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Minimally invasive technique facilitates early extubation after cardiac surgery: a single-center retrospective study

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Abstract

Background Postoperative time to extubation plays a role in prognosis after heart valve surgery; however, its exact impact has not been clarified. This study compared the postoperative outcomes of minimally invasive surgery and conventional sternotomy, focusing on early extubation and factors influencing prolonged mechanical ventilation.

Methods Data from 744 patients who underwent heart valve surgery at the Zhejiang Provincial People's Hospital between August 2019 and June 2022 were retrospectively analyzed. The outcomes in patients who underwent conventional median sternotomy (MS) and minimally invasive (MI) video-assisted thoracoscopic surgery were compared using inverse probability of treatment weighting (IPTW) and Kaplan–Meier curves. Clinical data, including surgical data, postoperative cardiac function, postoperative complications, and intensive care monitoring data, were analyzed.

Results After propensity score matching and IPTW, 196 cases of conventional MS were compared with 196 cases of MI video-assisted thoracoscopic surgery. Compared to patients in the conventional MS group, those in the MI video-assisted thoracoscopic surgery group in the matched cohort had a higher early postoperative extubation rate ($P < 0.01$), reduced incidence of postoperative pleural effusion ($P < 0.05$), significantly shorter length of stay in the intensive care unit ($P < 0.01$), shorter overall length of hospital stay ($P < 0.01$), and lower total cost of hospitalization ($P < 0.01$).

Conclusions Successful early tracheal extubation is important for the intensive care management of patients after heart valve surgery. The advantages of MI video-assisted thoracoscopic surgery over conventional MS include significant reductions in the duration of use of mechanical ventilation support, reduced length of intensive care unit stay, reduced total length of hospitalization, and a favorable patient recovery rate.

Keywords Thoracoscopy, Conventional median sternotomy, Heart valve surgery, Mechanical ventilation, Extubation, Intensive care

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Introduction

Current surgical approaches for heart valve surgery such as conventional median sternotomy (MS), minimally invasive (MI) surgical approaches, and transcatheter aortic valve replacement, pose challenges to the postoperative management of critically ill patients.

Conventional MS, a traditional surgical approach, has several shortcomings, including unavoidable blood loss, the need for blood transfusion, and a longer recovery period [1]. To improve postoperative outcomes after cardiac surgery, MI surgical approaches, including upper and lower sternal incisions and left and right anterolateral incisions, were developed [2, 3]. MI surgery has been previously shown to be advantageous by preserving sternal integrity, improving surgical site healing, decreasing infection rates, and enhancing postoperative recovery [4–7]. However, whether these advantages contribute to the early extubation and postoperative management benefits of these patients remains to be determined.

This study hypothesizes that MI surgery is more effective than MS in facilitating early extubation and optimizing postoperative management for patients. The analysis was conducted using propensity score matching (PSM) and inverse probability of treatment weighting (IPTW) during intensive care monitoring, while also analyzing factors influencing prolonged mechanical ventilation.

Materials and methods

Institutional review board approval

This study was approved by the Institutional Review Board and the Ethics Committee of the of Zhejiang Provincial People's Hospital, which complies with the Declaration of Helsinki (ethics approval number: QT2022383, date: November 21, 2022). Individual consent for this retrospective analysis was waived.

Patient characteristics

Data from patients who underwent mitral, tricuspid, or aortic valve treatments at the Zhejiang Provincial People's Hospital were retrospectively collected and analyzed. Valve treatments included valve replacement and valvuloplasty. Patients undergoing coronary artery bypass grafting or other concomitant procedures, such as cardiac myxoma resection, transcatheter aortic valve replacement, or right ventricular outflow tract reconstruction, were excluded. Moreover, patients aged < 18 years or those who underwent secondary cardiac surgery were excluded (Fig. 1).

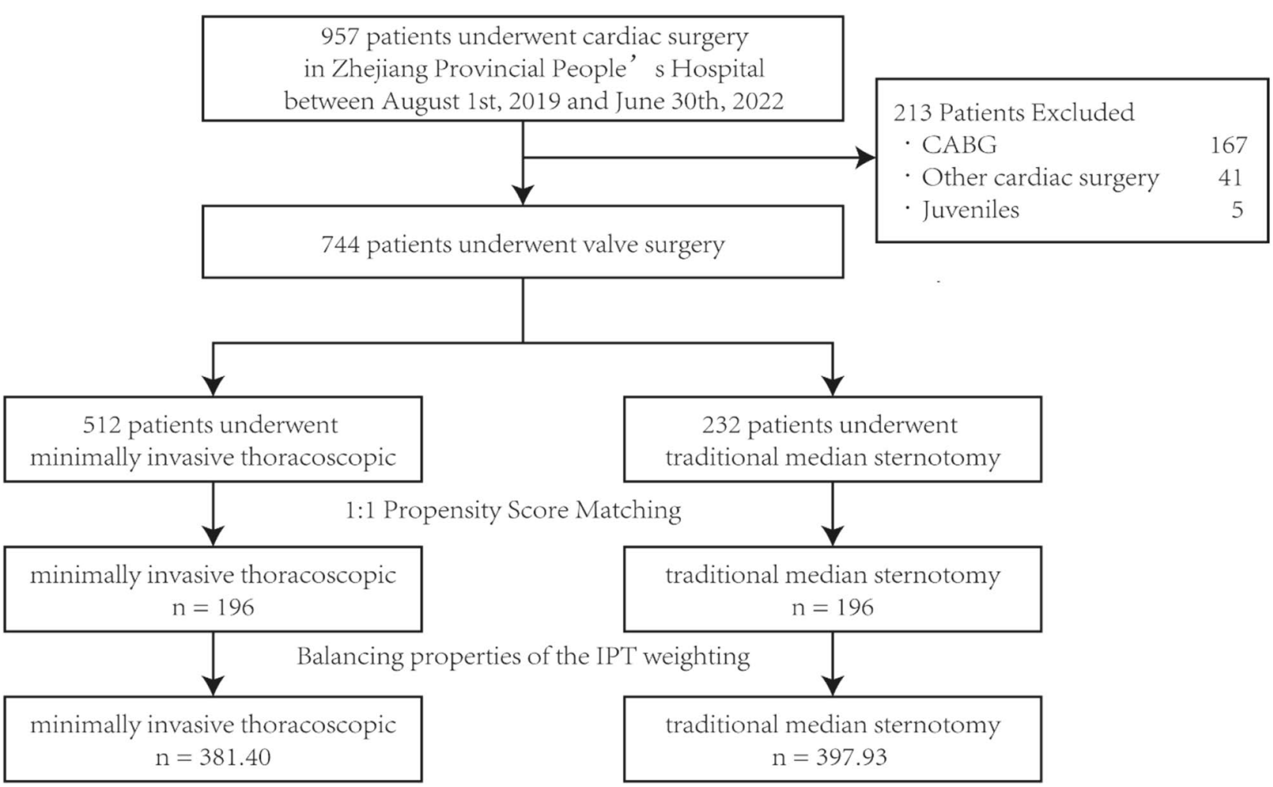

Fig. 1 Flowchart demonstrating patient inclusion and cohort matching using PSM and IPTW. Patients with angioplasty, CABG, other concomitant procedures such as cardiac myxoma removal, or right ventricular outflow tract reconstruction are excluded. CABG, coronary artery bypass grafting; IPTW, inverse probability of treatment weighting; PSM, propensity score matching

The primary endpoint was successful extubation within 48 h post-cardiac surgery, without the need for mechanical ventilation assistance thereafter. The records of patients who died or voluntarily left the hospital were right-censored. The secondary endpoints were postoperative complications during the intensive care monitoring period (patients were selected for rapid tracheal extubation on initial admission or based on clinical presentation and test results within 48 h of extubation), including postoperative pneumonia, arrhythmias, pleural effusions, abnormal postoperative cardiac output, and stroke. Additionally, the length of hospital stay, length of ICU stay, and cost of hospitalization were recorded.

