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Analysis of Influencing Factors of Surgical Options for Coronary Atherosclerotic Heart Disease Complicated with Moderate Ischemic Mitral Regurgitation

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ABSTRACT

Background: There are several controversies regarding the surgical approach for patients with coronary atherosclerotic heart disease (CAHD) complicated with moderate ischemic mitral regurgitation (IMR).

Methods: A retrospective study was performed among 115 patients divided into two groups. Clinical and echocardiographic parameters, including perioperative indexes and follow ups, degree of stenosis in the coronary arteries, and cardiac function index, were analyzed. Patients who died in the hospital due to complications during the perioperative period were defined as the deterioration group (deterioration of coronary artery bypass grafting, CABG vs. deterioration of coronary artery bypass grafting combined with mitral valve surgery, CABG+MVS: *N* = 7, 58.3% vs. *N* = 5, 41.7%), whereas the remaining patients were defined as the rehabilitation group (rehabilitation of CABG vs. rehabilitation of CABG+MVS: *N* = 52, 50.5% vs. *N* = 51, 49.5%). Data were compared between the rehabilitation of the CABG and CABG+MVS groups to explore the predictors for surgical method selection.

Results: Postoperative patients who died during hospitalization were excluded (*N* = 12). At 1-year follow up, there were 52 patients in the CABG rehabilitation group and 51 in the CABG+MVS rehabilitation group. During the follow-up period, 10 patients died (rehabilitation of CABG vs. rehabilitation of CABG+MVS: *N* = 7, 13.7% vs. *N* = 3, 5.8%). Nevertheless, the difference was not statistically significant. The logistic regression analysis identified four independent factors when choosing the surgical modality: prior-myocardial infarction (prior-MI), preoperative atrial fibrillation (pre-AF), and the stenotic degree of the left circumflex (LCX) and left main (LM) arteries.

Conclusions: Prior-MI, pre-AF, and the degree of stenosis in LCX and LM could influence the choice of surgical method. This study provided new insights into the treatment of CAHD with moderate IMR.

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INTRODUCTION

Ischemic mitral regurgitation (IMR) is secondary mitral regurgitation induced by coronary stenosis or occlusion. At present, the principal mechanism leading to ischemic mitral regurgitation is valve movement restriction, due to papillary muscle displacement, papillary muscle dysfunction, mitral valve annulus enlargement, changed in the mitral valve saddle structure, decreased left ventricular systolic force, and asynchronous contraction of the left ventricle. An increasing body of evidence established that about 40% of IMR patients die from myocardial infarction (MI) associated with ventricular remodeling caused by chronic myocardial ischemia [Xu 2015; Shen 2019].

As is well-established, surgery is the primary treatment for CAHD with IMR. There was a broad consensus on the treatment options for mild and severe mitral regurgitation, namely coronary artery bypass grafting alone for mild regurgitation and coronary artery bypass grafting combined with mitral valve replacement or repair for severe regurgitation. However, the optimal surgical approach for CAHD complicated with moderate IMR remains controversial. Previous research reported that CABG alone had a low postoperative complication rate, favorable long-term efficacy, and significantly improved myocardial ischemia, thereby reducing valvular regurgitation. Nonetheless, it had been reported that concurrent MVS could further reduce the degree of mitral regurgitation and mortality [Zhang 2019].

Buja et al. reported significant differences in left ventricular end-diastolic volume index, left ventricular ejection fraction, and left internal mammary artery graft in various groups. It was speculated that combined surgeries could improve the survival rate [Buja 2006]. However, few studies have outlined the indications for CABG or the conditions for which the effect of combined surgery is superior. This was an urgent problem that needed to be addressed for clinical purposes. In their latest report, Ji et al. hypothesized that left ventricular wall motion abnormalities might be a predictor of surgical choice [Ji 2019]. Indeed, this conclusion was validated in a recent study conducted by Sun et al. [Sun 2018].

This retrospective study enrolled patients with coronary heart disease and moderate IMR who underwent surgical treatment in our hospital from 2018 to 2020. We aimed to identify risk factors in patients with concomitant CAHD and moderate IMR undergoing surgery based on previous studies. Since previous studies have not reported the coronary stenosis score, left anterior descending artery stenosis grading, left ventricular size, left ventricular diastolic function, bypass flow, and resistance, these factors should be considered to provide a reference for clinical decision-making.

METHODS

Subjects: This retrospective study was conducted at the Qilu Hospital of Shandong University between October 2021 and March 2022. (Figure 1) The study enrolled 115 patients suffering from CAHD with moderate IMR. Inclusion criteria were as follows: Patients with CAHD combined with moderate IMR who underwent CABG alone or CABG combined with MVS (CABG vs. CABG+MVS: N = 59 vs. N = 56) from 2018 to 2020. Patients with mild and severe IMR, as well as those who did not undergo CABG, were excluded from our study [Khallaf 2020]. We define rehabilitation of CABG as group A; deterioration of CABG as group B; rehabilitation of CABG+MVS as group C; deterioration of CABG+MVS as group D. Our study protocol conformed to the ethical guidelines of the Declaration of Helsinki and was approved by the Scientific Research Ethics Committee of Qilu Hospital of Shandong University (KYLL-202203-016).

Echocardiography: Preoperative echocardiography was performed 1 week before surgery. All patients underwent standard transthoracic echocardiography on a Philips IE 33 system, GEVivid-E95, EPIQ 7c. The severity of mitral regurgitation (MR) was evaluated by the ratio between the MR color flow jet area and the left atrium area. MR was graded as mild (regurgitant fraction, RF<30%, regurgitant volume, RV<30 ml, and effective regurgitant orifice area, EROA< 4 cm^2), moderate (RF30~50%, RV30~60 ml, and EROA 4-8 cm^2), or severe (RF>50%, RV>60 ml, and EROA>8 cm^2). The left ventricular ejection fraction was assessed by volumetric methods.

