x ± s), and analysis was done using SPSS Statistics 21.0 software. Normality tests and homogeneity of variance tests were performed first, followed by one-way ANOVA for statistical analysis. Rank sum tests were used for those with uneven variance. ETA correlation analysis was used to analyze the correlation between CTA performances and cardiac function. Specifically, $0.06 < Eta^2 < 0.16$ represents moderate correlation, $Eta^2 > 0.16$ represents strong correlation, $Eta^2 < 0.06$ represents no correlation. The receiver operating characteristic (ROC) curve was used to analyze the prediction value of cardiac function indicators for the severity of MB-MCA. $P < 0.05$ was regarded with statistical difference.

Results

The general data of patients

As shown in **Tables 1**-**4**, there were no statistical differences in the general data between the moderate stenosis group and mild stenosis group, between the atherosclerosis group and non-atherosclerosis group, between the deep group and superficial group, and between the LAD moderate stenosis group and LAD mild stenosis group (all $P > 0.05$).

The relationship between mural coronary artery stenosis and cardiac function

As shown in **Table 5**, ESV and EDV in the moderate stenosis group was higher than that in the mild stenosis group ($P < 0.05$), while SV, CO, and LVEF in the moderate stenosis group were lower than those in the mild stenosis group ($P < 0.05$). Mural coronary artery stenosis has a moderate correlation with ESV ($0.06 < Eta^2 < 0.16$), and has a strong correlation with EDV, SV, CO and LVEF ($Eta^2 > 0.16$).

The relationship between atherosclerosis and cardiac function

Table 6 shows that there were no differences in ESV and EDV between the atherosclerosis group and non-atherosclerosis group (both $P > 0.05$). In addition, SV, CO, and LVEF in the atherosclerosis group were lower than those in the non-atherosclerosis group (all $P < 0.05$). Atherosclerosis had no correlation with ESV ($Eta^2 < 0.06$), but had a moderate correlation with SV ($0.06 < Eta^2 < 0.16$), and a strong correlation with EDV, CO and LVEF ($Eta^2 > 0.16$).

Table 4. The general information in LAD moderate stenosis group and LAD mild stenosis group

Index	LAD moderate stenosis group (n=27)	LAD mild stenosis group (n=33)	t/χ²	P
Age	54.56±4.49	55.24±4.75	-0.571	0.570
Gender	16 (59.26%)	14 (42.42%)	1.684	0.194
BMI	24.00±1.14	23.92±0.71	0.355	0.724
Course of disease	9.56±2.83	10.18±1.97	-1.041	0.302

Note: BMI, body mass index.

Table 5. The relationship between mural coronary artery stenosis and cardiac function

Index	Moderate stenosis group (n=30)	Mild stenosis group (n=30)	t/χ²	P	Eta²
ESV	76.82±5.42	73.67±6.26	0.072	0.043	0.069
EDV	155.90±9.61	148.07±8.37	3.386	0.001	0.385
SV	70.90±4.50	78.17±4.84	-6.022	< 0.001	0.164
CO	2.79±0.42	4.47±0.36	-16.707	< 0.001	0.828
LEVF	34.73±4.43	53.77±3.65	-18.164	< 0.001	0.850

Note: ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

Table 6. The relationship between atherosclerosis and cardiac function

Index	Atherosclerosis group (n=27)	Non-atherosclerosis group (n=33)	t/χ²	P	Eta²
ESV	75.89±5.23	74.70±6.63	0.761	0.450	0.010
EDV	155.00±9.54	149.52±9.37	0.236	0.529	0.162
SV	71.93±5.19	76.67±5.66	-3.350	0.001	0.079
CO	3.07±0.78	4.09±0.79	-5.036	< 0.001	0.304
LVEF	38.15±7.38	49.24±9.91	-4.821	< 0.001	0.286

Note: ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

Table 7. The relationship between myocardial bridge thickness and cardiac function

Index	Deep group (n=23)	Superficial group (n=37)	t/χ²	P	Eta²
ESV	73.91±5.66	76.05±6.16	-1.349	0.183	0.030
EDV	153.70±11.15	150.92±8.79	1.072	0.288	0.090
SV	72.30±4.71	75.92±6.20	-2.395	0.020	0.019
CO	3.29±0.78	3.85±0.96	-2.326	0.024	0.085
LVEF	40.43±9.27	46.62±10.48	-2.321	0.024	0.085