Data analysis

Continuous variables conforming to the normal distribution are presented as mean ± standard deviation, and categorical variables as proportions. Kaplan–Meier survival curves were utilized for the analysis of time to extubation, and log-rank tests were used to detect differences between groups.

To control for confounding by indication and balance potential confounders when comparing groups, we estimated propensity scores (PS) using a logistic regression model with conditional probabilities of extubation for covariates measured at baseline. PS included variables, such as age, type of valve surgery, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, New York Heart Association (NYHA) classification, infective endocarditis, and cross-clamp time, which were estimated separately based on the type of valve surgery. We used the nearest neighbor method for 1:1 PS matching with a maximum radius of 0.5 to balance potential confounders that may arise due to different surgical approaches.

Conceptually, IPTW was mathematically considered as standardized equivalents. The equilibrium properties of IPTW can be determined by comparing the covariate distributions of IPTW before and after standardizing differences (conditional probability of 1/PS for tracheal extubation and 1/[1-PS] for mechanical ventilation). Standardized differences of > 10% were considered meaningful. After matching, no differences were observed between the two groups in terms of sex, age, height, weight, body mass index, APACHE II score, infective endocarditis, rheumatic heart disease, cardiomyopathy, coronary artery disease, NYHA classification, type of surgery, CPB time, and cross-clamp time (all $P > 0.05$, Table 1).

The two surgical modalities were compared in terms of total drainage volume and overall blood product requirements. Patient preoperative and postoperative RBC (Fig. 2) and WBC counts (Fig. 3) were compared using intra- and intergroup tests. A matched cohort of patients was selected, and the total drainage volume from the chest tubes of the patients, total amount of blood products, RBC count, and amount of plasma transfused were recorded, and the mean and standard deviation were calculated for each subgroup (Fig. 4).

Postoperative extubation time was further analyzed for its association with various secondary outcome indicator, including mortality, poor wound healing, arrhythmia, pleural effusion, stroke, EF < 50%, pneumonia, admission in the ICU, and admission in the hospital. This analysis utilized a restricted cubic spline based on matched data, with the surgical approach serving as the covariate. (Fig. 5). In addition, univariate and multivariate regression analyses were used to evaluate the factors influencing secondary outcome indicators, and the optimal model was selected according to the Akaike information criterion, with results of $P < 0.05$ (Fig. 6).

All statistical tests were two-sided; differences with $P < 0.05$ were considered statistically significant. R v. 4.1.0 (R Foundation for Statistical Computing; Vienna, Austria; https://www.rproject.org/) was used for statistical analysis.

Results

Patient characteristics

Between August 1, 2019, and June 30, 2022, 957 patients underwent cardiac surgery. The data of 744 patients who underwent tricuspid valve surgery, mitral valve surgery, or aortic valve treatment at the Zhejiang Provincial People's Hospital were analyzed. Overall, 326 (43.82%) patients were male and 418 (56.18%) female, with a median age of 62 years (interquartile range [IQR], 52–69 years). Overall, 232 patients (31.18%) underwent conventional MS and 512 (68.82%) underwent MI thoracoscopic procedures. The distribution of surgery type and NYHA classification differed between the two groups ($P < 0.01$). Compared to the conventional MS group, in the MIs group, cardiopulmonary bypass (CPB) time (161 [IQR: 125–203] min, $P < 0.0001$) and cross-clamp time (106 [IQR: 81–146] min, $P < 0.0001$) were shorter. Other variables, including coronary heart disease, rheumatic heart disease, and APACHE II scores, were similar between the two groups (Table 1).

In the unmatched cohort, the MI surgery group had fewer instances of arrhythmias, pneumonia, pleural effusion, and abnormal postoperative cardiac output, along with a shorter duration of ICU stay. The incidence of mortality was higher in the conventional MS group than in the MI group ($P < 0.05$). Notably, MI surgery was more expensive than the conventional MS surgery (cost of MI surgery: 19815.7 [IQR, 16,816.95–23,345.25] ¥ vs. cost of conventional MS surgery: 18,454.15 [IQR, 14,586.175–21,955.9] ¥, $P < 0.01$); however, the total cost of MI surgery was significantly lower than that of conventional

Table 1 Patient demographics after PSM and IPTW

	Category	PSM		*P*	SMD	IPTW		*P*	SMD
		MS (*n* = 196)	**MI surgery (*n* = 196)**			**Conventional MS (*n* = 397.93)**	**MI surgery (*n* = 381.4)**		
Surgical operation (%)	AVR	117 (59.69)	117 (59.69)	1	< 0.0001	232.59 (58.45)	214.19 (56.16)	0.9927	0.0538
	AVR + MVR	27 (13.78)	27 (13.78)			55.34 (13.91)	54.25 (14.22)		
	AVR + MVR + TVR	10 (5.10)	10 (5.10)			20.13 (5.06)	19.18 (5.03)		
	MVR	16 (8.16)	16 (8.16)			35.71 (8.98)	38.62 (10.13)		
	MVR + TVR	26 (13.27)	26 (13.27)			54.15 (13.61)	55.16 (14.46)		
BMI (median [IQR])		22.862 [20.761– 25.973]	22.878 [21.101–24.870]	0.5545	0.1193	22.837 [20.760–25.677]	22.862 [21.166–25.043]	0.8946	0.049
APACHE II (median [IQR])		14.000 [11.000–18.000]	14.500 [11.000–17.000]	0.6566	0.1364	14.000 [11.000–17.000]	14.586 [11.000–17.000]	0.5142	0.0284
Height (median [IQR])		165.000 [160.000–, 170.000]	165.000 [158.000–170.000]	0.2719	0.0701	165.000 [158.000–170.000]	165.000 [158.000–170.000]	0.8548	0.022
Weight (median [IQR])		63.250 [54.750– 72.000]	62.000 [55.000–70.000]	0.3905	0.1221	63.000 [54.000–70.000]	62.000 [55.000–70.000]	0.9434	0.0177
SEX (%)	female	73 (37.24)	75 (38.27)	0.917	0.0211	152.61 (38.35)	140.16 (36.75)	0.7551	0.0331
	male	123 (62.76)	121 (61.73)			245.32 (61.65)	241.24 (63.25)		
AGE (median [IQR])		59.000 [52.000–69.000]	63.000 [53.000– 68.000]	0.2175	0.1318	60.000 [53.000–69.000]	63.000 [52.000–68.000]	0.9925	0.0107
NYHA Classification (%)	Level I	31 (15.82)	11 (5.61)	0.0097	0.3464	40.70 (10.23)	30.24 (7.93)	0.9021	0.0812
	Level II	50 (25.51)	64 (32.65)			113.17 (28.44)	113.57 (29.78)		
	Level III	100 (51.02)	106 (54.08)			213.65 (53.69)	208.00 (54.54)		
	Level IV	15 (7.65)	15 (7.65)			30.40 (7.64)	29.58 (7.76)		
Infective endocarditis (%)		22 (11.22)	10 (5.10)	0.0424	0.225	31.94 (8.03)	30.31 (7.95)	0.9785	0.0029
Rheumatic heart disease (%)		22 (11.22)	20 (10.20)	0.8703	0.033	47.97 (12.05)	38.73 (10.16)	0.5624	0.0605
Cardiomyopathy (%)		5 (2.55)	4 (2.04)	1	0.0341	11.48 (2.88)	11.87 (3.11)	0.9212	0.0133
Coronary heart disease (%)		32 (16.33)	38 (19.39)	0.5097	0.08	72.40 (18.19)	70.81 (18.57)	0.9285	0.0096
CPB (median [IQR])		194.000 [140.000–242.750]	160.000 [129.500–194.250]	< 0.0001	0.483	165.000 [121.873–217.000]	168.001 [137.877–202.442]	0.9293	0.0117
Cross clamp time (median [IQR])		139.500 [96.000–179.250]	107.000 [82.000–138.000]	< 0.0001	0.5299	109.299 [83.631–159.759]	115.261 [89.000–151.000]	0.9346	0.0362

