Original Research

The transition and outcomes of perioperative low ejection fraction status in cardiac surgical patients

Jun Zhong[1,†], Jing-chao Luo[2,†], Huan Wang[2,†], Kanhua Yin[3], Yi-jie Zhang[2], Jian Gao[4,5], Zhe Luo[2,6,7,*], Guo-wei Tu[2,*]

[1] *Department of Nursing, Zhongshan Hospital, Fudan University, 200032 Shanghai, China*

[2] *Department of Critical Care Medicine, Zhongshan Hospital, Fudan University, 200032 Shanghai, China*

[3] *Department of Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA*

[4] *Center of Clinical Epidemiology and EBM of Fudan University, 200032 Shanghai, China*

[5] *Department of Nutrition, Zhongshan Hospital, Fudan University, 200032 Shanghai, China*

[6] *Department of Critical Care Medicine, Xiamen Branch, Zhongshan Hospital, Fudan University, 361015 Xiamen, Fujian, China*

[7] *Shanghai Key Lab of Pulmonary Inflammation and Injury, 200032 Shanghai, China*

*Correspondence: luo.zhe@zs-hospital.sh.cn (Zhe Luo); tu.guowei@zs-hospital.sh.cn (Guo-wei Tu)

† These authors contributed equally.

DOI:10.31083/j.rcm2204180

Submitted: 15 September 2021 Revised: 16 November 2021 Accepted: 16 November 2021 Published: 22 December 2021

Low left ventricular ejection fraction (LVEF) was always considered a high-risk factor for surgery. A growing number of patients with preoperative low LVEF have undergone cardiac surgery in recent years. The transition of postoperative LVEF and its correlation with short-term outcomes is not yet clear. We retrospectively collected the clinical data of cardiac surgery patients with low preoperative LVEF ($\leq$40%). LVEF measurements were collected preoperatively and at least twice postoperatively. The primary endpoint was the composite endpoint of hospital mortality or length of intensive care unit (ICU) stay $\geq$7 days. Univariate logistic regression was used to evaluate the association of each indicator with the outcomes, including calculation of the area under the receiver operating characteristic (ROC) curve. A two-piecewise linear regression model was applied to examine the threshold effect of the LVEF on the composite endpoint using a smoothing function. From 1 January to 31 December 2018, a total of 123 patients had low LVEF preoperatively, of whom 35 (28.5%) met the composite endpoint. LVEF was 35% [interquartile range (IQR) 30%–42%] at first measurement and increased to 40% (IQR 35%–45%) at final measurement during their hospitalization. There was a linear relationship between composite endpoint and lowest level of postoperative LVEF. The base e logarithm of odds ratio [Ln(OR)] of composite endpoint decreased with increasing LVEF (OR = 0.83, 95% confidence interval 0.76–0.91, $p < 0.01$). Most patients with low preoperative LVEF will benefit from cardiac surgery. The lowest measurement of postoperative LVEF can be used to evaluate the short-term outcome of patients after cardiac surgery.

Keywords

Left ventricular ejection fraction (LVEF); Transition; Outcome; Cardiac surgery

1. Background

Left ventricular ejection fraction (LVEF) is the most frequently used indicator of cardiac function [1, 2]. Patients with low preoperative LVEF are at high risk in cardiac surgery, with associations with substantially elevated postoperative morbidity and mortality [3, 4]. With improvements to surgical procedures and the use of various circulatory support devices and drugs, outcomes after cardiac surgery have improved over time, leading to a decrease in surgical contraindications and broad adjustment in the range of preoperative risk assessment [5, 6]. The safety of cardiac surgery among patients with preoperative cardiac insufficiency has been well established by several studies [7–9].

A large number of studies have verified the correlation between preoperative LVEF and patient prognosis, but little attention has been paid to the transition of postoperative LVEF. LVEF is usually monitored on an ongoing basis to evaluate the outcome of the surgery and the patients' recovery of cardiac function, sometimes as reference for transfer out of the intensive care unit (ICU) or discharge [10, 11]. Patients with shorter-term changes in LVEF after surgery are of concern to clinicians, especially those who already had low LVEF before surgery. Studies have shown that the LVEF of some patients does not improve from surgery but decreases in the early postoperative period, confusing clinicians about surgical and patient outcomes [12, 13]. Further studies have revealed that preoperative LVEF may be affected by the structural compensation of the heart itself or other factors that cannot fully reflect actual cardiac function [14, 15]. The prognostic value of LVEF and its short-term changes among cardiac surgery patients remains understudied in the real world. Questions concerning low LVEF in patients need answering to guide treatment decisions.

The aim of this study was to investigate the change in LVEF and prognosis of patients with low preoperative LVEF after cardiac surgery. At the same time, we explored the predictive value of postoperative LVEF for patient prognosis.

Reviews in Cardiovascular Medicine

2. Methods

2.1 Patients

This retrospective cohort study enrolled patients with preoperative low LVEF who underwent cardiac surgery between 1 January and 31 December 2018 in Zhongshan Hospital, Shanghai, China. Patients younger than 18 years of age and pregnant patients were excluded from the study.

