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RESEARCH ARTICLE

Early Extubation After Minimally Invasive Coronary Artery Bypass Grafting: Perioperative Predictors and Clinical Outcomes

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ABSTRACT

Objectives: This study aimed to identify perioperative predictors of early extubation and to evaluate its impact on postoperative outcomes in patients undergoing minimally invasive coronary artery bypass grafting (MICS-CABG).

Methods: This single-center retrospective cohort study included 95 adult patients who underwent isolated MICS-CABG between January 2021 and January 2024. Patients were categorized according to extubation time as early (≤6 hours, n=60) or late (>6 hours, n=35). Standard perioperative care was applied to all patients, and an early extubation protocol was implemented in eligible cases.

Results: Patients in the early extubation group were younger (58 vs. 67 years, p=0.0002), had higher ejection fractions (55% vs. 45%, p<0.001), and lower EuroSCORE II values (1.3% vs. 3.36%, p<0.001). Intraoperative blood transfusion (p=0.0001) and inotrope use (p=0.031) were more frequent in the late extubation group. Postoperative pneumonia (p=0.016) and arrhythmia (p=0.029) rates were also significantly higher among patients with delayed extubation. In multivariate analysis, EuroSCORE II (OR 0.20, 95% CI 0.08–0.51, p=0.0008), blood transfusion (OR 0.23, 95% CI 0.08–0.66, p=0.006), and inotrope use (OR 0.31, 95% CI 0.11–0.90, p=0.031) were identified as independent predictors. ROC analysis confirmed excellent discriminative ability of the model (AUC=0.95).

Conclusion: Early extubation following MICS-CABG is a safe and feasible approach in appropriately selected patients. EuroSCORE II was identified as the strongest predictor, while blood transfusion and inotrope use were associated with delayed extubation. These findings support structured risk assessment and intraoperative optimization as essential components of fast-track recovery protocols.

Keywords: Early extubation, fast-track recovery protocols, minimally ınvasive coronary artery bypass, predictors of perioperative outcomes

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Introduction

Minimally invasive cardiac surgery (MICS) has been developed to minimize surgical trauma, accelerate postoperative recovery, reduce pain, and shorten hospital stay compared with the conventional median sternotomy approach. MICS and similar techniques are increasingly adopted worldwide, particularly in centers where fast-track recovery protocols are implemented.[1] One of the core components of these protocols is early extubation, typically defined as within six hours after surgery, which is recommended by the Enhanced Recovery After Surgery (ERAS) Society and the Society of Thoracic Surgeons.[2]

Minimally invasive cardiac surgery attenuates the physiological stress response compared with conventional sternotomy, making early extubation more readily achievable. Early extubation following cardiac surgery has been consistently associated with multiple clinical benefits, including reduced rates of ventilator-associated pneumonia, shorter ICU and hospital stays, enhanced patient comfort, and more efficient use of healthcare resources.[3] In addition, MICS offers further advantages

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such as preservation of sternal integrity, improved wound healing, lower infection rates, and accelerated recovery.[4,5]

Despite these benefits, the decision for early extubation remains multifactorial and is influenced by patient comorbidities, intraoperative events, and institutional protocols. Prior research has identified younger age, higher ejection fraction, and absence of pulmonary disease as favorable predictors, emphasizing the role of patient selection in achieving safe and successful fast-track recovery.[6]

Although several studies have examined factors influencing extubation after conventional cardiac surgery, evidence focusing specifically on minimally invasive coronary artery bypass grafting (MICS-CABG) remains limited. In particular, the interplay between preoperative risk scores, intraoperative events such as transfusion and inotrope use, and postoperative outcomes has not been comprehensively addressed. The present study aimed to identify perioperative predictors of early extubation in patients undergoing MICS-CABG and to evaluate its impact on postoperative complications and recovery profiles.

Methods

Study Design and Patient Population

This retrospective, single-center study included adult patients (≥18 years) who underwent MICS-CABG between January 2021 and January 2024. The study was approved by the Ethics Committee of Istinye University (approval number: 24-51, March 14, 2024) and conducted in accordance with the Declaration of Helsinki.