APACHE II, Acute Physiology and Chronic Health Evaluation II; AVR, aortic valve replacement; BMI, body mass index; IPTW, inverse probability of treatment weighting; MI, minimally invasive; MS, median sternotomy; MVR, mitral valve replacement; NYHA, New York Heart Association; PSM, propensity score matching; SMD, standardized mean difference; TVR, tricuspid valve repair; CPB, cardiopulmonary bypass

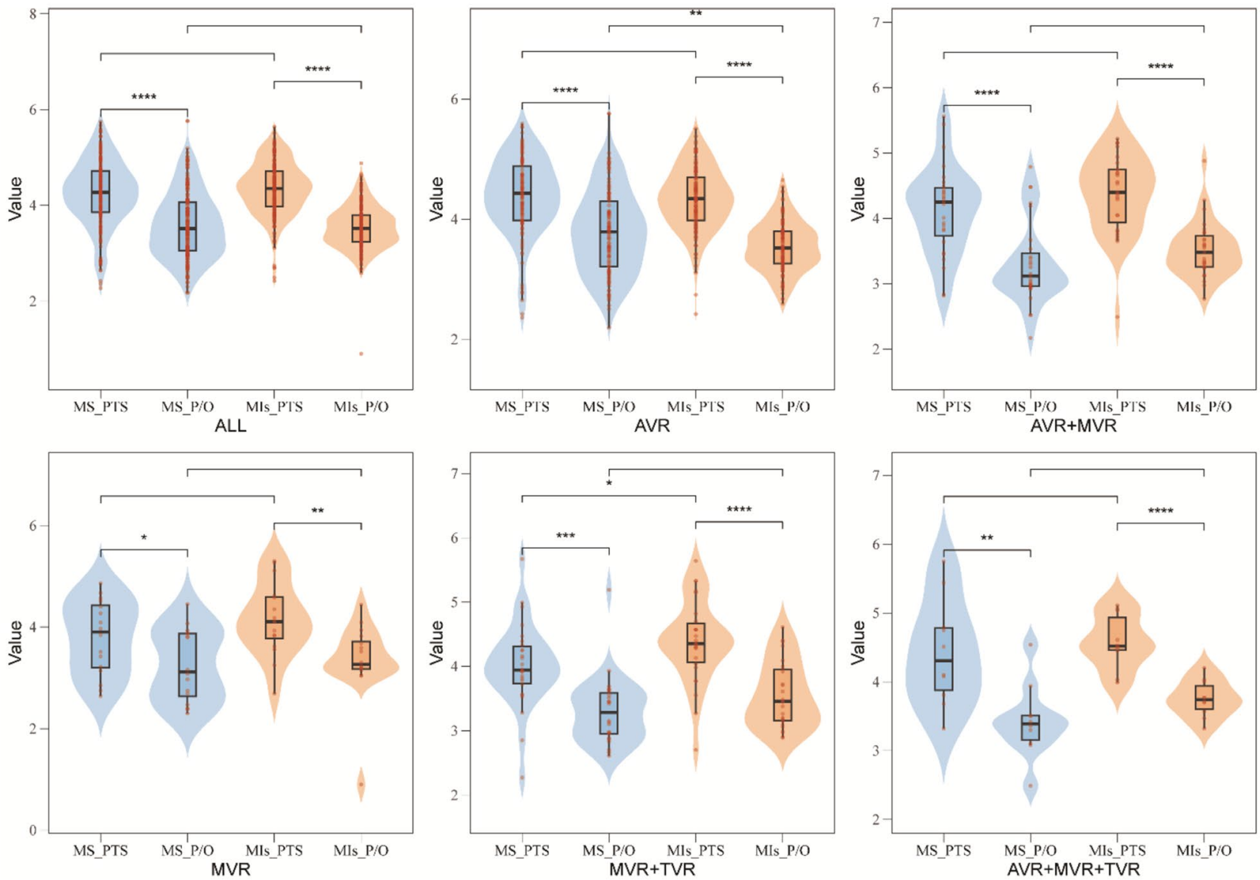

Fig. 2 Changes of RBC count level before and after operation. Preoperative and postoperative RBC count levels are compared using violin diagrams and differential analysis, and analysis was performed at different subgroup levels

MS surgery (MI surgery: 122,544.535 [IQR, 102,001.02–147,933.02] ¥ vs. conventional MS surgery: 167,053.945 [IQR, 132,491.198–213,130.198] ¥, $P<0.01$) (Table 2).

PSM and IPTW

After PSM, the measured covariates, including sex, age, height, weight, body mass index, APACHE II score, infective endocarditis, rheumatic heart disease, cardiomyopathy, coronary artery disease, NYHA classification, type of surgery, CPB time, and cross-clamp time, were well balanced between the MI surgery and conventional MS groups(Table 1). The smallest standardized mean difference (<0.1) between the MI surgery and conventional MS groups before and after IPTW. After IPTW, the two groups had well-balanced covariates.

Figure 7 shows the Kaplan–Meier survival curves for time to extubation in the MI surgery and conventional MS group in the unmatched cohort (conventional MS group: 20.34 h, 95% confidence interval [CI]: 17.72–31.18 vs. MI surgery group: 10.33 h, 95% CI: 9.37–11.61 h; log-rank $P<0.001$), in the matched cohort after PSM (conventional MS group: 17.39 h, 95% CI: 16.11–19.92 vs. MI surgery group: 9 h, 95% CI: 7.60–10.86; log-rank $P<0.001$), and in the matched cohort after IPTW (conventional MS group: 16.42 h, 95% CI: 15.70–18.18 vs. MI surgery group: 10 h, 95% CI: 8.21–12.04; log-rank $P<0.001$). In all three cohorts, postoperative extubation times were significantly shorter in the MIs group than in the conventional MS group. In addition, in the matched cohort, the patients in the conventional MS group had a higher incidence of postoperative cardiac output abnormalities (PSM: 28% [4.29] vs. 14% [7.14], $P=0.0338$) and pleural effusion (PSM: 137 [69.90] vs. 114 [58.16], $P=0.0206$). No significant difference in the incidence of other postoperative complications was observed between the MI surgery and conventional MS groups.

Postoperative complications and secondary outcomes are presented in Tables 2 and 3. The most common major complication in both groups was pleural effusion ($n=439$, 59.01%). In the unmatched cohort (Table 2), compared to that observed in the conventional MS group, in the MI surgery group, a shorter overall length of hospital stay (MS: 18 days [IQR: 15–24 days] vs. MI: 15 days [IQR: 12–18 day], $P<0.0001$) and duration of intensive care