All patients underwent formal two-dimensional echocardiography less than 2 weeks prior to surgery and at least twice after surgery during hospitalization. Patients received standard anesthetic care and monitoring during the procedure and were transferred to the intensive care unit (ICU) after surgery. Standard care was provided by intensivists, respiratory therapists and ICU nurses. Standard therapy included fluid management, airway management, vasoactive medications, and inotropic and mechanical circulatory support according to hemodynamic status. The decision to discharge from the ICU was made by intensivists, based on the patient's general condition. Data were collected from the electronic medical records during hospitalization.

2.2 Data collection

Preoperative characteristics, including patient demographics and comorbidities were collected retrospectively. The latest measurement of preoperative LVEF (LVEF_Pre), first measurement of postoperative LVEF (LVEF_First), lowest level of postoperative LVEF (LVEF_Low), and last measurement of postoperative LVEF (LVEF_Last) were recorded. Laboratory measurements including creatinine, cardiac troponin T (cTnT), and N-terminal pro-brain natriuretic peptide (NT-proBNP) and were measured preoperatively and within 24 h after the surgery. In addition, we collected information about patients' procedures, supportive therapies (such as intra-aortic balloon pump, renal replacement therapy and inhaled nitric oxide), and clinical outcomes during hospitalization. All data were obtained from the patients' electronic medical record system.

The LVEF and tricuspid annular plane systolic excursion (TAPSE) values were measured using echocardiography, and the LVEF was evaluated using Simpson's biplane method. Comorbid conditions were evaluated using the Charlson Comorbidity Index. EuroSCORE was used to calculate the predicted operative mortality for patients undergoing cardiac surgery. APACHE II was used to evaluate the severity of the patient's condition after patients were transferred to ICU following surgery. These scores were evaluated by the intensivists.

2.3 Definition

Preoperative low LVEF was defined as the latest measurement of preoperative echocardiography showing LVEF of $\leq$40% and was calculated using Simpson's biplane method [16]. The primary endpoint was the composite endpoint of hospital mortality or length of ICU stay $\geq$7 days.

2.4 Statistical analysis

Discrete variables were expressed as numbers and percentages and compared using the Fisher's exact test. According to the normality of the data, continuous variables were expressed as mean $\pm$ standard deviation or median (interquartile range) and compared using the student's t test or Wilcoxon rank-sum test. Logistic regression models were used to investigate the relationship between indicators and composite endpoints in univariable analyses. The area under the receiver operating characteristic curve (AUROC), with 95% confidence interval (CI), was used to compare the prediction of composite endpoints by each indicator.

A two-piecewise linear regression model was applied to examine the threshold effect of the LVEF on the composite endpoint using a smoothing function. The threshold level (i.e., turning point) was determined by trial and error, including by selection of turning points along a pre-defined interval and then choosing the turning point that gave the maximum model likelihood. A log likelihood ratio test was conducted to compare the one-line linear regression model with a two-piecewise linear model. Statistical tests were two-tailed, and a value of $p < 0.05$ indicated statistical significance. Statistical analyses were performed using R, version 3.6.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1 Patient characteristics

A total of 4402 patients received cardiac surgery in 2018 and were admitted to the ICU in Zhongshan Hospital, of whom 123 patients had low LVEF preoperatively. The median age of the patients was 59 (IQR 53–68) years and 97 patients (78.9%) were male. Patients who underwent aortic valvuloplasty or valve replacement surgery (47.2%) comprised the highest percentage, followed by coronary artery bypass surgery (40.7%) and mitral valvuloplasty or valve replacement (32.5%). The median duration of mechanical ventilation was 2 (IQR 1–3) days, 20 patients (13%) received postoperative intra-aortic balloon pump (IABP) support, 10 patients (4.1%) received renal replacement therapy (RRT), 18 patients (8.9%) received noninvasive ventilation (NIV) after extubation, and 12 patients (8.9%) required tracheotomy (Table 1).

3.2 Transition of low ejection fraction status

For 123 patients with preoperative low LVEF, the latest measurement of preoperative LVEF was 37% (IQR 33%–39%). In the first echocardiography after surgery, a total of 88 patients (71.5%) had low LVEF, and the mean LVEF was 35% (IQR 30%–42%). The lowest level of postoperative LVEF in these patients was 34% (IQR 28%–41%), with low LVEF in 92 cases (74.8%). At the final measurement during hospitalization, LVEF increased to 40% (IQR 35%–45%), and the number of low LVEF cases dropped to 68 (55.3%) (Table 1, Fig. 1).

Table 1. Clinical characteristics.