Gensini's degree integral: The Gensini score was calculated, according to the results of coronary angiography and used to quantitatively grade atherosclerosis for each vessel. The scoring standard consists of two parts: (1) The basic score was determined, according to the degree of coronary artery stenosis. The score for no abnormal finding was 0; stenosis ≤ 25% was 1; 26%-50% was 2; 51%-75% was 4; 76%-90% was 8; 91%-99% was 16; and 100% (occlusion) was 32; and (2) The score coefficient was determined based on the location of the coronary artery lesions. The lesion coefficient of the left main trunk was determined to be 5; that of the anterior descending branch was 2.5 in the proximal segment, 1.5 in the middle segment, 1.0 in the apical branch, 1.0 in the first diagonal branch, 0.5 in the second diagonal branch, 2.5 in the proximal segment, 1.0 in the obtuse marginal branch, 1.0 in the distal segment and 1.0 in the posterior descending branch. The quantitative score then was calculated by multiplying the basic score with the coefficient of the lesion site. If a patient had multiple atherosclerotic vessels and lesions, the cumulative total score of each lesion was the total score of the degree of coronary artery disease in the patient. Afterward, the patients were divided into four groups, according to their Gensini score: group 1 (no coronary stenosis group), group 2 (mild coronary stenosis group), group 3 (moderate coronary stenosis group), and group 4 (severe coronary stenosis group).

Surgical procedures: All operations were performed through a median sternal incision. The left internal mammary artery was resected by the pedicled method. It frequently was used as the bridging vessel of the LAD, while the great saphenous vein was excised as the rest of the bridging vessels. The flow and resistance of the bridging vessel were measured by a flow probe (Medistim flow meter), during the operation. For patients undergoing combined surgery, cardiopulmonary bypass first was established. Next, the right atrium and atrial septum were incised. The impaired mitral valve then was excised. Afterward, a biological valve, mechanical valve, or mitral annuloplasty ring was inserted and sutured to the mitral valve annulus. Finally, the valve was assessed for regurgitation.

Follow up: All clinical follow ups were conducted via telephone and WeChat. Routine echocardiography was performed within two weeks of the patient's perioperative follow up (peri-follow-up). Long-term follow up was conducted at the end of 2021, mainly by assessing patients' survival or the cause of death and collecting patients' echocardiography reports. Finally, the echocardiography results of the patients were compiled and analyzed.

Statistical analysis: Baseline characteristics and details of the CABG and CABG+MVS groups' perioperative period were summarized using medians and means for continuous variables and frequencies and percentages for categorical variables [Deja 2012]. The χ^2 test (χ^2) was used to compare categorical variables. For comparisons between two sets of continuous variables that follow the normal distribution, the independent T-test (t) or Wilcoxon Rank Sum Test (z) was employed. The paired t-test was utilized to compare mean indexes following a normal distribution before and after surgery, and the Wilcoxon signed-rank test was employed to compare two medians. Pearson correlation (two sets of continuous variables) and Spearman rank correlation analyses (rank variable and continuous variables) were performed to analyze the correlation between the indicators. The baseline and index values with $P < 0.05$ acquired through the above analyses were then inputted into multivariable linear regression (continuous variables as dependent variables) and logistic regression analyses (the rehabilitation group including CABG and CABG+MVS as dependent variables) to identify the independent factors for the selection of the surgical method [Sun 2018]. The cumulative survival curve was plotted using the Kaplan-Meier method with a log-rank test for group comparisons. Statistical analyses were performed with the SPSS statistical software (version 26.0) and Graphpad Prism (version 9.0). $P < 0.05$ was considered statistically significant.

RESULTS

Baseline data analysis: A comparison of the baseline between the two groups is depicted in Table 1. (Table 1) A total of 115 cases were eligible to participate in the study. Among these patients, one group was treated with a single CABG (N =

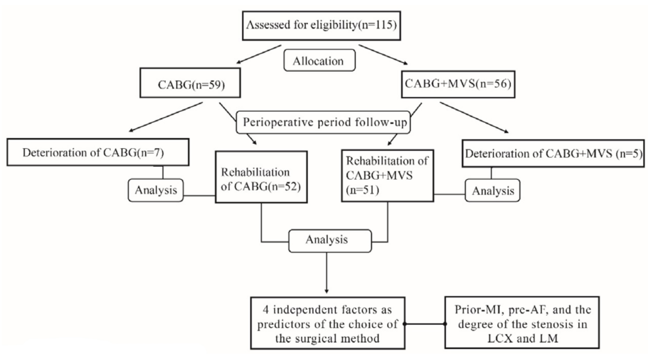

Figure 1. Flowchart of the study. CABG, coronary artery bypass grafting; CABG+MVS, coronary artery bypass grafting combined with mitral valve surgery; prior-MI, prior-myocardial infarction; pre-AF, preoperative atrial fibrillation; LCX and LM, the stenotic degree of the left circumflex and left main arteries

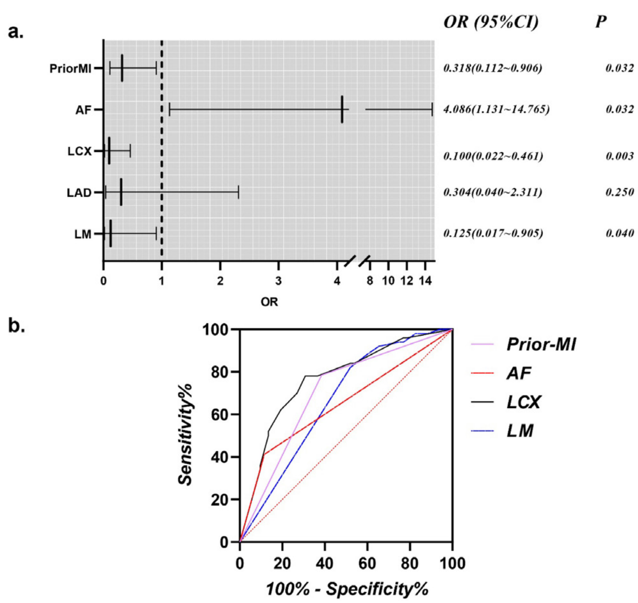

Figure 2. Logistic regression (A) and ROC analysis (B). ROC, receiver operating characteristic; OR, odds ratio; 95%CI, 95% confidence interval; AUC, area under curve, area under the ROC curve

59), while the other group underwent CABG+MVS ($N = 56$). However, 12 patients died during the perioperative period (CABG: $N = 7$, 11.9%; CABG+MVS: $N = 5$, 8.9%). The two matched groups were comparable for baseline variables (Table 1). Preoperative characteristics were similar between the two groups, except for the coronary artery condition and echocardiography results. Moreover, significant differences were noted in preoperative clinical data, including pre-AF, prior-MI, previous cerebrovascular history (pre-CVA), coronary score, coronary score grouping, preoperative left ventricular ejection fraction (pre-LVEF), the size of the preoperative left atrium (pre-LA), preoperative E- peak, E-peak < A-peak, the stenotic degree of LM,LAD and LCX, etc., between the two matched groups. For instance, the CABG