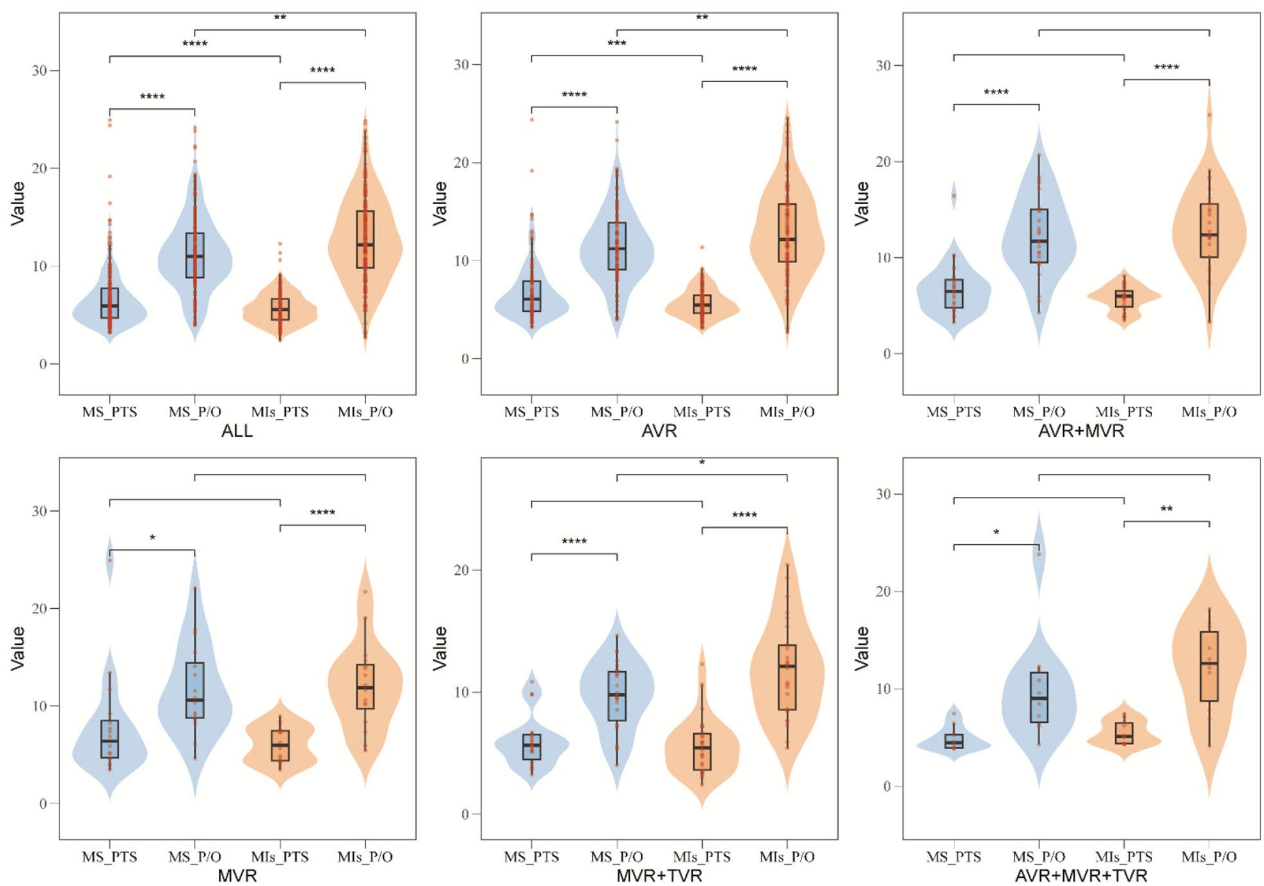

Fig. 3 Changes of WBC count level before and after operation. Preoperative and postoperative WBC count levels are compared using violin diagrams and differential analysis, and analysis performed at different subgroup levels

unit (ICU) stay (MS: 3 days [IQR: 2–6.25 days] vs. MI: 2 days [IQR: 1–3 days], $P<0.0001$) were observed. These results remained consistent after matching using PSM and IPTW (Table 3).

Examining the association between each complication and prolonged mechanical ventilation support therapy (Fig. 5) showed that prolonged mechanical ventilation was associated with the development of postoperative complications. Furthermore, patients with successful extubation within 15 h had a lower overall rate of these complications than those who required prolonged mechanical ventilation support therapy. A strong positive correlation was observed between the occurrence of postoperative complications and prolonged mechanical ventilation because reliance on mechanical ventilation requires enhanced postoperative intensive care management and attention to the development of common complications. Similarly, patients who were successfully extubated within 15 h had reduced duration of ICU and hospital stay.

Using odds ratios (ORs), factors influencing the development of each complication (Fig. 6) were further analyzed, specific models designed, and predictive accuracies measured (Supplementary Table 1). MI surgery had a protective advantage against the adjusted postoperative development of abnormal cardiac output (OR: 0.5742 [0.5361–0.6149], $P=0.035$), stroke (OR: 0.3665 [0.3422–0.3926, $P=0.035$), and pleural effusion (OR: 0.6902 [0.6675–0.7137], $P=0.0171$), but contributed to the probability of developing pneumonia during the postoperative period (OR: 5.971 [5.8601–6.0839], $P=0.0096$).

Overall management during intensive care

This study examined postoperative management in heart valve surgery patients in intensive care, focusing on pre- and postoperative circulation data. Analysis centered on changes in white blood cell (WBC) and red blood cell (RBC) counts, comparing intra- and intergroup differences. Results indicated no significant variance in WBC counts post-surgery, consistent across subgroups. Despite potential bias in estimating intraoperative bleeding, changes in RBC count demonstrated that there was no significant difference in intraoperative blood loss between the two groups. Excluding unmatched aortic

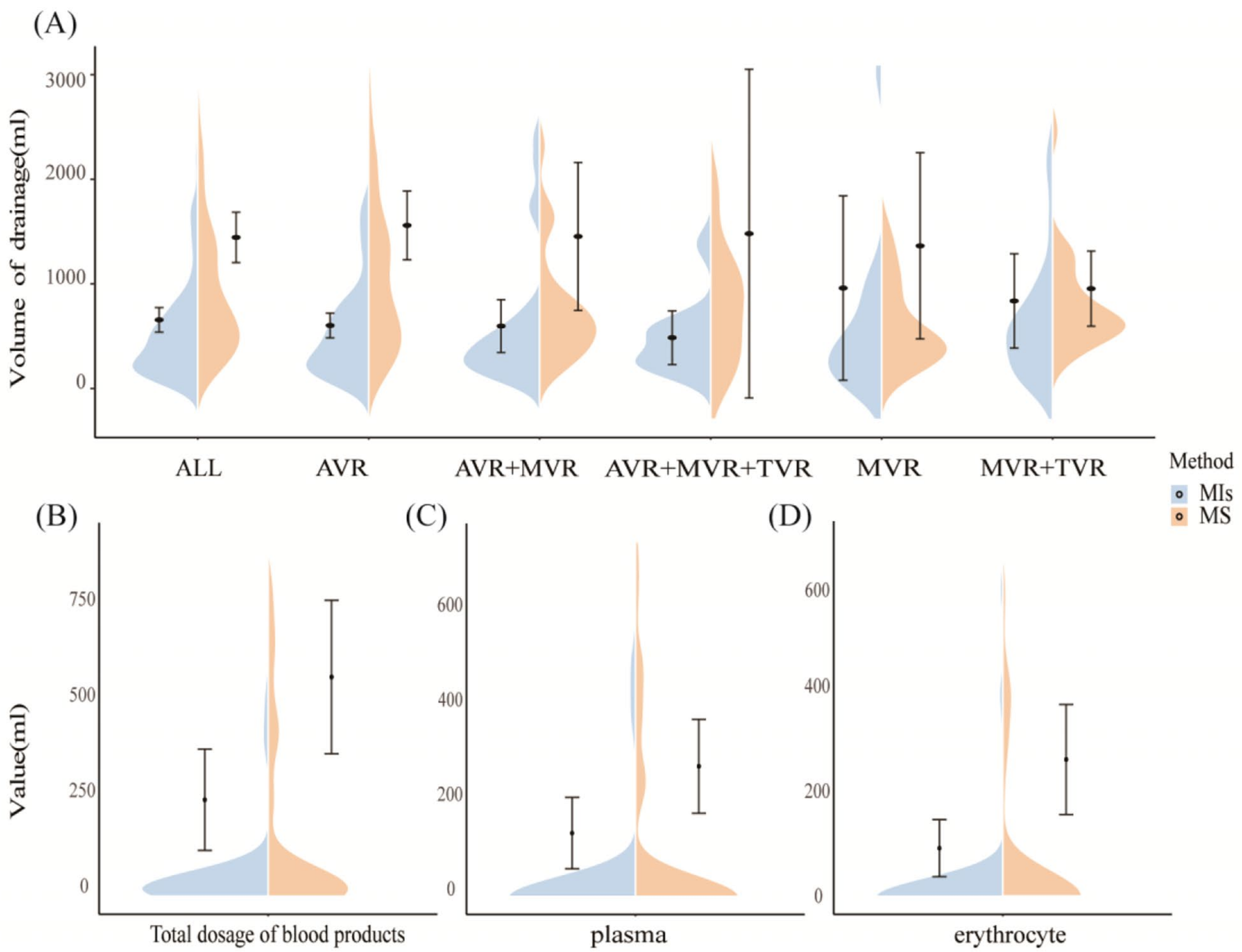

Fig. 4 The violin diagram and bar line chart respectively counted the drainage fromthe chest tube and the amount of postoperative blood products during the ICU. The violin chart shows the overall distribution of data, and the bar chart shows the statistical distribution of data. ICU, intensive care unit

valve replacement cases, no differences were found in endpoints among remaining surgical procedures. This suggests consistent surgical outcomes, emphasizing the importance of both WBC and RBC counts in postoperative assessment.