Note: ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

The relationship between myocardial bridge thickness and cardiac function

The comparison of general data and cardiac function between the deep group and the superficial group is shown in **Table 7**. The result showed that there were no statistical differences in ESV and EDV between the deep group and superficial group (both $P > 0.05$). In addition, SV, CO, and LVEF in the deep group (72.30±4.71, 3.29±0.78, 40.43±9.27) were lower than those in the superficial group (75.92±6.20, 3.85±0.96, 46.62±10.48) (all $P < 0.05$). Myocardial bridge thickness had no correlation with ESV and SV ($Eta^2 < 0.06$), but had a moderate correlation with EDV, CO and LVEF ($0.06 < Eta^2 < 0.16$).

The relationship between stenosis of the LAD branch and cardiac function

The result in **Table 8** shows that there was no difference in ESV and SV between the moderate LAD stenosis group and mild LAD stenosis group (both $P > 0.05$), while EDV in the moderate LAD stenosis groups was higher than that in the mild LAD stenosis group ($P < 0.05$) and the levels of CO and LVEF in the moderate LAD stenosis group were lower than those in the

Table 8. The relationship between stenosis of the LAD branch and cardiac function

Index	LAD moderate stenosis group (n=27)	LAD mild stenosis group (n=33)	t/χ^2	P	Eta^2
ESV	74.85±5.86	75.55±6.22	-0.441	0.661	0.003
EDV	155.48±10.51	149.12±8.21	2.633	0.011	0.051
SV	73.07±5.97	75.73±5.67	-1.761	0.083	0.107
CO	3.28±0.81	3.92±0.94	-2.797	0.007	0.119
LEVF	39.00±8.74	48.55±9.77	-3.992	< 0.001	0.212

Note: ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

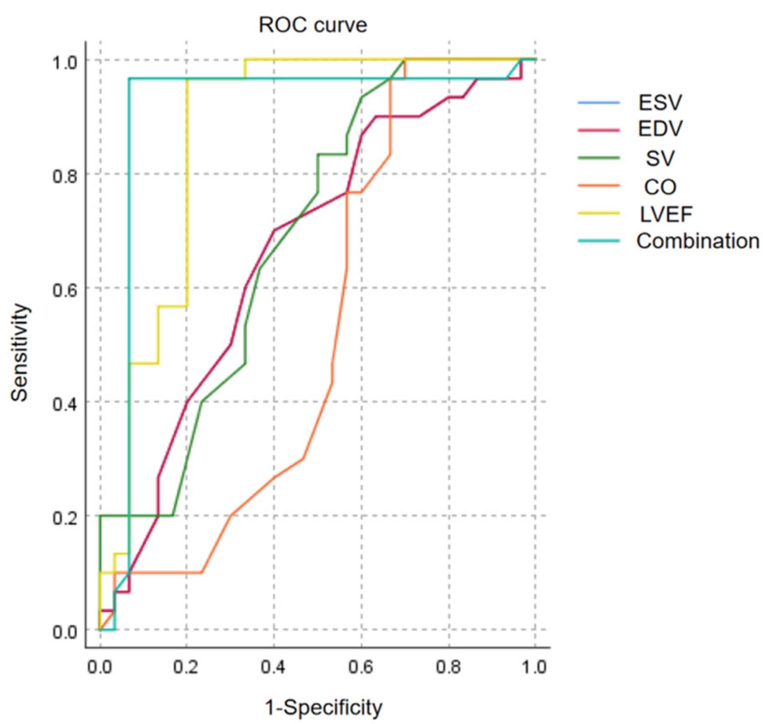

Figure 1. ROC curve analysis of cardiac function indicators for predicting the severity of MB-MCA. Note: BMI, body mass index; ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

Table 9. ROC curve analysis of cardiac function indicators for predicting the severity of MB-MCA

Item	Standard error	AUC	95% CI	Sensitivity (%)	Specificity (%)
ESV	0.071	0.665	0.526~0.804	60.00	66.70
EDV	0.069	0.672	0.523~0.821	70.00	60.00
SV	0.069	0.691	0.557~0.826	63.30	63.30
CO	0.079	0.527	0.372~0.682	76.70	43.30
LVEF	0.050	0.872	0.774~0.970	96.70	80.00
Combination	0.051	0.907	0.806~1.007	96.70	93.30

Note: ESV, left ventricular end systolic volume; EDV, left ventricular end diastolic volume; SV, stroke volume; CO, cardiac output; LVEF, left ventricular ejection fraction.

mild LAD stenosis group (both $P < 0.05$). Stenosis of the LAD branch had no correlation with ESV and EDV (Eta^2 < 0.06), but had a moderate correlation with SV, CO (0.06 < Eta^2 < 0.16), and a strong correlation with LVEF (Eta^2 > 0.16).