	All patients (n = 123)	Composite outcome negative (n = 88)	Composite outcome positive (n = 35)	*p* value
Age (years), median (range)	59 (53–68)	60 (52–68)	59 (55–70)	0.269
Sex (male), n (%)	97 (78.9)	73 (83.0)	24 (68.6)	0.090
Hypertension, n (%)	42 (34.1)	30 (34.1)	12 (34.4)	1.000
Charlson Comorbidity Index, median (range)	2 (1–3)	2 (1–3)	3 (2–4)	0.009
APACHE II score, median (range)	8 (5–11)	8 (5–10)	11 (7–14)	0.002
EuroSCORE, median (range)	4 (3–7)	4 (3–6)	5 (3–7)	0.339
NYHA class, n (%)				0.429
I	1 (0.8)	0 (0.0)	1 (2.9)	
II	17 (13.8)	13 (14.8)	4 (11.4)	
III	88 (71.5)	64 (72.7)	24 (68.6)	
IV	17 (13.8)	11 (12.5)	6 (17.1)	
Preoperative examinations				
Creatinine (μmol/L), median (range)	90 (79–108)	89 (78–100)	94 (81–121)	0.040
cTnT (ng/mL), median (range)	0.03 (0.02–0.05)	0.02 (0.02–0.04)	0.05 (0.02–0.15)	<0.001
NT-proBNP (pg/mL) median (range)	1865 (1006–4052)	1562 (1007–3415)	3114 (1113–5267)	0.030
TAPSE <16 mm, n (%)	15 (12.2)	8 (9.1)	7 (20.0)	0.126
Procedures, n (%)				
Aortic valvuloplasty or valve replacement	58 (47.2)	48 (54.5)	10 (28.6)	0.010
Mitral valvuloplasty or valve replacement	40 (32.5)	31 (35.2)	9 (25.7)	0.395
Tricuspid valvuloplasty or valve replacement	28 (22.8)	20 (22.7)	8 (22.9)	1.000
Coronary artery bypass surgery	50 (40.7)	29 (33.0)	21 (60.0)	0.008
Others	8 (6.5)	3 (3.4)	5 (14.3)	0.041
Off-pump surgery	31 (25.2)	18 (20.5)	13 (37.1)	0.054
Postoperative examinations				
Creatinine (μmol/L), median (range)	116 (92–156)	106 (90–130)	156 (120–212)	<0.001
cTnT (ng/mL), median (range)	0.50 (0.31–0.95)	0.46 (0.26–0.80)	0.68 (0.39–1.73)	0.004
NT-proBNP (pg/mL), median (range)	4915 (2899–9201)	3640 (2572–5752)	12925 (8962–28641)	<0.001
TAPSE <16 mm, n (%)	43 (35.0)	28 (31.8)	15 (42.9)	0.296
LVEF (%), median (range)				
LVEF_Pre	37 (33–39)	37 (34–39)	35 (30–37)	0.003
LVEF_First	35 (30–42)	37 (32–44)	30 (25–35)	<0.001
LVEF_Low	34 (28–41)	36 (31–42)	27 (23–33)	<0.001
LVEF_Last	40 (35–45)	40 (35–45)	40 (33–43)	0.222
Low LVEF, n (%)				
LVEF_First	88 (71.5)	57 (64.8)	31 (88.6)	0.008
LVEF_Low	92 (74.8)	61 (69.3)	31 (88.6)	0.026
LVEF_Last	68 (55.3)	47 (53.4)	21 (60.0)	0.507
Inotropic or vasopressor drugs				
Epinephrine, n (%)	18 (14.6)	10 (11.4)	8 (22.9)	0.104
Norepinephrine, n (%)	67 (54.5)	47 (53.4)	20 (57.1)	0.708
Milrinone, n (%)	49 (39.8)	36 (40.9)	13 (37.1)	0.700
Dobutamine, n (%)	50 (40.7)	32 (36.4)	18 (51.4)	0.125
Levosimendan, n (%)	12 (9.8)	8 (9.1)	4 (11.4)	0.954
Supportive therapies				
IABP, n (%)	16 (13.0)	4 (4.5)	12 (34.3)	<0.001
RRT, n (%)	5 (4.1)	2 (2.3)	3 (8.6)	0.139
iNO, n (%)	3 (2.4)	1 (1.1)	2 (5.7)	0.195
Length of mechanical ventilation (day), median (range)	2 (1–3)	1 (1–2)	5 (2–8)	<0.001
Noninvasive ventilation, n (%)	11 (8.9)	4 (4.5)	7 (20.0)	0.012
Tracheotomy, n (%)	11 (8.9)	0 (0.0)	11 (31.4)	<0.001
Length of ICU stay (day), median (range)	4 (2–7)	3 (2–5)	11 (8–14)	<0.001
Length of hospital stay (day), median (range)	17 (13–24)	15 (11–18)	28 (20–43)	<0.001

Composite outcome: hospital mortality or ICU stay more than 7 days.

NYHA, New York Heart Association; cTnT, cardiac troponin T; NT-proBNP, N-terminal pro-brain natriuretic peptide; TAPSE, tricuspid annular plane systolic excursion; LVEF, left ventricular ejection fraction; IABP, intra-aortic balloon pump; RRT, renal replacement therapy; iNO, inhaled nitric oxide; ICU, intensive care unit.