All procedures were performed via a left anterior mini-thoracotomy approach with peripheral cannulation. Eligible patients were those who underwent elective, isolated MICS-CABG performed by the same surgical team, had complete perioperative data available, and were extubated within the first 24 hours postoperatively. Exclusion criteria were concomitant valve surgery, cardiac myxoma resection, emergency procedures, conversion to full sternotomy, requirement for intra-aortic balloon pump (IABP) or extracorporeal membrane oxygenation (ECMO), preoperative mechanical ventilation, and incomplete or inadequate medical records.

Patients were divided into two groups based on extubation time: early extubation (≤6 hours postoperatively) and delayed extubation (>6 hours), according to ERAS cardiac surgery recommendations and prior literatüre.[2] Demographic characteristics, comorbidities, preoperative cardiac function parameters, intraoperative variables, postoperative complications, and clinical outcomes were extracted from the hospital's electronic medical records and patient charts.

Anesthesia Management

All patients underwent a standardized general anesthesia protocol. Induction was achieved with intravenous fentanyl (2–5 µg/kg), midazolam (0.05–0.1 mg/kg), propofol (1–2 mg/kg), and rocuronium (0.6–1 mg/kg). Anesthesia was maintained with sevoflurane (1–2%) in a 50% oxygen–air mixture, supplemented by continuous remifentanil infusion (0.05–0.2 µg/kg/min). Depth of anesthesia was monitored using the bispectral index (BIS).

Hemodynamic monitoring included invasive arterial pressure measurement via radial artery catheter and central venous access through the left internal jugular vein. Anticoagulation during cardiopulmonary bypass (CPB) was achieved with heparin to maintain an activated clotting time (ACT) >450 seconds, and reversed post-CPB with protamine.

Postoperative Management

Following surgery, all patients were transferred intubated to the cardiovascular intensive care unit for continuous monitoring. Extubation eligibility was assessed according to ERAS and STS recommendations, based on predefined criteria including hemodynamic stability, normothermia, adequate oxygenation (SpO_2 > 92% on $FiO_2 \leq 0.4$), $PaCO_2$ < 50 mmHg, spontaneous respiratory effort, and appropriate neurological response. Patients fulfilling these criteria were extubated under a standardized fast-track protocol.[2]

Postoperative analgesia was provided using a standardized multimodal protocol. All patients received intravenous paracetamol (1 g every 8 hours), complemented by tramadol (25–50 mg IV) as rescue therapy based on NRS-guided pain assessment. Non-opioid adjuncts, including ketorolac or alternative NSAIDs, were added according to individual clinical suitability. When necessary, a low-dose opioid bolus was administered at the discretion of the anesthesia team. This multimodal ERAS-oriented strategy ensured effective analgesia while minimizing opioid exposure.

Patients were closely monitored for early postoperative complications including reintubation, atrial fibrillation, pneumonia, bleeding, and surgical site infection. Length of ICU and hospital stay were also recorded. Mortality was defined as the in-hospital mortality rate, encompassing any death that occurred during the patient's hospitalization, from admission to discharge.

Statistical Analysis

All statistical analyses were performed using Python (version 3.11; SciPy, Statsmodels, Seaborn). Categorical variables were summarized as frequencies and percentages, while continuous variables were expressed as medians with

Table 1. Demographic and preoperative characteristics (values are presented as n(%) or mean±SD)

Variable	Early extubation group (n=60)	Delayed extubation group (n=35)	p
Age (years)	58.2±9.5	65.2±7.3	0.0001
Weight (kg)	80.4±15.5	80.5±13.7	0.974
BMI (kg/m^2)	28.3±4.5	28.1±4.3	0.932
Creatinine (mg/dL)	0.7±0.2	0.78±0.19	0.424
EF (%)	53.8±4.5	42.5±7.7	0.0001
EuroSCORE II (%)	1.5±0.7	5.8±4.8	0.0001
Gender (male), n (%)	45 (75.0)	27 (77.1)	1.000
Diabetes, n (%)	11 (18.3)	16 (45.7)	0.009
Smoking, n (%)	26 (43.3)	28 (80.0)	0.001
COPD, n (%)	2 (3.3)	14 (40.0)	0.0001
Hypertension, n (%)	50 (83.3)	34 (97.1)	0.090

SD: Standard deviation; BMI: Body mass index; EF: Ejection fraction; COPD: Chronic obstuctive pulmonary disease.