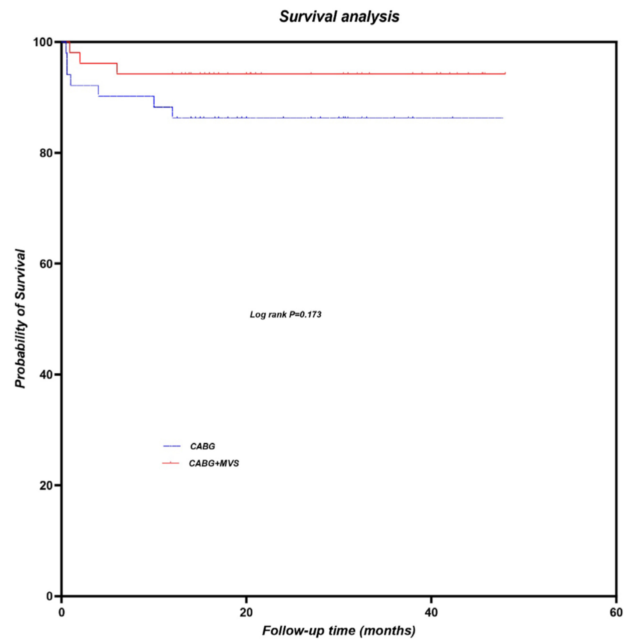

Figure 3. Survival analysis at long-term follow up

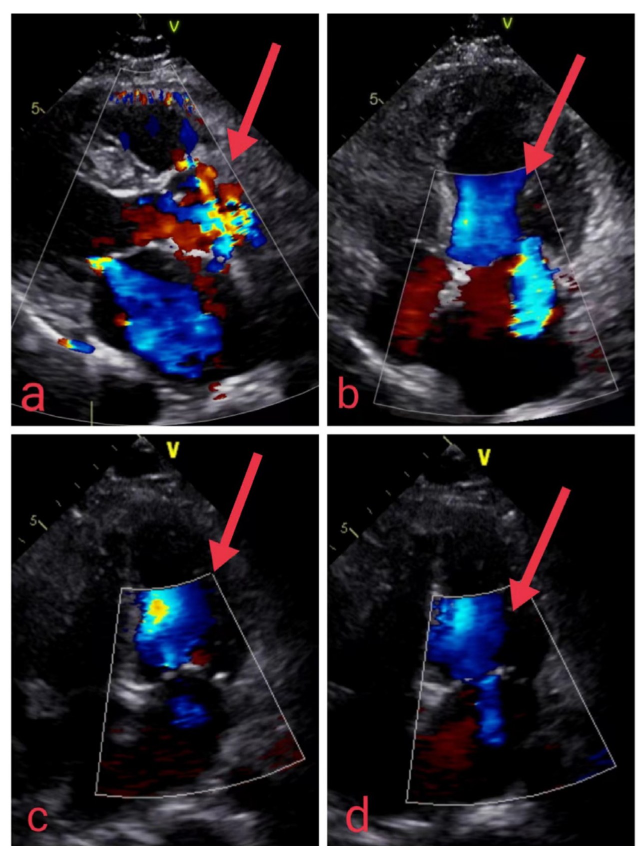

Figure 4. The echocardiogram of a patient treated with CABG. 4A and 4B depicts the preoperative mitral regurgitation status; 4C and 4D portray the degree of mitral regurgitation in patients after CABG. The arrow is pointed to the mitral valve area.

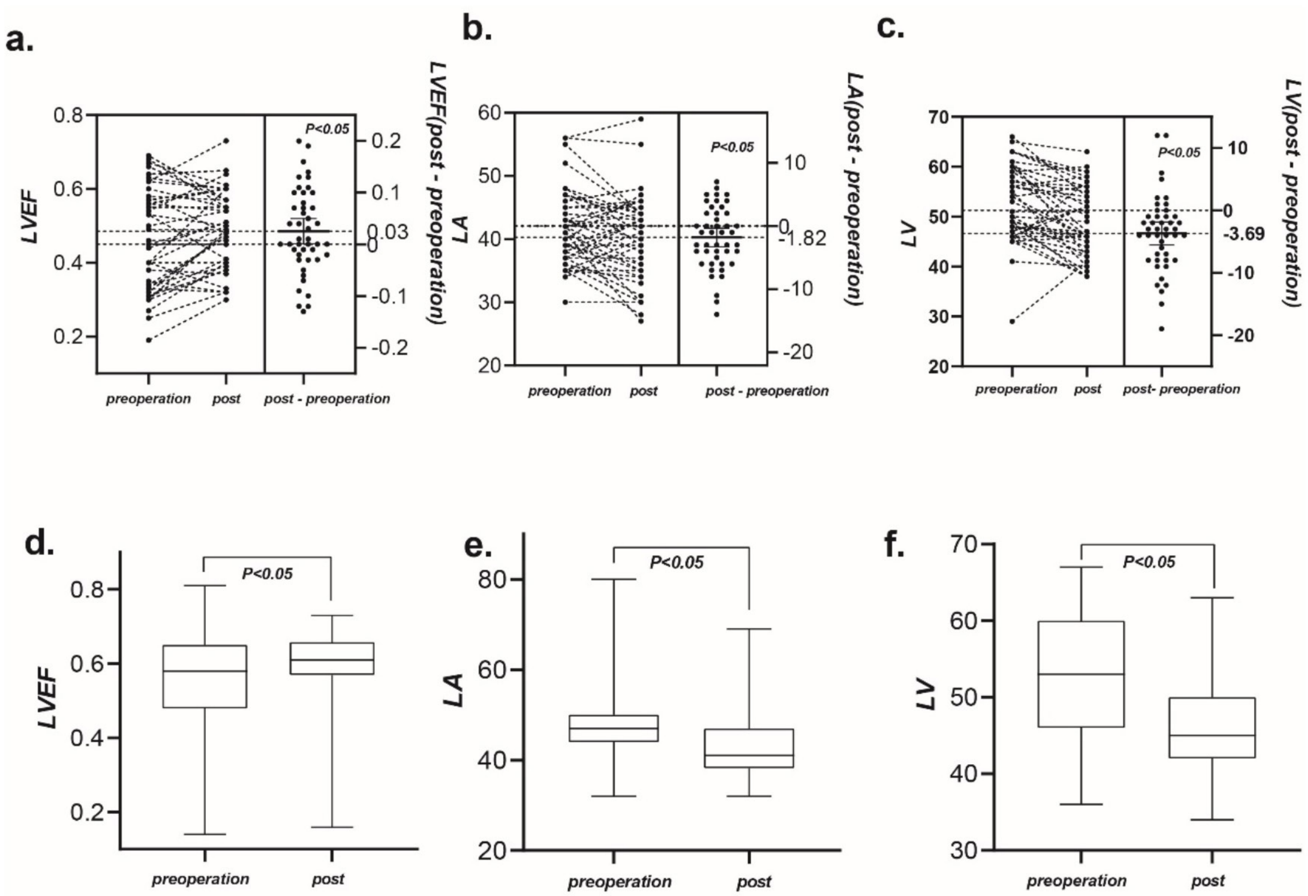

Figure 5. Differences between perioperative and postoperative echocardiographic index in the perioperative rehabilitation group. 5A, 5B, and 5C depict the data of the group A. 5D, 5E, and 5F, depict the data of the group C. Post, from postoperative period to discharge