Postoperative ICU chest tube drainage was counted and represented using violin plots (Fig. 4). According to the subgroup and overall analysis results, there was less total volume of drainage during the ICU monitoring period in the MI surgery group than in the conventional MS group. Similarly, there was a good consistency with postoperative blood product transfusion, with the MI surgery group having a lower total requirement for blood products, lower RBC counts, and fewer plasma units used during the ICU monitoring period than the MS surgery group.

Discussion

This study performed a retrospective analysis of patients who underwent heart valve surgery and were transferred to the ICU. The included data were derived from raw data collected from different information systems. PSM and IPTW were used to minimize the effects of bias and confounders. The study primarily focused on early extubation, with the aim of investigating differences in postoperative outcomes after MI and conventional MS surgeries to improve patient healthcare management during intensive care.

First, the decision regarding the timing of extubation is entirely within the autonomy of the physicians in the ICU. Our study found that the median time to postoperative extubation in the MI group was 10.33 h (95% CI: 9.37–11.61), which was significantly shorter than the 20.34 h (95% CI: 17.72–31.18) observed in the conventional MS group. The results were consistent between the unmatched and PSM- and IPTW-matched cohorts, indicating a robust result. This is consistent with previous

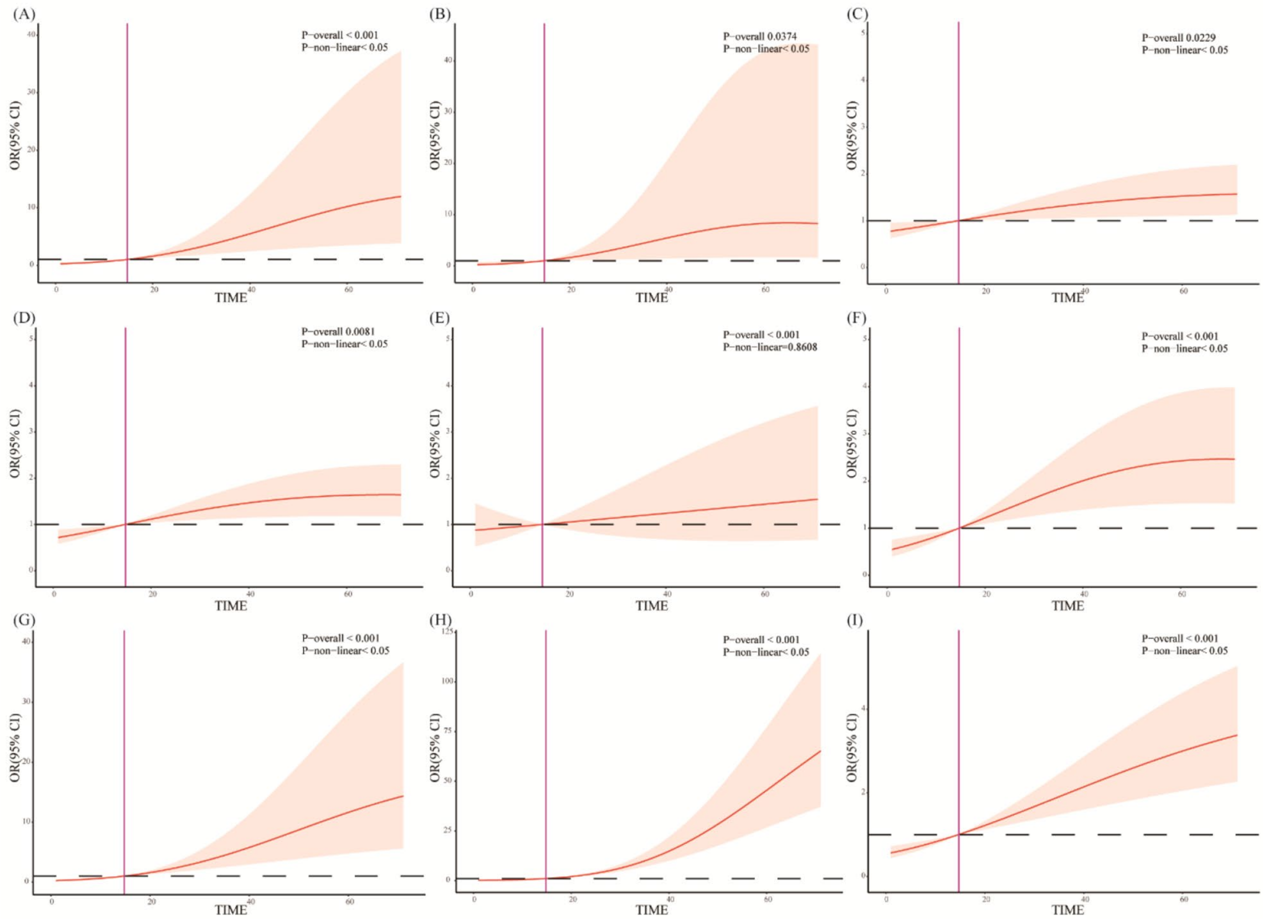

Fig. 5 The influence of postoperative extubation time is further analyzed by visually assessing the association between the different secondary outcome indicators and extubation time using a restricted cubic spline based on the matched data, Influencing factors include: (**A**) Dead; (**B**) Poor wound healing; (**C**) Arrhythmia; (**D**) Pleural effusion; (**E**) Stroke; (**F**) EF < 50%; (**G**) Pneumonia; (**H**) Admission in the ICU; (**I**) Admission in the hospital, with the covariate being the surgical approach

reports suggesting that MI procedures facilitate early extubation [8–11].

Early extubation prevents the adverse effects associated with prolonged positive pressure ventilation in patients undergoing cardiac surgery, reduces postoperative complications (such as ventilator-associated pneumonia and diaphragmatic atrophy), shortens the duration of ICU stay and total length of hospitalization, and decreases healthcare costs without increasing mortality [12–17]. This study showed that prolonged duration of mechanical ventilation was positively correlated with postoperative complications that include mortality, poor wound healing, arrhythmia, pleural effusion, stroke, EF < 50%, and pneumonia. Further analysis of matched data using restricted cubic spline showed that extubation within 15 h is a watershed for all complications.

The Society of Thoracic Surgeons' recommendation to extubate within 6 h has been accepted in clinical practice [18, 19]. This discrepancy may stem from several related factors. First, the selection of the observation sample was biased, and the study was limited to adult patients who underwent valve surgery. Second, currently available studies do not define early extubation period clearly, which ranges from 1 to 12 h postoperatively. Thus, the optimal timing for safe extubation remains unclear [13, 15, 20, 21]. Early extubation is a key factor for rapid recovery and fast-track processes after cardiac surgery in recent years. However, the 6-h time point was questioned in a study that included 3007 patients undergoing cardiac surgery that were categorized into four groups based on the time of extubation: 0–6 h, 6–9 h, 9–12 h, and 12–18 h. The risk of mortality and postoperative complications was increased considerably among patients extubated within 12–18 h postoperatively compared to that among patients extubated within 12 h postoperatively, whereas no difference was observed among patients extubated within 6–9 h and 0–6 h. Based on the results of our study, it was impossible to confirm the advantage