Table 2. Intraoperative parameters (values are presented as n (%) or mean±SD))

	Early extubation group (n=60)	Delayed extubation group (n=35)
CPB time (min)	159.4±39.9	163.8±43.7
Cross-clamp time (min)	86.3±32.3	89.4±38.8
Blood transfusion, n (%)	8/60 (13.3)	18/35 (51.4)
Fresh frozen plasma, n (%)	2/60 (3.3)	6/35 (17.1)
Crystalloid (ml)	1434.5±241.9	1473.7±255
Inotrope use, n (%)	10/60 (16.7)	17/35 (48.6)

SD: Standard deviation; CPB: Cardiopulmonary bypass.

Table 3. Postoperative complications (values are present as n (%))

	Early extubation group (n=60)		Late extubation group (n=35)	
	n	%	n	%
Arrhythmia	4	6.7	8	22.9
Pneumonia	0	0.0	4	11.4
Re-operation	1	1.7	4	11.4
Re-intubation	1	1.7	3	8.6
Mortality	0	0.0	1	2.9

interquartile ranges (IQR) due to non-normal distribution. Between-group comparisons were conducted using the Mann–Whitney U test for continuous variables and Fisher's exact test for categorical variables. For variables with more than two categories, chi-square tests were applied where appropriate.

To identify potential predictors of early extubation, univariate logistic regression was first performed. Variables with clinical relevance or a p-value <0.10 in univariate analysis were subsequently included in a multivariate logistic regression model. Results were reported as odds ratios (OR) with 95% confidence intervals (CI) and corresponding p-values. Discriminatory performance of the final multivariate model was assessed using receiver operating characteristic (ROC) analysis, with the area under the curve (AUC) reported. A two-tailed p-value <0.05 was considered statistically significant.

Results

Between January 2021 and January 2024, a total of 98 patients underwent isolated MICS-CABG at our center. Three patients were excluded due to intraoperative conversion to full sternotomy (n=1), requirement for mechanical circulatory support such as intra-aortic balloon pump (n=1), and incomplete medical records (n=1). The final analysis included 95 patients. Based on extubation time, patients were divided into two groups: early extubation (≤6 hours, n=60; 63.2%) and delayed extubation (>6 hours, n=35; 36.8%).

Demographic and preoperative characteristics are shown in Table 1. Patients in the early extubation group were significantly younger (median age: 58 vs. 67 years; p=0.0002), had higher left ventricular ejection fraction (EF; 55% vs. 45%; p<0.001), and lower EuroSCORE II (1.3% vs. 3.36%; p<0.001). Other baseline factors such as sex, BMI, creatinine, diabetes, COPD, and hypertension did not differ significantly.

Intraoperative parameters are summarized in Table 2. Cardiopulmonary bypass and cross-clamp times were similar between groups. However, intraoperative blood transfusion was significantly more frequent in the delayed extubation group (n=18 (51.4%) / n=8 (13.3%), p=0.0001). Similarly, the use of fresh frozen plasma was higher in the delayed group (6/35, 17.1% vs. 2/60, 3.3%; p=0.048). Inotropic support was also required more often in the delayed extubation group (48.6% vs. 16.7%; p=0.001). The mean ICU stay was significantly shorter in the early extubation group compared with the delayed extubation group (21.4±3.1 hours vs. 36±18.5 hours, p=0.0001). The mean hospital length of stay was also significantly shorter in the early extubation group (4.2±1.1 days) compared with the delayed extubation group (6.8±2.5 days, p=0.0005).

Postoperative complications (Table 3) showed higher incidences of pneumonia (8.6% vs. 0%, p=0.016) and arrhythmia (20% vs. 6.3%, p=0.032) in the delayed extubation group. Re-operation, re-intubation, and mortality rates were not significantly different.