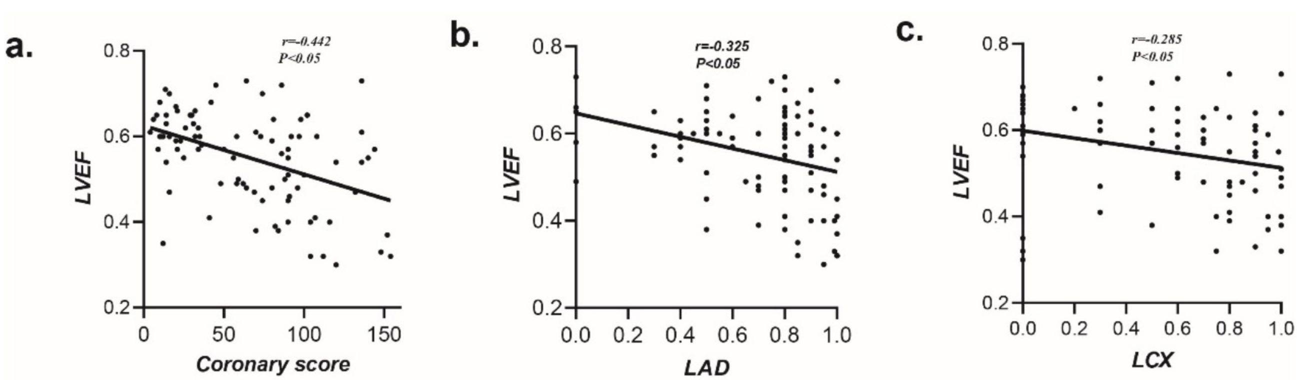

Figure 6. Pearson's linear correlation analysis. The correlation between postoperative LVEF, coronary score, and stenosis of the LAD and LCX is delineated. LVEF represents the postoperative LVEF. r, Pearson correlation coefficient

+ MVS group had a higher proportion of patients with AF (*P* = 0.004) and a lower proportion of patients with prior-MI (*P* = 0.000), pre-CVA (*P* = 0.041), and coronary score (*P* = 0.000) than the CABG group. On the other hand, patients in the CABG group had a poorer myocardial diastolic function discernable through preoperative E-peak (*P* = 0.000) and E-peak < A-peak (*P* = 0.000) compared with those in the CABG+ MVS group (Table 1). Furthermore, it was discovered that patients in the CABG group had a smaller cardiac size than in the CABG+MVS group (CABG vs. CABG+MVS, LA: 41.92±5.87 vs. 47.00 (42.25~50.00), z=-3.96, *P* = 0.000; LV: 52.69±7.15 vs. 53.09±8.10, t=-0.28, *P* = 0.78). The CABG group manifested lower pre-LVEF values, which could be attributable to the increased severity of LM,LAD and LCX

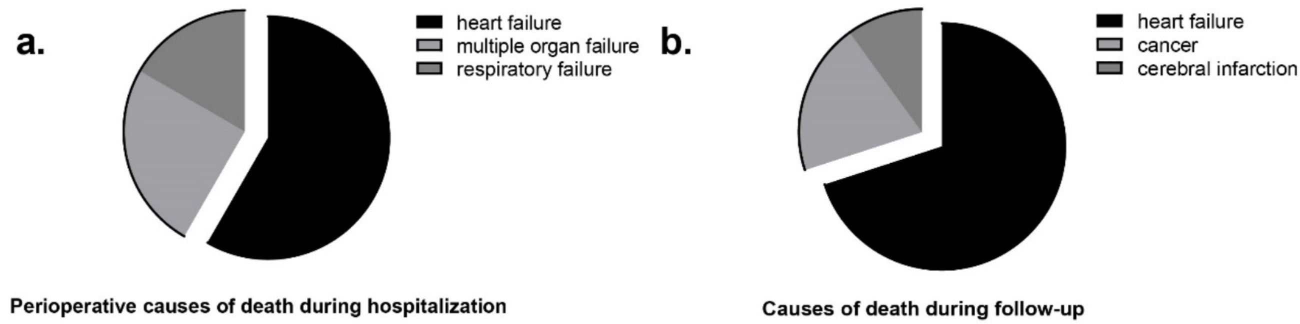

Figure 7. Causes of death during the perioperative period and at follow up.

stenosis (CABG vs. CABG+MVS, LM: 0.15 (0.00~0.60) vs. 0 (0~0), z=-3.853, P = 0.000; LAD: 0.90 (0.74~0.95) vs. 0.75 (0.50~0.85), z=-3.15, P = 0.002; LCX: 0.80 (0.60~0.95) vs. 0.5 (0.0~0.80), z=-4.52, P = 0.000) [Buja 2006].

Comparison of the rehabilitation and deterioration groups during the perioperative period: As displayed in Tables 2 and 3, the CABG and CABG+MVS groups were further subdivided into rehabilitation and deterioration groups according to perioperative death events. (Table 2) (Table 3) Results from the z-test and the χ^2 test established a significant difference in the number of patients with pre-AF and IABP use in the CABG group (rehabilitation vs. deterioration, N = 52 vs. N = 7; pre-AF: 6 (11.5%) vs. 3 (42.9%), P = 0.030; IABP: 12 (23.1%) vs. 5 (71.45%), P = 0.008). In patients who underwent CABG+MVS, the NYHA classification of the rehabilitation group was mostly grade III, which was lower than the deterioration group.