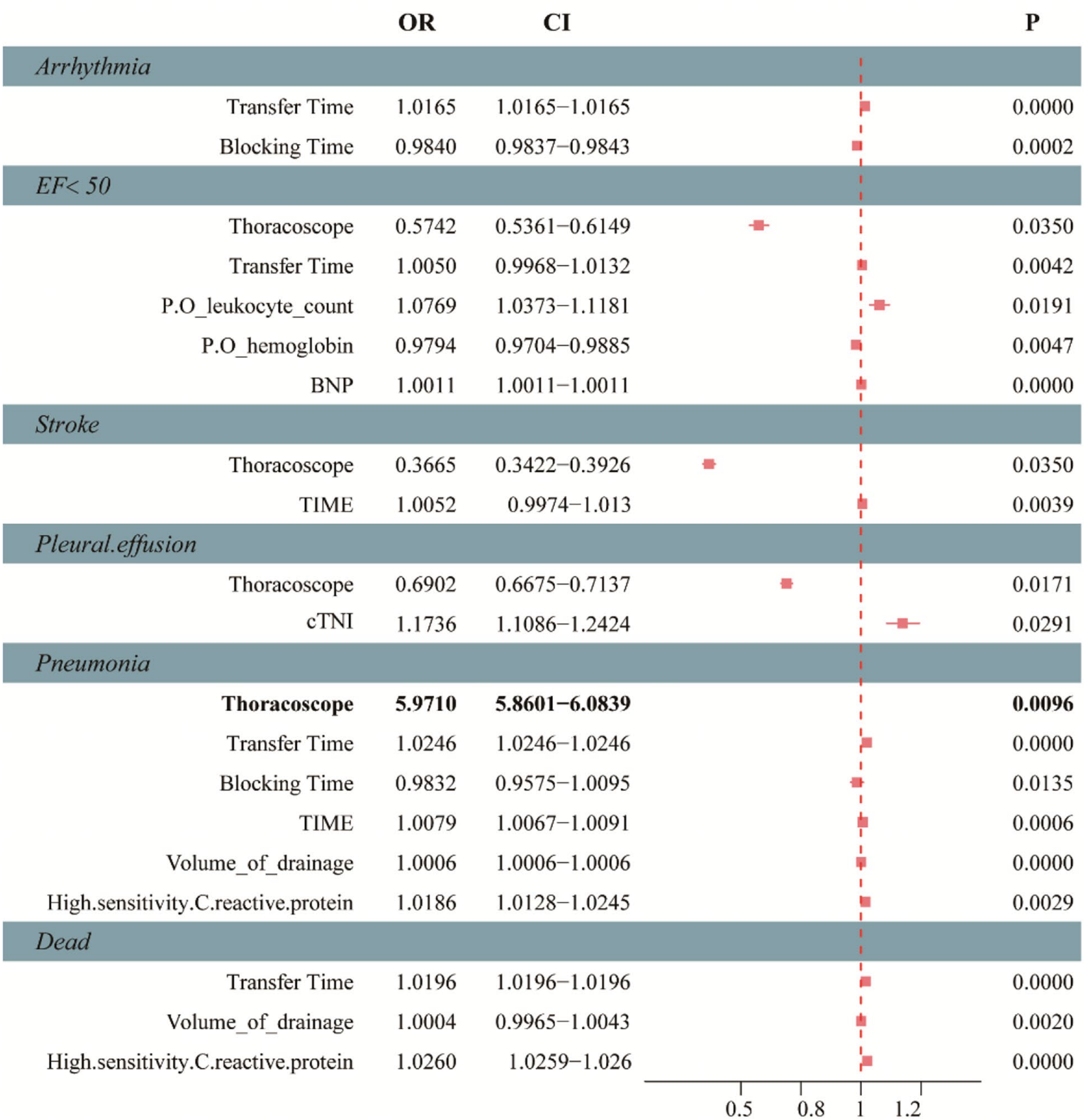

Fig. 6 univariate and multivariate regression analyses are used to evaluate the factors influencing secondary outcome indicators, and the optimal model was selected according to the Akaike information criterion, with results of $P < 0.05$

of extubation within 6 h postoperatively; however, it can be established that failure to extubate within 12 h postoperatively is associated with mortality, increased incidence of postoperative complications, and prolonged hospitalization [22]. In contrast, our study found that unsuccessful extubation within 15 h postoperatively was associated with an increased rate of postoperative complications and a longer ICU and total hospital stay, with a time threshold consistent with the 12–18 h extubation time in the previous report.

We did not evaluate the risk factors for unsuccessful early extubation in our study. Age, obesity (body mass index≥28 kg/m2), EF<50%, history of cardiac surgery, type of surgery, emergency surgery, CPB time, duration of operation, use of intra-aortic balloon pump, and estimated glomerular filtration rate<60 mL/min/1.73 m2 have been identified as potential risk factors for delayed

Table 2 Patient demographics before matching

	Category	Overall ($n=744$)	Conventional MS ($n=232$)	MI ($n=512$)	*P*
Type of surgery §	AVR	266 (35.75)	149 (64.22)	117 (22.85)	< 0.0001
	AVR + MVR	76 (10.22)	27 (11.64)	49 (9.57)	
	AVR + MVR + TVR	34 (4.57)	14 (6.03)	20 (3.91)	
	MVR	231 (31.05)	16 (6.90)	215 (41.99)	
	MVR + TVR	137 (18.41)	26 (11.21)	111 (21.68)	
BMI, kg/m^2 *		23.043 [20.900–25.391]	23.436 [20.812–26.647]	22.992 [20.951–24.983]	0.0267
APACHE II score *		15.000 [12.000–18.000]	15.000 [11.750–18.000]	15.000 [12.000–17.000]	0.7813
Height, cm *		164.000 [158.000–170.000]	166.000 [160.000–170.000]	163.000 [158.000–170.000]	0.0013
Weight, kg *		62.000 [53.000–70.000]	65.000 [55.000–73.250]	61.000 [53.000–69.000]	0.0013
SEX §	Female	326 (43.82)	85 (36.64)	241 (47.07)	0.01
	Male	418 (56.18)	147 (63.36)	271 (52.93)	
AGE *		62.000 [52.000–69.000]	59.000 [51.000–69.000]	63.000 [53.000–70.000]	0.0253
NYHA Classification §	Level I	60 (8.06)	35 (15.09)	25 (4.88)	< 0.0001
	Level II	220 (29.57)	68 (29.31)	152 (29.69)	
	Level III	408 (54.84)	109 (46.98)	299 (58.40)	
	Level IV	56 (7.53)	20 (8.62)	36 (7.03)	
Infective endocarditis §		39 (5.24)	22 (9.48)	17 (3.32)	0.0009
Rheumatic heart disease §		92 (12.37)	22 (9.48)	70 (13.67)	0.1368
Cardiomyopathy §		49 (6.59)	7 (3.02)	42 (8.20)	0.0131
Coronary heart disease §		133 (17.88)	36 (15.52)	97 (18.95)	0.3043
CPB Time *		161.000 [125.000–203.000]	191.000 [145.000–237.000]	150.500 [121.000–187.250]	< 0.0001
cross-clamp Time *		106.000 [81.000–146.000]	137.500 [97.750–172.250]	97.500 [77.750–130.000]	< 0.0001
Poor wound healing §		8 (1.08)	2 (0.86)	6 (1.17)	1
Surgical expenses, ¥ *		19273.150 [16234.450–22825.800]	18454.150 [14586.175–21955.900]	19815.700 [16816.950–23345.250]	0.0005
Total expenses, ¥ *		132930.810 [107380.022–166609.552]	167053.945 [132491.198–213130.198]	122544.535 [102001.020–147933.065]	< 0.0001
ICU length of stay, days *		2.000 [1.000–4.000]	3.000 [2.000–6.250]	2.000 [1.000–3.000]	< 0.0001
Hospital length of stay, days *		16.000 [13.000–20.000]	18.000 [15.000–24.000]	15.000 [12.000–18.000]	< 0.0001
IABP §		1 (0.13)	0 (0.00)	1 (0.20)	1
ECMO §		4 (0.54)	1 (0.43)	3 (0.59)	1
Tracheotomy §		12 (1.61)	8 (3.45)	4 (0.78)	0.0182
Reintubation §		10 (1.34)	7 (3.02)	3 (0.59)	0.0201
Arrhythmia §		261 (35.08)	61 (26.29)	200 (39.06)	0.001
Pneumonia §		21 (2.82)	15 (6.47)	6 (1.17)	0.0001
Pleural effusion §		439 (59.01)	155 (66.81)	284 (55.47)	0.0046
Stroke §		31 (4.17)	15 (6.47)	16 (3.12)	0.0556
EF < 50 §		65 (8.74)	30 (12.93)	35 (6.84)	0.0097
TIME *		13.889 [7.029–25.698]	20.170 [13.852–74.045]	10.331 [1.000–17.553]	< 0.0001
Dead §		10 (1.34)	7 (3.02)	3 (0.59)	0.0128
Volume of drainage *		550.000 [267.5001042.500]	995.000 [540.000–1755.000]	440.000 [210.000–751.250]	< 0.0001