Table 4. Predictors of early extubation

Variable	OR	95% CI lower	95% CI Upper	p
Age	1.02	0.92	1.12	0.742
EF (%)	1.13	0.95	1.35	0.174
EuroSCORE II (%)	0.20	0.08	0.51	0.0008
Creatinine	0.58	0.30	1.12	0.104
BMI	1.08	0.85	1.37	0.518
COPD	0.60	0.03	11.5	0.731
Hypertension	0.01	0.0	909.97	0.429
Blood transfusion	0.23	0.08	0.66	0.006
Inotropic support	0.31	0.11	0.90	0.031

OR: Odds ratio; CI: Confidence interval; EF: Ejection fraction; BMI: Body mass index; COPD: Chronic obstructive pulmonary disease.

Regression analysis identified several predictors of extubation timing (Table 4). Younger age, higher EF, and lower EuroSCORE II were significant in univariate analysis. In the final multivariate model, EuroSCORE II (OR 0.20, 95% CI: 0.08–0.51, p=0.0008), intraoperative blood transfusion (OR 0.23, 95% CI: 0.08–0.66, p=0.006), and inotropic support (OR 0.31, 95% CI: 0.11–0.90, p=0.031) emerged as independent predictors of extubation timing.

The ROC curve demonstrates the discriminative performance of the multivariable logistic regression model including EuroSCORE II, intraoperative blood transfusion, and inotropic support, with an AUC of 0.95 (95% CI: 0.90–1.00) (Fig. 1). The marginal effect plot displays the predicted probability of early extubation across the range of EuroSCORE II values, showing a decreasing probability as EuroSCORE II increases (Fig. 2).

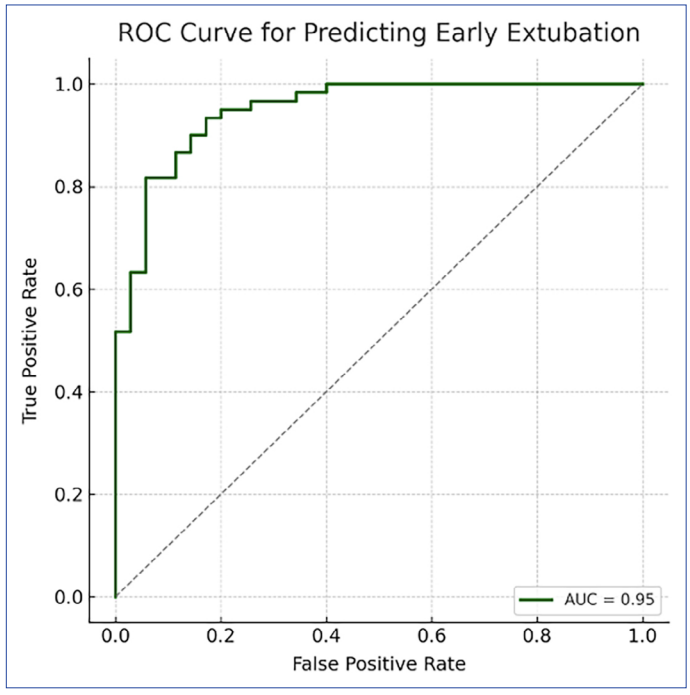

Figure 1. ROC curve for predicting early extubation. This figure illustrates the receiver operating characteristic (ROC) curve of a multivariable logistic regression model including EuroSCORE II, intraoperative blood transfusion, and inotrope use. The model showed excellent discriminative ability in identifying patients suitable for early extubation following MICS-CABG, with an area under the curve (AUC) 0.95.