As presented in Table 4, all patients were divided into the rehabilitation and deterioration groups according to perioperative death events (rehabilitation vs. deterioration, N = 103 vs. N = 12). (Table 4) There was no statistically significant difference between patients who underwent different surgical procedures (CABG and CABG+MVS groups: rehabilitation vs. deterioration, N = 52 (50.5%) and N = 51 (49.5%) vs. N = 7 (58.3%) and N = 5 (41.7%), P = 0.607). Besides, IABP usage rate was markedly higher in the deterioration group (rehabilitation vs. deterioration, N = 17(16.5%) vs. N = 9 (75.0%), P = 0.000).

Differential index between preoperative and postoperative echocardiography: As illustrated in Figure 5, statistical analysis between the pre- and postoperative indicators of patients in the perioperative rehabilitation group (N = 103) was performed. (Figure 5) Compared with the preoperative values, the sizes of LA and LV were significantly smaller postoperatively, regardless of the group (Figure 5B, 5C, 5E, and 5F) [Doig 2021]. The alterations in size were more evident in the CABG+MVS group during the perioperative period. Conversely, left ventricular ejection fraction increased following surgery in both groups (Figure 5A and 5D). Furthermore, cardiac function enhancement was more pronounced in the CABG group during the perioperative period. Data from the rehabilitation subgroup of the CABG group were drawn with a paired sample t-test scatter plot, and the preoperative and postoperative differences followed the normal distribution. The differences were analyzed using the t-test (P < 0.05), which revealed that the differences were statistically significant (P < 0.05). Similarly, the CABG +MVS rehabilitation group's data was drawn with a paired sample z-test box plot, and the difference between preoperative and postoperative was statistically significant (P < 0.05).

Analyzing the correlation and regression between the indexes: As outlined in Table 5, patients who were rehabilitated during the perioperative period were divided into two groups, according to the employed operative method (CABG vs. CABG+MVS: N = 52 vs. N = 51). (Table 5) The indicators with differences between the two groups were similar to those in Table 1. Afterward, Pearson linear and Spearman rank correlation analyses were performed for these indicators. As depicted in Figure 6, coronary score and the degree of stenosis in the LAD and LCX were correlated with postoperative LVEF. (Figure 6) The results revealed that post-LVEF depended on the degree of the coronary score and stenosis in the LAD and LCX of the patients (Figure 6). Moreover, their correlation was moderately negative (post-LVEF and coronary score: P < 0.05, r=-0.442; post-LVEF and LAD: P < 0.05, r=-0.325; post-LVEF and LCX: P < 0.05, r=-0.285) [Yoshida 2017].

In Table 6, post-LVEF was marginally negatively correlated with the number of bridging (P < 0.05, r=-0.320) and coronary score grouping (P < 0.05, r=-0.402). (Table 6) Similarly, the size of post-LV was slightly positively correlated with coronary score grouping. In Table 7, multivariate linear regression was performed on the differential indicators of rehabilitated patients during the perioperative period. (Table 7) It could be seen that the degree of stenosis in the LAD negatively affected post-LVEF (P = 0.018<0.05, B=-0.105<0). Indeed, when the degree of stenosis in the LAD increased by 1%, the post-LVEF value of the patients correspondingly decreased by 0.105. Nonetheless, the degree of stenosis in the LCX (P = 0.101>0.05, B=-0.056<0) and the number of bridging vessels (P = 0.199>0.05, B=-0.016<0) did not significantly influence post-LVEF. The linear regression analysis formula was as follows: post-LVEF=0.692-0.105* stenotic degree in LAD. The variance inflation factor (VIF) values of the three independent variables were all less than 5, implying no multicollinearity among the three independent variables. Hence, the results of the regression model were reliable. The residual of the regression model following the normal distribution

Table 1. Baseline characteristics of patients who underwent CABG or CABG+MVS

	CABG (*N* = 59)	CABG+MVS (*N* = 56)	z/t/x^2	*P*
Death	7 (11.9)	5 (8.9)	0.265	0.607
Female	20 (33.9)	28 (50.0)	3.063	0.080
Age (years)	66.20±7.80	62.59±7.24	2.57	0.01
Weight (kg)	66.47±11.39	65.61±11.01	0.42	0.68
High (cm)	165.39±7.75	163.27±7.39	1.50	0.14
Smoke	24 (40.7)	18 (32.1)	0.903	0.342
Drink	19 (32.2)	12 (21.4)	1.694	0.193
Hp	38(64.4)	32(57.1)	0.636	0.425
DM	21 (35.6)	13 (23.2)	2.114	0.146
Pre-AF	9 (15.3)	22 (39.3)	8.427	0.004
Prior-MI	36 (61.0)	14 (25.0)	15.166	0.000
Pre-CVA	23 (39.0)	12 (21.4)	4.182	0.041
CHF	6 (10.2)	5 (8.9)	0.051	0.821
COPD	3 (5.1)	3 (5.4)	0.004	0.948
CRF	3 (5.1)	3 (5.4)	0.004	0.948
NYHA			0.166	0.920
I	0 (0.0)	0 (0.0)		
II	3 (5.1)	2 (3.6)		
III	46 (78.0)	44 (78.6)		
VI	10 (16.9)	10 (17.9)		

suggested that the operation results of the regression model were stable and reliable.

Predictors of the choice of the surgical method: Based on the above differential test, logistic regression analysis was performed for the rehabilitative patients throughout the perioperative period (CABG vs. CABG+MVS, *N* = 52 vs. *N* = 51) to investigate independent predictive factors impacting the selection of surgical methods (Figure 2A). (Figure 2) Since the dotted line (odds ratio (OR)=1) crossed the line of the LAD, the degree of stenosis in the LAD was not an independent risk factor for surgical grouping in the forest plot (Figure 2A, $P > 0.05$). Moreover, the prior-MI, LCX, and LM lines were distributed on the left side of the dotted line (OR=1), indicating that these have a significantly negative effect on the choice of CABG. Furthermore, a history of myocardial infarction before surgery (OR=0.318, 95% confidence interval (95%CI) 0.112~0.906; $P < 0.05$), and greater severity of stenosis in the LCX (OR=0.100, 95%CI 0.022~0.461; $P < 0.05$) and LM (OR 0.125, 95%CI 0.017~0.905; $P < 0.05$) advocated for CABG+MVS surgery. The line for AF was located on the right side of the dotted line (OR=1), which signified that AF had a significantly positive impact on the choice of CABG (OR 4.086, 95%CI 1.131~14.765; $P < 0.05$). In other words, CABG was preferred for patients with a prior history of AF. According to the results of the logistic regression analysis depicted in Figure 2A, prior-MI, AF, the degree of stenosis in LCX and LM influence the selection of surgical methods [Matoq 2020]. This study might help identify patients who were optimal candidates for CABG alone or combined with MVS surgery, which was essential for clinical decision-making, optimization of surgical strategies, and prognosis. Regarding the Goodness-of-Fit Index Test, Cox & Snell R2=0.363 and Nagelkerke R2=0.485, the multivariate logistic regression model of the 4 factors had a superior fitness. The Hosmer-Lemeshow test determined that the model closely mirrored the data ($P = 0.942>0.05$). The degree of stenosis in LM and LCX, a prior history of AF, and prior MI were predictive factors for the selection of surgical methods (Figure 2B, LM: AUC=0.664, $P = 0.004$; LCX: AUC=0.764, $P < 0.0001$; prior-AF: AUC=0.648, $P = 0.0095$; prior-MI: AUC=0.6998, P = 0.0005). ROC analysis established that the AUC of the LCX model (0.764) was significantly higher than the others, while the degree of stenosis in the LCX was determined to be the optimal predictor for the selection of surgical methods.