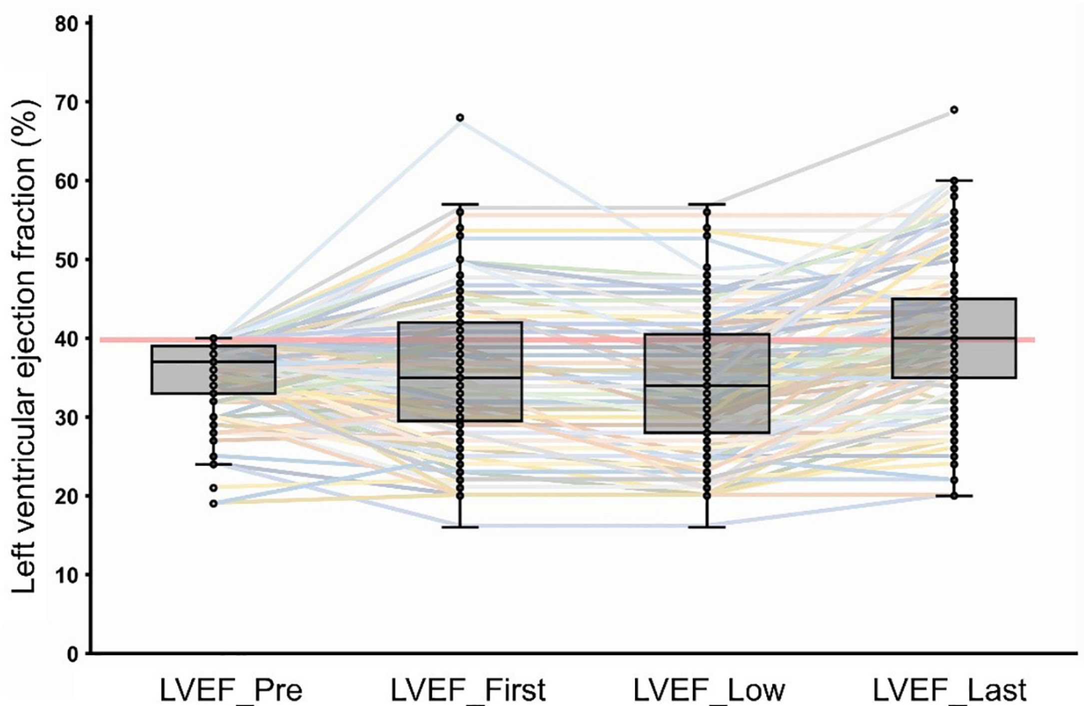

Fig. 1. Transition of LVEF during the perioperative period. The colored lines represent LVEF measurements at four time points in individual patients. Box-and-whisker plots are used to depict median, interquartile interval, minimum and maximum.

3.3 Clinical outcomes and related factors

Of 123 patients, four patients died, giving a mortality rate of 3.3%. The overall length of ICU stay was 4 days (IQR 2–7 days) and length of hospital stay was 17 days (IQR 13–24 days). A total of 35 patients (28.5%) met the composite endpoint of death or ICU ≥7 days. Pre- and postoperative level of creatinine, cTnT, NT-proBNP, Charlson comorbidity index and APACHE II score were significantly higher in patients who met the composite endpoint. Patients who met the composite endpoint also had lower pre- and postoperative LVEF, longer mechanical ventilation, longer ICU stay, and more frequently had IABP (Table 1).

Univariate logistic regression analysis showed that higher preoperative cTnT (per 0.1 ng/mL, OR = 3.52, 95% CI 1.75–8.51), APACHE II score (OR = 2.01, 95% CI 1.35–3.16), postoperative cTnT (per 0.1 ng/mL, OR = 1.78, 95% CI 1.24–2.84), and postoperative NT-proBNP (per 10000 pg/mL, OR = 2.78, 95% CI 1.76–4.93) were risk factors for the composite endpoint of death or ICU ≥7 days. Lower measurement of first and lowest postoperative LVEF were also risk factors. To avoid overfitting, only three parameters were used for multivariate analysis. The results are presented in Appendix Table 3 to demonstrate the correlation between LVEF and composite outcome. The ROC curve analysis is summarized by the area under the curve (AUC) at 95% CI and p-values in Fig. 2. NT-proBNP had the highest AUC value among the analyzed variables.

3.4 Association between left ventricular ejection fraction and composite outcome

Two smooth curves were fitted, and the relationship between LVEF_Pre and LVEF_Low with composite endpoint was assessed. Adjusted smoothed plot shows a non-linear relationship between composite endpoint and LVEF_Pre (p for likelihood ratio test (LRT) <0.05). The relationship between Ln(OR) of composite endpoint and LVEF_Pre was not significant up to the turning point (LVEF = 34%; $p > 0.05$). After the turning point, the Ln(OR) of the composite endpoint decreased with increasing LVEF (OR = 0.58, 95% CI 0.42–0.80, $p = 0.001$). However, there was a linear relationship between the composite endpoint and LVEF_Low (p for LRT = 0.12). The Ln(OR) of the composite endpoint decreased with increasing LVEF (OR = 0.83, 95% CI 0.76–0.91, $p < 0.01$) (Table 2, Fig. 3).