Table 2 (continued)

Category	Overall ($n = 744$)	Conventional MS ($n = 232$)	MI ($n = 512$)	*P*
Plasma *	0.000 [0.000, 0.000]	0.000 [0.000352.650]	0.000 [0.000, 0.000]	< 0.0001
Platelet *	0.000 [0.000, 0.000]	0.000 [0.000, 0.000]	0.000 [0.000, 0.000]	0.0105
Erythrocyte *	0.000 [0.000, 0.000]	0.000 [0.000–300.000]	0.000 [0.000, 0.000]	< 0.0001
Total dosage of blood products *	0.000 [0.000, 0.000]	0.000 [0.000, 547.500]	0.000 [0.000, 0.000]	< 0.0001
PTS leukocyte count *	5.730 [4.617–7.120]	6.330 [4.850–8.173]	5.520 [4.578–6.682]	< 0.0001
P/O leukocyte count *	11.685 [8.990–14.728]	11.230 [9.135–13.972]	11.900 [8.970–14.940]	0.0875
PTS RBC *	4.360 [3.960–4.722]	4.335 [3.920–4.750]	4.360 [3.980–4.703]	0.5091
P/O RBC *	3.520 [3.180–3.893]	3.565 [3.087–4.125]	3.500 [3.228–3.812]	0.1297
PTS hemoglobin *	132.000 [118.000–145.000]	131.500 [116.750–146.000]	132.000 [119.000–145.000]	0.5765
P/O hemoglobin *	108.000 [98.000–119.000]	110.500 [94.000–, 129.000]	107.000 [99.750–117.000]	0.093
Glucose (median [IQR])	6.020 [4.950–7.735]	7.000 [5.600, 8.500]	5.700 [4.828–7.302]	< 0.0001
High Sensitivity C reactive protein (median [IQR])	2.000 [1.200–6.425]	3.350 [1.375–19.025]	1.600 [1.075, 3.625]	< 0.0001
Total bilirubin (median [IQR])	13.800 [10.300–19.700]	16.150 [10.800–22.800]	13.100 [10.200–18.300]	0.0001
Direct.bilirubin (median [IQR])	3.000 [2.200–4.600]	4.200 [2.700–, 6.300]	2.700 [2.100–4.000]	< 0.0001
Prothrombin time (median [IQR])	12.000 [11.300–12.925]	12.100 [11.500–, 13.300]	11.800 [11.200–12.800]	0.0005
Creatinine (median [IQR])	78.850 [66.900–90.700]	82.650 [66.575–, 96.350]	77.800 [67.200, 88.625]	0.0489
Urea.nitrogen (median [IQR])	6.290 [5.058–7.750]	6.410 [5.160–7.878]	6.230 [5.050–7.615]	0.482
Glutamic pyruvic transaminase (median [IQR])	19.000 [13.000–30.000]	22.000 [14.000–, 34.000]	18.000 [13.000–29.000]	0.0009
Glutamic oxaloacetic transaminase (median [IQR])	23.000 [18.000–35.000]	33.000 [21.000–, 66.000]	22.000 [18.000–, 29.000]	< 0.0001
Alkalinephosphatase (median [IQR])	70.000 [58.000–88.000]	68.000 [54.750–, 85.250]	71.000 [59.000–91.000]	0.0342
Glutamyl transpeptidase (median [IQR])	27.000 [17.000–47.000]	28.000 [17.000–, 47.000]	27.000 [17.000–46.250]	0.3067
BNP (median [IQR])	157.550 [70.975–339.575]	203.850 [89.800–395.900]	141.500 [60.000–318.175]	0.0005
cTNI (median [IQR])	0.010 [0.004–0.039]	0.015 [0.006–0.064]	0.008 [0.003–0.027]	< 0.0001

APACHE II, Acute Physiology and Chronic Health Evaluation II; AVR, aortic valve replacement; BMI, body mass index; ICU, intensive care unit; MI, minimally invasive; MS, median sternotomy; MVR, mitral valve replacement; NYHA, New York Heart Association; TVR, tricuspid valve repair; CPB, cardiopulmonary bypass

* Values presented as median (interquartile range); variables compared by the Mann–Whitney U test

§ Values presented as number (percentage); variables compared by chi-square test

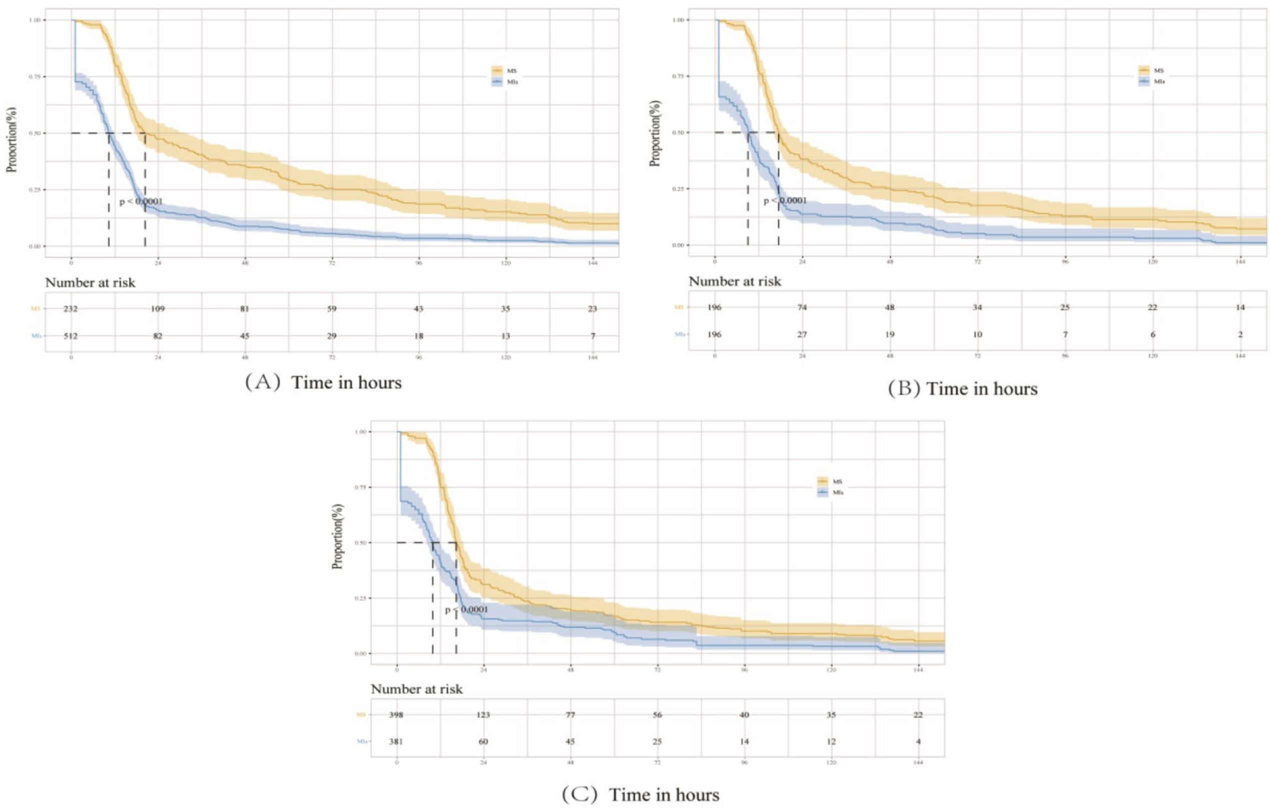

Fig. 7 Kaplan–Meier curves of MI surgery and MS in the unmatched cohort (**A**), the matched cohort PSM (**B**), and the matched cohort after IPTW (**C**). Postoperative offline extubation time in the MI surgery group is significantly shorter than that in MS group in all three cohorts. MI, minimally invasive; MS, median sternotomy; IPTW, inverse probability of treatment weighting; PSM, propensity score matching