Figure 3 illustrates the Kaplan–Meier survival analysis for the groups (group A vs. group C: *N* = 52 vs. *N* = 51) [Pang 2019]. There was no difference in long-time survival between the groups at a mean follow-up duration of 43.7 months (log-rank $P = 0.173$). After discharge, the long-term follow-up mortality rate was 13.7% and 5.8% (group A vs. group C) [Doig 2021].

Coronary score grouping			29.79	0.000
None	0 (0.0)	0 (0.0)		
Light	3 (5.2)	24 (43.6)		
Moderate	5 (8.6)	10 (18.2)		
Severe	50 (86.2)	21 (38.2)		
Pre-LVEF	0.49±0.13	0.57 (0.47~0.65)	-2.93	0.003
Pre-LV (mm)	52.69±7.15	53.09±8.10	-0.28	0.78
Pre-LA (mm)	41.92±5.87	47.00 42.25~50.00)	-3.96	0.000
pre-E-peak (cm/s)	83.72±20.45	114.56±32.15	-4.67	0.00
E-peak < A-peak	37 (62.7)	17 (30.4)	19.877	0.000
e'^1 (cm/s)	5.0 (4.0~6.0)	5.51±1.95	-0.59	0.558
e'_2 (cm/s)	7.04±2.04	8.26±2.93	-1.72	0.09
E-peak /e'	13.95 (11.13~17.53)	16.45±7.19	-0.521	0.602
Coronary score	92.81±36.81	90.00 (69.75~121.00)	-5.34	0.000
LM	0.15 (0.00~0.60)	0 (0~0)	-3.853	0.000
LAD	0.90 (0.74~0.95)	0.75 (0.50~0.85)	-3.15	0.002
LCX	0.80 (0.60~0.95)	0.50 (0.0~0.80)	-4.52	0.000

Continuous variables that did not follow the normal distribution were expressed as mean ± SD; SD, standard deviation; continuous variables that did not obey the normal distribution were expressed as percentiles (25%–75%); categorical variables were expressed as n (%). Hp, hypertension; DM, diabetes mellitus; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; GFR, glomerular filtration rate; NYHA, New York Heart Association; pre-, preoperative; LA, left atrium; LV, left ventricle; E-peak, A-peak, the two peaks of the mitral valve diastolic blood flow spectrum corresponded to the rapid filling period of the ventricle and the atrial systole, respectively; e', when the ventricle contracted and relaxes, the mitral valve annulus moved along with it, and the motion velocity of the mitral valve annulus was measured by the tissue Doppler technique; E-peak < A-peak, suggestive of decreased ventricular diastolic function; E-peak /e', <8, indicative of a normal left ventricular filling pressure (LVFP), >15 was indicative of a significant increase in LVFP, 8~15 needed to be considered in combination with other indicators; e'^1 (cm/s), velocity of motion at the mitral septal annulus; e'^2 (cm/s), velocity of motion at the anterior and lateral mitral valve annuli.

Table 2. Differential index between the rehabilitation and deterioration subgroups of the CABG group

	Group A (*N* = 52)	Group B (*N* = 7)	z/x^2	*P*
Pre-AF	6 (11.5)	3 (42.9)	4.68	0.030
IABP	12 (23.1)	5 (71.4)	7.03	0.008
MVT (hours)	18.50 (14.50~26.25)	12.25±3.10	-2.02	0.044

IABP, intra-aortic balloon pump; MVT, mechanical ventilation time. Group A: rehabilitation of CABG; Group B: deterioration of CABG

Clinical outcomes: As displayed in Figure 7A, among the 12 patients who died during the perioperative period, four deaths were due to heart failure, three to multiple organ failure, and two to respiratory failure. (Figure 7) Regarding the causes of death during long-term follow up (Figure 7B), seven people died of heart failure, two died of cancer, and one died of cerebral infarction. Consequently, heart failure was the principal cause of death.

Figure 4 listed a case with CAHD and moderate IMR treated with CABG. (Figure 4) The patient was old, with the LCX severely stenosed, and with normal ventricular wall motion (LVEF:0.68). Only coronary artery bypass grafting (CABG) was performed on the patient (number of bridging, *N* = 4). Postoperatively, reexamination of the patient prior to discharge revealed that the LA and LV were smaller than before the surgery (pre-operation, LA: 42 mm, LV: 40 mm; post-operation, LA: 37 mm, and LV: 39 mm). Moreover, mitral valve regurgitation was mild, and there was no difference in cardiac function (LVEF: 0.64) compared with preoperative values.

DISCUSSION

This study revealed four independent factors as predictors of the choice of the surgical method: prior-MI, AF, LCX, and LM. Our results suggested that both CABG and CABG+MVS significantly improved symptoms in rehabilitative patients. There was no significant difference in the outcomes of

Table 3. Differential index between the rehabilitation and deterioration subgroups of the CABG+MVS group

	Group C (*N* = 51)	Group D (*N* = 5)	z/t/x^2	*P*
Drink	9 (17.6)	3 (60.0)	4.85	0.028
NYHA			6.70	0.035
I	0	0		
II	2(3.9)	0		
III	42 (82.4)	2 (40.0)		
VI	7 (13.7)	3 (60.0)		
E-peak < A-peak	16 (31.4)	1 (20.0)	10.44	0.005
IABP	5 (9.8)	4 (80.0)	16.64	0.000
Pre-LV	47.0 (44.0~50.0)	40.40±4.98	-2.19	0.029

Group C, rehabilitation of CABG+MVS; group D, deterioration of CABG+MVS

Table 4. Differential index between the rehabilitation and deterioration subgroups in all patients

	Rehabilitation (*N* = 103)	Deterioration (*N* = 12)	x^2	*P*
Operation method			0.265	0.607
CABG	52 (50.5)	7 (58.3)		
CABG+MVS	51 (49.5)	5 (41.7)		
Sequential	37 (35.9)	8 (66.7)	4.27	0.039
IABP	17 (16.5)	9 (75.0)	21.02	0.000

Sequential, sequential anastomosis for CABG

patients with different surgical modalities. Indeed, the study aimed to identify the optimal surgical approach based on the patient's preoperative indicators. This study might be crucial for identifying suitable patients with moderate IMR who would benefit from different surgical modalities. This might be helpful in clinical decision-making, optimization of operation strategies, and enhancing prognosis [Ji 2019].