4. Discussion

Patients with preoperative low LVEF had increased mortality and postoperative morbidity after cardiac surgery. In our study, the overall mortality rate was 3.3% and a total of 35 patients (28.5%) met the composite endpoint, which was similar to reports in the literature. In one cohort study, 781 patients underwent cardiac surgery with a preoperative LVEF ≤40%, with a perioperative mortality rate of 5.6% [3]. Another study included a total of 588 cardiac patients with a preoperative LVEF ≤25%, and the overall operative mortality was 7.8% [7]. A study among off-pump coronary artery bypass patients found that 30-day mortality was 2.9% in 137 pa-

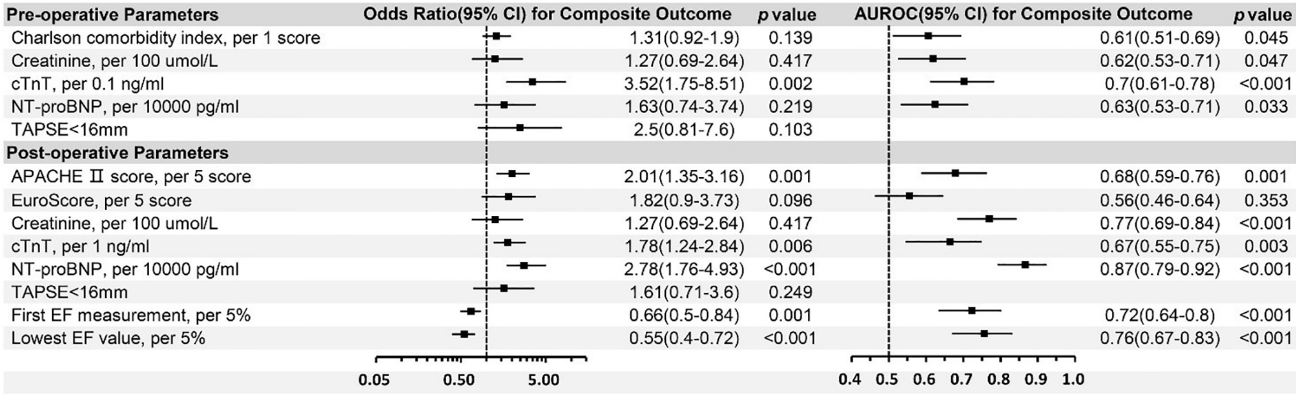

Fig. 2. Odds ratio and area under the curve of indicators for composite outcome. Each line segment indicates the corresponding Odds ratio and 95% confidence interval for each risk factor.

Table 2. Threshold effect analysis for the relationship between left ventricular ejection fraction and composite endpoint.

Models	LVEF_Pre		LVEF_ Low	
	Adjusted OR (95% CI)	*p* value	Adjusted OR (95% CI)	*p* value
Model I				
One line slope	0.85 (0.76–0.94)	<0.01	0.83 (0.76–0.91)	<0.01
Model II				
Turning point (K)	34		22	
<K slope 1	1.01 (0.85–1.21)	0.88	1.93 (0.75–4.96)	0.17
>K slope 2	0.58 (0.42–0.80)	<0.01	0.80 (0.72–0.89)	<0.01
LRT		0.007		0.119

Model I: linear analysis; Model II: non-linear analysis. *p* value < 0.05 means Model I is significantly different from Model II, which indicates a non-linear relationship.

Adjusted: adjusted for sex, age, APACHE II, EuroSCORE.

LRT, likelihood ratio test; LVEF, left ventricular ejection fraction; CI, confidence interval; OR, odds ratio.

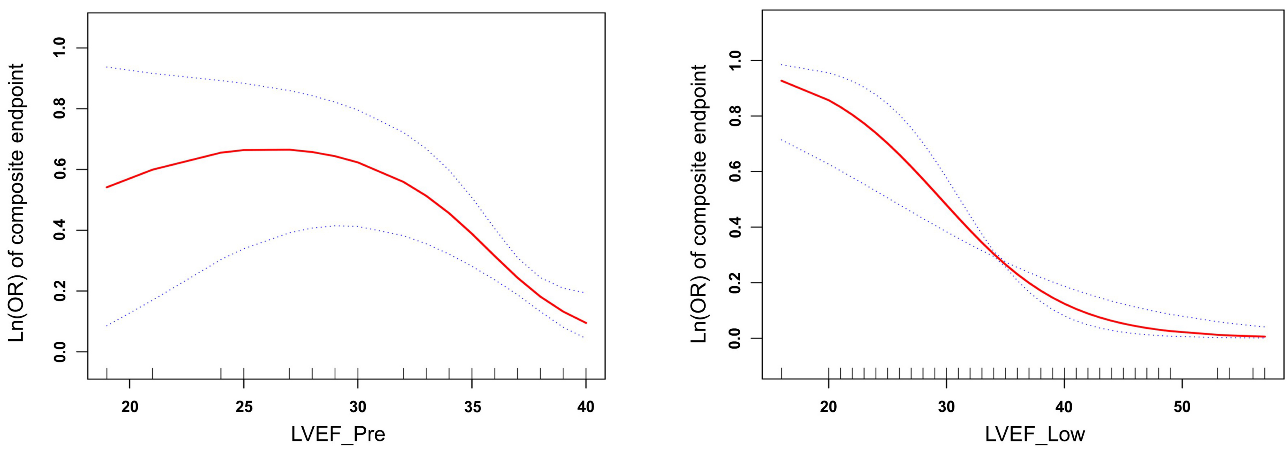

Fig. 3. Relationship between left ventricle ejection fraction (LVEF) and log odds ratio Ln(OR) of the composite endpoint after controlling for potential confounding variables (adjusted for sex, age, APACHE II, EuroSCORE).

tients with ejection fraction (EF) ≤35% [8]. Differing definitions of low LVEF, condition of patients and operative methods can be considered as leading to discrepancies in patient mortality among studies.