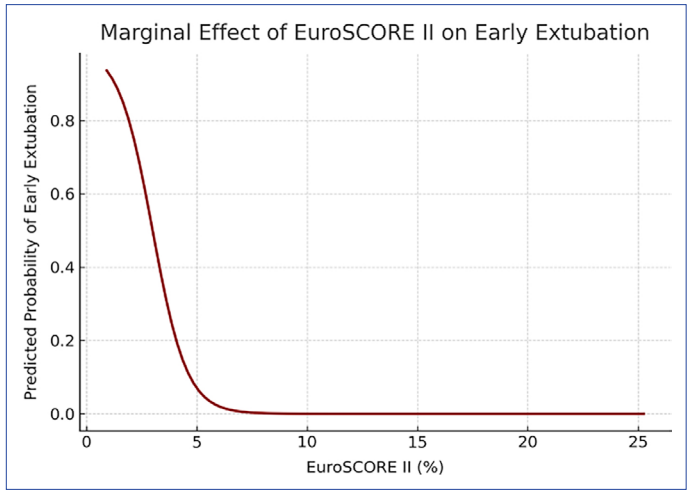

Figure 2. Marginal effect plot showing the relationship between EuroSCORE II and the predicted probability of early extubation. As the EuroSCORE II increases, the likelihood of early extubation decreases in a non-linear fashion, indicating higher surgical risk is associated with delayed extubation.

Discussion

In this retrospective cohort of 95 patients undergoing MICS-CABG, early extubation was achieved in 63.2% of cases, highlighting its feasibility in the minimally invasive setting. Patients extubated within six hours were generally younger, had better preoperative cardiac function, and demonstrated lower operative risk profiles. Multivariable logistic regression identified EuroSCORE II, intraoperative blood transfusion, and the need for inotropic support as independent predictors of delayed extubation. Importantly, early extubation was associated with lower rates of postoperative pneumonia and arrhythmia without increases in reintubation or mortality. These findings suggest that early extubation can be safely applied in carefully selected MICS-CABG patients and support its integration into structured fast-track strategies for minimally invasive coronary surgery.

Previous studies in cardiac surgery have consistently shown that early extubation, as part of fast-track protocols, is both safe and effective. Subramaniam et al.[7] demonstrated that extubation in the operating room was feasible, not associated with increased morbidity or mortality, and led to shorter ICU and hospital stays. Similarly, James et al.[8] reported that early extubation after CABG experienced

fewer postoperative complications and shorter recovery times. Other large observational series and meta-analyses have confirmed that early extubation shortens ICU stay and hospitalization, and does not increase the risk of reintubation or mortality.[9] In our MICS-CABG cohort, nearly two-thirds of patients were extubated within six hours, a proportion comparable to that reported in conventional CABG populations, thereby confirming that early extubation is also feasible and safe in the minimally invasive setting.

Our results confirmed the predictive value of EuroSCORE II for extubation timing. Developed by Nashef et al.[10] as an integrative risk index, EuroSCORE II has consistently been associated with prolonged postoperative ventilation across multiple cardiac surgery cohorts. Kermani et al.[11] demonstrated that elevated EuroSCORE II was a strong predictor of prolonged intubation, often in conjunction with increased postoperative bleeding, and higher EuroSCORE II scores were independently linked to delayed separation from mechanical ventilation after CABG. In our study, while age and ejection fraction initially appeared significant in univariate analysis, their effects diminished once EuroSCORE II was included, underscoring the ability of this composite score to capture the broader perioperative risk profile relevant to extubation.

In our cohort, the need for intraoperative inotropic support was higher among patients extubated after six hours, indicating that hemodynamic instability was an important factor contributing to delayed extubation. Inotrope requirement should therefore be considered not only a marker of intraoperative instability but also a determinant of postoperative recovery. It has been reported that patients requiring inotropes after CABG had higher rates of postoperative arrhythmias, renal dysfunction, and delayed extubation.[12] Likewise, Ibrahim et al.[13] observed that perioperative vasopressor or inotrope use was strongly associated with prolonged mechanical ventilation and extended ICU stay. Our findings are consistent with these results, as patients requiring inotropic support were significantly less likely to achieve extubation within six hours. Similarly, Jaquet et al.[14] demonstrated in a minimally invasive valve surgery cohort that minimizing vasopressor administration facilitated earlier extubation and reduced pulmonary complications.