A critical finding of this study was that there was no significant difference in long-term survival between the two groups, which provided a scientific basis for our retrospective analysis to select the surgical method based on the patient's preoperative indicators. Sun et al. found two independent factors as predictors of IMR improvement following off-pump coronary artery bypass grafting (OPCAB): absence of papillary muscle systolic dysynchrony (DYS-PAP) and preserved preoperative LVEF [Sun 2018]. In addition, a preoperative LVEF of >37.4% was a vital predictor of IMR improvement in their study [Sun 2018]. The predictive value of preoperative LVEF values has been widely documented. The study by Jeong et al. pointed out that concomitant mitral annuloplasty (MAP) was more effective against recurrent MR than was OPCAB alone in patients with LVEF ≤40%. They suggested that MAP should be considered in patients with moderate ischemic MR with low LVEF [Jeong 2012]. Additionally, Sun et al. reported that the absence of DYS-PAP reflected the effect of myocardial motility on IMR improvement. In our study, pre-E-peak and pre-E-peak<A-peak in the CABG and combination groups reflected the indicators of myocardial diastolic dysfunction and poor ventricular wall motion. Moreover, there were significant differences between the two groups (62.7% vs. 30.4%). The CABG group had worse ventricular wall conditions and higher perioperative (11.9% vs. 8.9) and follow-up mortality rates (13.7% vs. 5.8%). These results were in line with the findings of Sun et al., whereby uncoordinated regional LV contraction in papillary muscle insertion sites eventually caused geometrical changes in the attachments and mitral leaflet tethering [Kanzaki H. 2004]. They highlighted the direct impact of uncoordinated regional contractions on the mitral valve. We theorized that the uncoordinated regional motion of the left ventricle influenced the recovery of postoperative mitral regurgitation, especially in patients who underwent CABG. In order to elucidate the responses of ventricular diastolic degrees such as E-peak and E-peak <A-peak, further investigations are warranted.

Likewise, a significantly negative correlation was observed between the perioperative LVEF and the number of bridging vessels and coronary score grouping in the correlation analysis. This observation might be related to the longer

Table 5. Differential data in the CABG and CABG+MVS rehabilitation groups at baseline

	Group A (*N* = 52)	Group C (*N* = 51)	z/x^2	*P*
Pre-AF	6 (11.5)	21 (41.2)	11.69	0.001
Prior-MI	32 (61.5)	11 (21.6)	16.91	0000
Coronary score	-	-	28.97	0.000
None	0	0 (0.0)		
Light	3 (5.8)	23 (46.0)		
Moderate	5 (9.6)	10 (20.0)		
Severe	44 (84.6)	17 (34.0)		
Sequential	24 (46.2)	13 (25.5)	4.78	0.029
Number of bridging			16.91	0.002
1	7 (13.5)	24 (47.1)		
2	13 (25.0)	9 (17.6)		
3	19 (36.5)	15 (29.4)		
4	12 (23.1)	3 (5.9)		
5	1 (1.9)	0		
LM	0 (0~0.54)	0 (0~0)	-3.41	0.001
LAD	0.88 (0.73~0.95)	0.73 (0.50~0.85)	-3.36	0.001
LCX	0.8 (0.6~0.95)	0.35 (0~0.70)	-4.64	0.000
Coronary score	90.50 (69.25~123.00)	30.50 (14.00~73.25)	-5.40	0.000
Pre-LVEF	0.47±0.13	0.58 (0.48~0.65)	-2.91	0.004
Pre-LA (mm)	41.85±5.95	47.0 (44.0~50.0)	-4.30	0.000
Pre-E-peak (cm/s)	83.67±21.91	113.93±33.44	-3.92	0.000
Pre-E-peak < A-peak	33 (63.5)	16 (31.4)	19.89	0.000
Post-LVEF	0.50±0.10	0.61 (0.57~0.66)	-4.54	0.000
Operation time	302.50 (262.50~373.75)	400.0 (330.0~460.0)	-4.82	0.000
ECT	130.32±104.66	185.73±74.24	-2.50	0.015

ECT, extracorporeal circulation turnaround time

operation time for intraoperative bypass and further proximal anastomotic occlusion due to excessive anastomosis, promoting myocardial infarction that endangers the patient's life. At the same time, our study reported that the proportion of sequential grafts in the CABG group was larger (46.2%), and the number of grafts was 3 (36.5%) among the rehabilitative patients in the perioperative period. On the other hand, the proportion of sequential grafts was relatively smaller (25.5%), and most patients only had one graft (47.1%) in the CABG+MVS group. Previous studies had determined that the proximal portion of sequential bypass grafts had greater blood flow velocities than single bypass grafts, resulting in lower total resistance to graft flow and satisfactory long-term patency [Joshi 2021]. On the surface, the proportion of sequential bypass in the CABG group was relatively larger. However, more patients in the combined group had a single bridge, causing limited blood flow resistance of the bridging vessels, consistent with the above-mentioned point. Herein, the multivariate linear regression model demonstrated that the degree of the stenosis in the LAD significantly correlated with postoperative LVEF but not with the degree of the stenosis in the LCX and the number of bridging vessels. We postulated that this might be due to the location of the anterior descending artery.