Owing to the relatively small sample size and few events, only univariate analyses were conducted. Some factors, including pre- and postoperative cTnT, NT-proBNP, APACHE II, and LVEF differed significantly between the groups. These factors might be correlated with poor progno-

Table 3. Odds ratio and 95% confidence interval of different variables.

	LVEF_Pre		LVEF_Low	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Crude	0.897 (0.825–0.975)	0.011	0.886 (0.836–0.940)	<0.001
Included one covariate in a separate logistic regression model				
+ Age	0.899 (0.826–0.977)	0.012	0.883 (0.832–0.937)	<0.001
+ Sex	0.883 (0.809–0.964)	0.005	0.882 (0.831–0.937)	<0.001
+ Charlson Comorbidity Index	0.898 (0.824–0.978)	0.014	0.878 (0.828–0.931)	<0.001
+ APACHE II score	0.899 (0.823–0.982)	0.018	0.893 (0.841–0.948)	<0.001
+ Preoperative Creatinine	0.897 (0.825–0.975)	0.011	0.881 (0.829–0.935)	<0.001
+ Preoperative cTnT	0.898 (0.823–0.981)	0.017	0.883 (0.829–0.942)	<0.001
+ Preoperative NT-proBNP	0.900 (0.826–0.980)	0.015	0.888 (0.838–0.941)	<0.001
+ Coronary artery bypass surgery	0.905 (0.831–0.987)	0.024	0.876 (0.825–0.941)	<0.001
+ Postoperative Creatinine	0.895 (0.821–0.975)	0.011	0.881 (0.829–0.936)	<0.001
+ Postoperative cTnT	0.889 (0.816–0.970)	0.008	0.893 (0.842–0.947)	<0.001
+ Postoperative NT-proBNP	0.891 (0.814–0.976)	0.013	0.896 (0.840–0.956)	0.001
+ IABP	0.910 (0.832–0.995)	0.038	0.885 (0.831–0.943)	<0.001
Included two covariates in a separate logistic regression model				
+ IABP+ Coronary artery bypass surgery	0.912 (0.833–0.998)	0.045	0.878 (0.823–0.937)	<0.001
+ Age + APACHE II score	0.899 (0.823–0.982)	0.018	0.891 (0.838–0.946)	<0.001
+ Charlson Comorbidity Index + APACHE II score	0.901 (0.824–0.984)	0.021	0.884 (0.832–0.939)	<0.001
+ APACHE II score+ Preoperative cTnT	0.895 (0.815–0.983)	0.020	0.887 (0.830–0.948)	<0.001
+ APACHE II score+ Preoperative NT-proBNP	0.900 (0.823–0.985)	0.021	0.894 (0.842–0.949)	<0.001

sis. On further analysis of the data, postoperative indicators had larger OR values and larger areas under the ROC curve, which seemed to suggest that postoperative indicators were more closely related to patient outcomes than preoperative indicators [17, 18].

In this cursory statistical study, we found a trend that LVEF decreased after surgery and then gradually increased. Few studies have focused on the short-term changes in ventricular performance and LVEF before and after cardiac surgery. Sugimura *et al.* [19] reviewed the perioperative and 1-year follow-up data of 436 patients with primary mitral regurgitation to analyze patients' postoperative evolution of LVEF and its factors. The result showed that overall mean LVEF slightly decreased at 1-year follow-up (mean change of LVEF: –2.63% ± 9.00%). Newman *et al.* [20] measured scintigraphic LVEF 16 weeks after coronary bypass surgery. No change in resting ejection indices were detected and end-diastolic volume increased slightly only in those patients with postoperative symptoms. In a study of patients undergoing coronary artery bypass surgery, Mintz *et al.* [21] found a decrease in LVEF at 1 week when compared with preoperative measurements. Ejection indices returned to preoperative levels by 2 months and remained stable over the year follow-up. In our study, we found that LVEF did change with surgical intervention, and this change was more often a transient deterioration, which was also consistent with laboratory indicators. With postoperative treatment, the LVEF of most patients could be improved. Such changes are acceptable and prove that the majority of patients with low LVEF can benefit from cardiac surgery.

With further exploration of the relationship between LVEF and prognosis, we found that an increased log odds ratio (OR) of composite endpoint was linearly related to the decreased postoperative LVEF, but not significantly linearly related to preoperative LVEF. Multiple studies have explored the association between LVEF and prognosis in cardiac surgery patients and have found that preoperative LVEF was an independent predictor affecting long-term prognosis. In a study by Furer *et al.* [22], patients who underwent transcatheter aortic valve replacement with preoperative LVEF <50% were included for analysis. The results showed that preoperative LVEF was associated with increased 2-year risk of both cardiovascular mortality and all-cause mortality. Dahl *et al.* [23] conducted a retrospective analysis of the data of patients with severe aortic stenosis and found that preoperative LVEF was a powerful predictor of outcome in patients with severe aortic stenosis undergoing aortic valve replacement. However, these two studies did not include postoperative LVEF in the analysis, nor did they analyze the linear correlation between LVEF and prognosis. There were also some differences in the characteristics of the subjects compared with those in our study.