extubation [23]. As mentioned earlier, early extubation may be beneficial for reducing postoperative complications. Our study found that prolonged CPB and surgery were equally important risk factors for postoperative complications, such as pneumonia, postoperative cardiac output abnormalities, cardiac arrhythmias, and all-cause mortality (Fig. 5; Table 3). A shorter duration of CPB reduces the release of inflammatory cytokines and lowers the incidence of complications such as hepatic and renal insufficiency, pulmonary infections, and ventilator-associated pneumonia. This, in turn, significantly shortens ICU and hospital stays, speeds up patient recovery, and ultimately reduces hospitalization costs [9]. No consensus exists on safe CPB time or overall duration of cardiac surgery. This shows that early extubation, postoperative complications, CPB time, and duration of the operation are inter-related. However, specific time thresholds and types of associated complications require further investigation. We found that MI procedures had a protective advantage over the adjusted postoperative incidence of abnormal cardiac output, stroke, and pleural effusion. The reasons for these clinical outcomes are unclear. In contrast to the results of other studies [24, 25], the CPB time and surgical duration were longer in the MS group than in the MIs group in our study. These differences may be associated with the inherent heterogeneity of the patients (complexity of the procedure), assumed difficulty of converting an MI procedure to a conventional MS procedure, and varying degrees of proficiency of surgeons during the procedure as MI surgery evolves.

Our study demonstrated that all relevant indicators for evaluating postoperative bleeding (including the total amount of blood products transfused, need for RBCs, and total amount of drainage from the chest tubes) among patients in the ICU following heart valve surgery were lower in the MI group than in the conventional MS group, which is consistent with other studies. These differences may be explained by the fact that MI surgery is less invasive, with less postoperative hemorrhage and a correspondingly low requirement for postoperative blood products [9]. Second, the differences may be due to the shorter duration of surgery and CPB [10]. CPB affects thrombin formation, platelet count, and functional abnormalities, causing coagulopathies and increasing the risk of intraoperative and/or postoperative hemorrhage [26].

Although a large body of literature supports early extubation after cardiac surgery and illustrates its benefits

Table 3 Patient demographics after PSM

	PSM		*P*	IPTW		*P*
	MS	**MI surgery**		**MS**	**MI surgery**	
	(*n* = 196)	**(*n* = 196)**		**(*n* = 397.93)**	**(*n* = 381.4)**	
Poor wound healing (%)	1 (0.51)	3 (1.53)	0.6153	1.48 (0.37)	4.42 (1.16)	0.301
Dead (%)	6 (3.06)	2 (1.02)	0.2839	9.50 (2.39)	8.31 (2.18)	0.9222
IABP (%)	0 (0.00)	0 (0.00)	NA	0.00 (0.00)	0.00 (0.00)	NA
ECMO (%)	1 (0.51)	2 (1.02)	1	1.27 (0.32)	4.34 (1.14)	0.2767
Tracheotomy (%)	6 (3.06)	1 (0.51)	0.1271	9.56 (2.40)	1.62 (0.42)	0.07
Arrhythmia (%)	57 (29.08)	55 (28.06)	0.911	113.86 (28.61)	110.34 (28.93)	0.9473
Pneumonia (%)	11 (5.61)	5 (2.55)	0.2018	18.93 (4.76)	14.68 (3.85)	0.7287
Pleural effusion (%)	137 (69.90)	114 (58.16)	0.0206	271.93 (68.34)	217.16 (56.94)	0.0298
Stroke (%)	12 (6.12)	4 (2.04)	0.074	22.07 (5.55)	6.96 (1.83)	0.043
EF.50 (%)	28 (14.29)	14 (7.14)	0.0338	58.02 (14.58)	29.26 (7.67)	0.0626
Surgical expenses (median [IQR])	17991.000 [13844.900–21718.375]	18820.700 [16858.200–21535.450]	0.0168	17245.221 [13241.389–21004.898]	18820.700 [16870.700–21932.432]	< 0.0001
Total expenses (median [IQR])	159090.085 [128142.250–209331.278]	126492.710 [105889.242–149521.120]	< 0.0001	150290.827 [121398.745–189707.916]	127980.260 [107051.530–153123.632]	< 0.0001
Admission in the ICU (median [IQR])	3.000 [2.000–5.000]	2.000 [1.000–3.000]	< 0.0001	2.000 [2.000–5.000]	2.000 [1.000–3.000]	< 0.0001
Admission in the hospital (median [IQR])	18.000 [15.000–23.000]	15.000 [13.000–18.000]	< 0.0001	18.000 [15.000–23.000]	15.000 [13.000–18.477]	< 0.0001

MI, minimally invasive; MS, median sternotomy; PSM, propensity score matching; ICU, intensive care unit

[12–17], early extubation is not suitable for every patient. Reintubation after extubation is an uncommon postoperative complication associated with worsened outcomes [19]. It is unclear whether early extubation is associated with an increased risk of reintubation. In the raw data, the reintubation rate was 0.59% in the MIs group and 3.02% in the conventional MS group. The occurrence of adverse events after early extubation greatly affects the patient's postoperative recovery and increases the difficulty of intensive care management. Therefore, early extubation should only be considered after adequately assessing the patient's condition and associated risk factors.

This study had some limitations. First, this was a single-center, retrospective study. Patients were not randomly assigned to the MI surgery or conventional MS groups, and the surgical approach was determined by the surgeon. There was no collection of surgical pathways in this trial, and the estimation of blood loss was ambiguous. Second, even though PSM and IPTW were used to balance some of the preoperative characteristics of the patients in the two groups, inherent selection bias could not be completely eliminated. Many post-cardiac surgery variables have been studied; however, such studies have been limited owing to different inclusion criteria or single small-sample studies. Multi-center, prospective, randomized controlled trials with adequate sample sizes are needed to confirm our results. In addition, the time to extubation is influenced by many factors, such as the use of analgesic medications and baseline lung function. This study did not collect data on these factors for further statistical analysis. Finally, the study did not collect data on the conversion of MI surgery to conventional MS surgery to assess the safety of MI surgery. However, subgroup analyses of different procedures and cardiac function classifications may produce different results.

Conclusion

Successful early tracheal extubation is important in the intensive care management of patients after heart valve surgery. The advantages of MI surgery over conventional MS include a substantial reduction in the duration of mechanical ventilation support, length of ICU stay, and total length of hospitalization, as well as a favorable prognostic recovery.

Abbreviations

APACHE II	Acute Physiology and Chronic Health Evaluation II
CI	Confidence interval
CPB	Cardiopulmonary bypass
ICU	Intensive care unit
IPTW	Inverse probability of treatment weighting
IQR	Interquartile range
MI	Minimally invasive
MS	Median sternotomy
NYHA	New York Heart Association
PS	Propensity score
PSM	Propensity score matching

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Author contributions

Siyu Tang: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Validation; Writing—original draft. Yan Qu, Huan Jiang and Zihao Zheng: Data curation; Formal analysis; Writing—review & editing. Run Zhang, Jun Hong and Hanhui Cai: Conceptualization; Methodology; Supervision; Validation; Writing—review & editing. Xianghong Yang: Conceptualization; Investigation; Methodology; Resources; Supervision; Validation; Writing—review & editing. Jingquan Liu: Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing—review & editing.

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Data availability

Data are available in a repository and can be accessed via a figshare. The data underlying this article are available in the figshare, at https://figshare.com/ [https://doi.org/10.6084/m9.figshare.22091507].

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Committee of the People's Hospital of Zhejiang Province, which complies with the Declaration of Helsinki(ethics approval number: QT2022383, date: November 21, 2022). And individual consent for this retrospective analysis was waived.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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