The performance of cardiac function indicators in predicting the severity of MB-MCA

The ROC analysis of cardiac function indicators in predicting the severity of MB-MCA is shown in **Figure 1** and **Table 9**. The area under curve (AUC) of ESV, EDV, SV, CO, and LVEF was 0.665, 0.665, 0.691, 0.527, and 0.872 respectively. The predictive performance of each single indicator was lower than that of their combined performance (0.907) ($P < 0.05$). The sensitivity and specificity of the combined prediction was 0.967 and 0.933 respectively.

Discussion

Myocardial bridge (MB) and mural coronary artery (MCA) are two anatomically independent and interdependent structures that are integrated with each other [16]. MB-MCA is more common in the LAD branch, with an average length of 31 mm and an average depth of 12 mm [17]. When the heart contracts, MB compresses MCA, causing stenosis or even occlusion of MCA, resulting in limited local coronary blood flow [18]. However, relevant research shows that MCA is compressed until the early and middle diastole [19]. In addition, MB makes MCA repeatedly compressed and distorted, which easily causes myocardial ischemia and hypoxia due to coronary spasm [20].

In this study, the patients were grouped into a moderate stenosis and a mild stenosis group according to the degree of stenosis of the LAD MCA. The two groups showed statistical differences in terms of ESV, EDV, SV, CO, and LVEF. The increased left ventricular EDV is not proportional to the cardiac ejection fraction, which can indirectly reflect the weakened ventricular systolic function. Therefore, we can conclude that the moderate stenosis group has a greater impact on cardiac function.

Again, the patients were divided into groups according to whether there was atherosclerosis in the anterior segment of MB of LAD branch [21]. The two groups showed statistical differences in terms of EDV, SV, CO, LVEF. This indicates a relationship between atherosclerosis and cardiac function [22].

According to the thickness of the left anterior descending myocardial bridge, the patients were divided into two groups: the superficial and deep group. We can see that the two groups showed significant differences in terms of SV, CO, and LVEF. The impact of superficial myocardial bridges on cardiac function is inconsistent with the literature [23]. The reasons may include: 1. Poor filling of coronary contrast media causes difficulty in distinguishing myocardial density and measurement errors in myocardial bridge thickness. 2. Motion artifacts affect the accuracy of the data. 3. The density difference between the heart cavity and the cavity wall is small, and the endocardium is not accurately delineated. The results suggest that myocardial bridge thickness ≥ 2 mm has a significant impact on SV, CO, and LVEF.

According to the degree of stenosis of simple LAD artery atherosclerosis, the patients were divided into the LAD mild stenosis group and LAD moderate stenosis group. The two groups showed statistical differences in terms of EDV, CO and LVEF, but no significant difference in the other cardiac indicators. This indicates that the more severe the stenosis of simple LAD artery atherosclerosis, the greater the impact on left ventricular systolic function [24]. In addition, the ROC analysis showed that the combination of ESV, EDV, SV, CO, and LVEF in predicting the severity of MB-MCA was higher than the single indicator predictive effect.

However, there are some limitations in our study. Firstly, retrospective electrocardiographic gating technology is applied during CT scanning, and data from various stages of the entire cardiac cycle were reorganized. For patients with irregular or fast heart rates, medication was applied to control their heart rate. Patients who could not cooperate with breathing during the examination had more obvious artifacts, which makes the measured data inaccurate. Secondly, the number of cases in the left anterior descending myocardial bridge and severe LAD atherosclerotic stenosis group is too small, so the sample size needs to be increased in the subsequent research to reduce sampling error. Due to the limited number of cases, further sub-grouping studies were not conducted on the predilection sites for LAD artery myocardial bridge and LAD artery stenosis in the study.

In summary, cardiac function indicators, mainly CO and LVEF, are correlated with the CTA performance of MB-MCA patients. The combination of cardiac function indicators has a good effect in predicting the severity of MB-MCA.

Acknowledgements

This work was supported by Zhangjiakou Science and Technology Bureau (No. 2021-019D).

Disclosure of conflict of interest

None.

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