We believe that postoperative LVEF can better predict the short-term outcomes of patients undergoing cardiac surgery. On the one hand, there is still controversy over whether LVEF reflects true cardiac function. For example, in patients with mitral regurgitation, preoperative LVEF measured by routine echocardiography may underestimate myocardial systolic dysfunction due to structural changes [24]. On the other hand, cardiac surgery is an important factor affecting the prognosis of patients. Postoperative LVEF not only reflects the preoperative cardiac function of patients, but also reflects the effect of cardiac surgery on patients. From further analysis of postoperative LVEF in this study, we recommend that short-term prognosis of patients with preoperative low LVEF should be evaluated according to postoperative LVEF.

5. Limitations

There were some limitations that should be addressed in this study. First, this was a retrospective cohort study with a small sample size. The number of patients with low LVEF before cardiac surgery was limited, even though they were enrolled from a large clinical cohort of over 4000 patients. Further investigation of a larger population is required, to increase statistical power and make the current results more convincing. Second, we only focused on patients' short-term outcomes during their hospitalization. As the long-term follow-up of these patients had not yet started, data on changes to long-term LVEF and prognosis are missing. A larger sample size and more long-term follow-up data would have made our conclusions more comprehensive and meaningful. Third, only Chinese people were included in this study. Whether this conclusion is also applicable to patients of other races needs further verification.

6. Conclusions

The mortality rate of patients with low preoperative LVEF was very low at a large-volume cardiovascular center. Most patients experience a short decline in LVEF after surgery and then an increase during hospitalization. The lowest postoperative LVEF was associated with short-term prognosis of patients after cardiac surgery.

Author contributions

JZ, JG, JCL, ZL, GWT—Conception and design; ZL, GWT—Provision of study material or patients; JZ, JCL, YJZ, KY, HW—Collection and assembly of data; JZ, JG, JCL, GWT—Data analysis and interpretation; all authors—Manuscript writing; all authors—Final approval of manuscript.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Zhongshan Hospital, Fudan University (B2019-075R). Individual consent for this retrospective analysis was waived.

Acknowledgment

We would like to express our gratitude to all those who helped us during the writing of this manuscript. Thanks to all the peer reviewers for their opinions and suggestions.

Funding

This research was funded by grants from Natural Science Foundation of Shanghai (grant number 20ZR1411100), Science and Technology Commission of Shanghai Municipality (grant number 20DZ2261200), National Natural Science Foundation of China (grant number 82070085), Construction Program of Key but Weak Disciplines of the Shanghai Health Commission (grant number 2019ZB0105), Clinical Research Project of Zhongshan Hospital (grant number 2020ZSLC38 and 2020ZSLC27), Smart Medical Care of Zhongshan Hospital (grant number 2020ZHZS01), Project for Elite Backbone of Zhongshan Hospital (grant number 2021ZSGG06), Foundation For Young Researchers of Zhongshan Hospital (grant number 2021ZSQN22, 2021ZSQN71 and 2021ZSQN72).

Conflict of interest

The authors declare no conflict of interest.

Appendix

See Table 3 for details.

References

[1] Potter E, Marwick TH. Assessment of Left Ventricular Function by Echocardiography: The Case for Routinely Adding Global Longitudinal Strain to Ejection Fraction. JACC: Cardiovascular Imaging. 2018; 11: 260–274.

[2] Paulus WJ, Tschope C, Sanderson JE, Rusconi C, Flachskampf FA, Rademakers FE, *et al.* How to diagnose diastolic heart failure: a consensus statement on the diagnosis of heart failure with normal left ventricular ejection fraction by the Heart Failure and Echocardiography Associations of the European Society of Cardiology. European Heart Journal. 2007; 28: 2539–2550.

[3] Pieri M, Belletti A, Monaco F, Pisano A, Musu M, Dalessandro V, *et al.* Outcome of cardiac surgery in patients with low preoperative ejection fraction. BMC Anesthesiology. 2016; 16: 97.

[4] Thuijs DJFM, Milojevic M, Stone GW, Puskas JD, Serruys PW, Sabik JF 3rd, *et al.* Impact of left ventricular ejection fraction on clinical outcomes after left main coronary artery revascularization: results from the randomized EXCEL trial. European Journal of Heart Failure. 2020; 22: 871–879.

[5] Lee LS, Clark AJ, Namburi N, Naum CC, Timsina LR, Corvera JS, *et al.* The presence of a dedicated cardiac surgical intensive care service impacts clinical outcomes in adult cardiac surgery patients. Journal of Cardiac Surgery. 2020; 35: 787–793.

[6] Alkashkari W, Alsubei A, Hijazi ZM. Transcatheter Pulmonary Valve Replacement: Current State of Art. Current Cardiology Reports. 2018; 20: 27.

[7] Seese L, Sultan I, Gleason T, Wang Y, Thoma F, Navid F, *et al.* Outcomes of Conventional Cardiac Surgery in Patients with Severely Reduced Ejection Fraction in the Modern Era. The Annals of Thoracic Surgery. 2020; 109: 1409–1418.