Intraoperative transfusion was also identified as an important determinant of extubation timing in our study. Previous studies have consistently associated transfusion of blood products with impaired pulmonary outcomes and prolonged mechanical ventilation. Xie et al.[15] identified intraoperative transfusion of red blood cells and platelets as independent predictors of prolonged ventilation, while Vlaar et al.[16] similarly reported higher rates of respiratory complications among transfused patients. In our MICS-CABG cohort, transfusion was confirmed as an independent predictor of delayed extubation. Although often clinically unavoidable, transfusion may complicate recovery through mechanisms such as inflammatory activation and impaired oxygenation, thereby lowering the likelihood of achieving early extubation.

From a clinical standpoint, the identification of EuroSCORE II, transfusion requirements, and inotropic support as predictors highlights the importance of both preoperative and intraoperative optimization. Careful risk stratification with EuroSCORE II may help identify patients most likely to benefit from fast-track approaches, while strategies aimed at minimizing transfusion and stabilizing hemodynamics intraoperatively could increase the likelihood of safe early extubation. Extubation timing should therefore be regarded not only as a postoperative endpoint but as an integral part of a multimodal strategy to improve perioperative outcomes in minimally invasive coronary surgery.

Our analysis has several practical implications for perioperative management. Early extubation was achievable and safe in patients with favorable baseline characteristics and stable intraoperative courses. By contrast, intraoperative events such as hemodynamic compromise requiring inotropes or the need for blood transfusion clearly reduced the likelihood of early extubation. These variables can serve as warning signals for clinicians, encouraging a flexible, individualized approach rather than rigid application of fast-track protocols. These findings are also highly relevant in the context of enhanced recovery after surgery (ERAS) pathways. ERAS protocols emphasize minimizing surgical stress, preserving physiologic stability, and promoting rapid rehabilitation.[17] Early extubation is important in cardiac surgery, as it has been linked to reduced pulmonary complications, shorter ICU stays, and improved resource utilization.[18] It has been reported that ERAS implementation, including early extubation, leads to better outcomes across diverse cardiac surgical populations.[19] Our data suggest that structured early extubation strategies can be safely incorporated into ERAS-based pathways for MICS-CABG.[6] The reduction in ICU length of stay observed with early extubation in our study is consistent with evidence from cardiac surgery showing that the timing of extubation plays a key role in enhancing perioperative recovery. Previous analyses have shown that implementing early extubation strategies as part of fast-track protocols significantly decreases ICU length of stay without increasing adverse outcomes.[20,21] Likewise, recent data support the association between early extubation in coronary surgery and shorter ICU length of stay, reflecting both improved patient recovery and optimized perioperative care.[17] Also, patients who remained intubated longer than six hours in our study experienced higher rates of pneumonia

and arrhythmia, two complications with substantial impact on morbidity and length of stay. The protective effect of shorter ventilation is well established in critical care, and our results confirm its relevance in MICS-CABG. By limiting exposure to ventilator-associated risks and enabling earlier mobilization, early extubation may directly contribute to improved postoperative recovery. Overall, these findings emphasize that structured early extubation in MICS-CABG can provide not only safety but also measurable benefits in terms of postoperative efficiency.

This study has several limitations. First, its retrospective single-center design may limit the generalizability of the findings to other institutions with different patient populations and perioperative management strategies. Second, although extubation followed standardized clinical criteria in our center, variations in sedation practices, analgesic regimens, or ICU staffing could have influenced extubation timing and postoperative outcomes. Finally, the relatively small sample size, while adequate to identify strong predictors in multivariable analysis, may have limited the detection of weaker associations.

Conclusion

This study demonstrates that early extubation after minimally invasive coronary artery bypass grafting is feasible in the majority of patients and is associated with lower rates of pulmonary and cardiac complications. EuroSCORE II, intraoperative blood transfusion, and the need for inotropic support emerged as independent predictors of delayed extubation, underscoring the importance of careful preoperative risk assessment and intraoperative management. Extubation timing should therefore be regarded as a modifiable perioperative target that can directly influence recovery and postoperative outcomes in this population.

Disclosures

Ethics Committee Approval: The study was approved by the Istinye University Ethics Committee (no: 24-51, date: 14/03/2024).

Informed Consent: Informed consent was obtained from all participants.

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