Table 6. Spearman rank correlation analysis at baseline and postoperative data

	r	*P*
Number of bridging & post-LVEF	-0.320	<0.05
Post-LV & coronary score grouping	0.220	<0.05
Post-LVEF & coronary score grouping	-0.402	<0.05

r: Spearman rank correlation coefficient

Table 7. Multivariate linear regression

	Non-standardized coefficient		Standardization coefficient		Significance
	B	Standard deviation	B	t	
Constant	.692	0.35	-	19.860	0.000
LAD	-.105	.043	-.253	-2.415	.018
LCX	-.056	.034	-.185	-1.656	.101
Number of bridging vessels	-.016	.012	-.153	-1.294	.199
		F		6.33	
		P		0.001<0.05	
		R^2		0.184	

Dependent variable: post-LVEF. Independent variable: the degree of stenosis in the LAD and LCX, number of bridging. B (Beta), regression coefficient. F, the variance test for the regression model as a whole, $P < 0.05$ indicates that the regression model was significant. R^2 is an elaboration of the model fitting effect.

Table 8. Echocardiographic index between preoperative and postoperative in the perioperative rehabilitative group

	Preoperative	Post-operation	t/z	*P*
Group A				
LVEF	0.47±0.14	0.50±0.10	-2.69	0.008
LA	42.09±5.97	40.27±6.72	2.47	0.017
LV	52.78±7.54	49.09±6.98	4.05	0.000
Group C				
LVEF	0.55 (0.40~0.62)	0.57 (0.48~0.63)	-2.44	0.015
LA	45.0 (39.0~48.0)	41.0 (36.5~46.0)	-4.99	0.000
LV	53.0 (47.0~60.0)	46.0 (42.5~53.5)	-5.77	0.000

Table 9. Echocardiographic index between preoperative and follow-up in the perioperative rehabilitative group

	Preoperative	Follow up	t/z	*P*
Group A				
LVEF	0.60 (0.53~0.65)	0.58 (0.55~0.61)	-0.939	0.348
LA	48.0 (44.0~52.0)	42.0 (40.0~52.0)	-0.990	0.322
LV	49.0 (43.0~59.0)	47.0 (44.0~50.0)	-2.65	0.008
Group C				
LVEF	0.49±0.15	0.54±0.12	2.665	0.018
LA	39.0 (37.0~47.0) 42.0 (38.0~45.0)	-0.37	0.711	
LV	49.0 (48.0~59.0)	49.0 (45.0~56.0)	-2.931	0.003

Herein, the number of rehabilitative patients with prior-MI in the CABG group was higher (group A vs. group C: 61.5 vs. 21.6) than in the CABG+MVS group. This might be related to irreversible ventricular remodeling in these patients. It did not significantly alleviate mitral regurgitation, and patients had high mortality and complication rates during the postoperative and perioperative period and follow up in the CABG group. This was consistent with the findings of Ji et al. [Ji 2019]. As for atrial fibrillation, regression analysis suggested that it was a risk factor for CABG+MVS. Therefore, patients with a history of AF should be considered for CABG surgery only. Atrial fibrillation (AF) is a commonly encountered heart arrhythmia as well as a risk factor for cardiovascular dysfunction [Yao 2020]. The incidence of stroke in patients with valvular disease and atrial fibrillation was 17.6 times that of normal people. Furthermore, the presence of AF resulted in worse outcomes for CABG+MVS, poorer cardiac reanimation following cardiopulmonary

Table 10. Echocardiographic index between post-operation and follow-up in the perioperative rehabilitative group

	Follow up	Post-operation	t/z	*P*
Group A				
LVEF	0.58 (0.55~0.61)	0.63 (0.59~0.66)	-1.32	0.186
LA	42.0 (40.0~52.0)	40.5 (39.0~46.3)	-2.40	0.016
LV	47.0 (44.0~50.0)	46.0 (42.8~49.3)	-0.211	0.833
Group C				
LVEF	0.55±0.12	0.50±0.12	2.144	0.053
LA	42.0 (38.0~45.0)	43.0 (35.0~44.0)	-0.875	0.381
LV	49.2±6.46	47.2±6.36	1.377	0.194

bypass, and increased mortality and surgical complications. In our study, the proportion of patients with atrial fibrillation in the CABG+MVS group was higher (group A vs. group C: 11.5% vs. 41.2%). We speculated that if fewer patients with AF underwent combined surgery, the mortality rate would diminish and eventually concluded that AF increased the risk of surgical complications.

Coronary vessels are important references when selecting the surgical method. Surprisingly, the anterior descending coronary artery, the main blood supplies to the heart, cannot be used as a reference [Li 2019]. We postulated that the reason was that the occlusion of the anterior descending branch accounted for most patients with CAHD, and the degree of stenosis in the LAD often was severe. When it became more common and severe, the reference role of the circumflex branch was highlighted. The LCX supplies blood to the anterior papillary muscle of the mitral valve, the left atrium, and the inferior wall of the heart. Consequently, ischemia of the circumflex branch impacted the atrium's contractility and the closure of the mitral valve. However, no studies have been conducted so far. The LM contains two main branches, the LAD and the LCX. The study determined that the degree of stenosis in the LM of the two groups was not severe (group A vs. group C: 0.15 vs. 0). It was hypothesized that LM, as a predictor, is closely related to LCX. In the Chinese population, the posterior mitral papillary muscle was supplied by the posterior descending branch, while it was supplied by the right coronary artery in Europeans and Americans. Hence, we postulated that the posterior descending branch could be used as a predictor as well.

From the follow-up data assessing the prognostic trend of patients, it was determined that the difference in the number of patients who died during the perioperative period and long-term follow up between the two surgical methods was not statistically significant ($P > 0.05$). However, it was uncovered that the CABG+MVS group had a lower mortality rate during both the perioperative period (CABG vs. CABG+MVS: 11.9% vs. 8.9%) and long-term follow up (group A vs. group C: 13.7% vs. 5.8%). Furthermore, the CABG+MVS group had superior improvements in cardiac function [Khallaf 2020]. Although the CABG+MVS group had a longer operative time, the risk of perioperative mortality and follow-up mortality did not increase herein [Yu 2019]. This finding differed from Shen et al.'s study, whereby mitral valve surgery increased follow-up deaths [Shen 2019]. (Table 8) (Table 9) (Table 10)

Limitations: This study has several limitations that need to be considered. First, the echocardiography data from our hospital had scientific inaccuracies, due to the diverse machine models and subjective measurements utilized by the operating physicians. Second, based on our knowledge of LCX, the effect of different degrees of stenosis on surgical choice had not been explored. Lastly, the eligible sample size was limited in single center.

CONCLUSION

To summarize, prior-MI, AF, LCX, and LM were independent predictors of the choice of the surgical method. However, indicators of myocardial diastolic dysfunction and poor ventricular wall motion also should be emphasized. Lastly, studies with a larger sample size and more detailed studies on LCX are warranted to establish a risk model to optimize surgical strategies [Sun 2018].

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