[8] Maltais S, Ladouceur M, Cartier R. The influence of a low ejection fraction on long-term survival in systematic off-pump coronary artery bypass surgery. European Journal of Cardio-Thoracic Surgery. 2011; 39: e122–e127.

[9] Maes F, Lerakis S, Barbosa Ribeiro H, Gilard M, Cavalcante JL, Makkar R, *et al.* Outcomes from Transcatheter Aortic Valve Replacement in Patients with Low-Flow, Low-Gradient Aortic Stenosis and Left Ventricular Ejection Fraction less than 30%: A Substudy From the TOPAS-TAVI Registry. JAMA Cardiology. 2019; 4: 64–70.

[10] Lee R, Haluska B, Leung DY, Case C, Mundy J, Marwick TH. Functional and prognostic implications of left ventricular contractile reserve in patients with asymptomatic severe mitral regurgitation. Heart. 2005; 91: 1407–1412.
[11] Khaled S, Kasem E, Fadel A, alzahrani Y, Banjar K, Al-Zahrani W, *et al.* Left ventricular function outcome after coronary artery bypass grafting, King Abdullah Medical City (KAMC)- single-center experience. The Egyptian Heart Journal. 2019; 71: 2.
[12] Papestiev V, Jovev S, Sokarovski M, Risteski P, Andova V, Zdraveski V, *et al.* Changes of Left Ventricular Systolic Function in Patients Undergoing Coronary Artery Bypass Grafting. Open Access Macedonian Journal of Medical Sciences. 2019; 7: 3574–3578.
[13] Jin Y, Wang HS, Wang ZW, Li XM, Yin ZT, Zhu Y. Risk factors for midterm cardiac function deterioration after valve replacement surgery in patients with rheumatic mitral stenosis. Journal of Cardiac Failure. 2013; 19: 565–570.
[14] Dubroff JM, Clark MB, Wong CY, Spotnitz AJ, Collins RH, Spotnitz HM. Left ventricular ejection fraction during cardiac surgery: a two-dimensional echocardiographic study. Circulation. 1983; 68: 95–103.
[15] Quan H, Li B, Couris CM, Fushimi K, Graham P, Hider P, *et al.* Updating and Validating the Charlson Comorbidity Index and Score for Risk Adjustment in Hospital Discharge Abstracts Using Data from 6 Countries. American Journal of Epidemiology. 2011; 173: 676–682.
[16] Cholley B, Caruba T, Grosjean S, Amour J, Ouattara A, Villacorta J, *et al.* Effect of Levosimendan on Low Cardiac Output Syndrome in Patients with Low Ejection Fraction Undergoing Coronary Artery Bypass Grafting with Cardiopulmonary Bypass: The LICORN Randomized Clinical Trial. The Journal of the American Medical Association. 2017; 318: 548–556.
[17] Rodseth RN, Biccard BM, Le Manach Y, Sessler DI, Lurati Buse GA, Thabane L, *et al.* The Prognostic Value of Pre-Operative and Post-Operative B-Type Natriuretic Peptides in Patients Undergoing Noncardiac Surgery: B-type natriuretic peptide and N-terminal fragment of pro-B-type natriuretic peptide: a systematic review and individual patient data meta-analysis. Journal of the American College of Cardiology. 2014; 63: 170–180.
[18] Manfrini O, Cenko E, Ricci B, Bugiardini R. Post Cardiovascular Surgery Atrial Fibrillation. Biomarkers Determining Prognosis. Current Medicinal Chemistry. 2019; 26: 916–924.
[19] Sugimura Y, Katahira S, Rellecke P, Kamiya H, Minol JP, Immohr MB, *et al.* The analysis of left ventricular ejection fraction after minimally invasive surgery for primary mitral valve regurgitation. Journal of Cardiac Surgery. 2021; 36: 661–669.
[20] Newman GE, Rerych SK, Jones RH, Sabiston DC Jr. Noninvasive assessment of the effects of aorta-coronary bypass grafting on ventricular function during rest and exercise. The Journal of Thoracic and Cardiovascular Surgery. 1980; 79: 617–624.
[21] Mintz LJ, Ingels NB Jr, Daughters GT 2nd, Stinson EB, Alderman EL. Sequential studies of left ventricular function and wall motion after coronary arterial bypass surgery. The American Journal of Cardiology. 1980; 45: 210–216.
[22] Furer A, Chen S, Redfors B, Elmariah S, Pibarot P, Herrmann HC, *et al.* Effect of Baseline Left Ventricular Ejection Fraction on 2-Year Outcomes after Transcatheter Aortic Valve Replacement: Analysis of the PARTNER 2 Trials. Circulation Heart Failure. 2019; 12: e005809.
[23] Dahl JS, Eleid MF, Michelena HI, Scott CG, Suri RM, Schaff HV, *et al.* Effect of Left Ventricular Ejection Fraction on Postoperative Outcome in Patients with Severe Aortic Stenosis Undergoing Aortic Valve Replacement. Circulation Cardiovascular Imaging. 2015; 8: e002917.
[24] Gaasch WH, John RM, Aurigemma GP. Managing Asymptomatic Patients with Chronic Mitral Regurgitation. Chest. 1995; 108: 842–847.