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Early Postoperative Recovery Outcomes of Minimally Invasive Versus Conventional Cardiac Surgery in Adult Patients in Pakistan: A Retrospective Cohort Study (2025-2026)

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ABSTRACT

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Background: Cardiac surgery is indicated when medical therapy fails to control myocardial ischemia, ventricular dysfunction, or hemodynamic instability. Conventional full sternotomy carries substantial perioperative trauma, while minimally invasive cardiac surgery (MICS) aims to reduce access-related morbidity, though evidence from Pakistan remains limited. This study compared early postoperative recovery and examined factors associated with prolonged ventilation and short intensive care unit (ICU) stay after MICS versus conventional surgery.

Methods: In this retrospective cohort study, records of 98 adults (49 conventional, 49 MICS) undergoing coronary or valvular surgery at a single tertiary center in Pakistan (November 2025–May 2026) were analyzed using the Mann–Whitney U test, chi-square or Fisher's exact test, and multivariable binary logistic regression to examine factors associated with prolonged ventilation and identify independent predictors of short ICU stay.

Results: MICS was associated with significantly shorter ventilation time, ICU stay and lower intra-aortic balloon pump (IABP) use (6.1% vs 22.4%; $p=0.040$). Inotropic support and re-exploration favored MICS without reaching significance (re-exploration: $p=0.090$). Surgical approach was the only independent predictor of short ICU stay (adjusted odds ratio [AOR] 7.47, 95% CI 2.28–24.55, $p=0.001$) and approached significance for prolonged ventilation (AOR 8.59, 95% CI 1.00–73.88, $p=0.050$); sex, diabetes, and hypertension were not significant in either model.

Conclusion: MICS was associated with faster early recovery than conventional surgery in this Pakistani cohort, despite higher BMI and longer operative time. Given the retrospective design, these findings reflect association rather than causation and support prospective evaluation of MICS in Pakistani tertiary centers.

Keywords: Minimally Invasive Surgical Procedures; Cardiac Surgical Procedures; Postoperative Care; Intensive Care Units; Intra-Aortic Balloon Pumping

INTRODUCTION

Cardiovascular disease (CVD) remains the leading cause of death and disability worldwide, responsible for an estimated 19.2 million deaths and 626 million prevalent cases in 2023, with the greatest age-standardized burden concentrated in low and low-middle sociodemographic-index countries¹. Rising exposure to modifiable risk factors, population growth, and aging are projected to push global cardiovascular deaths to 35.6 million annually by 2050.^{2,3} Coronary artery disease and valvular heart disease, the two principal indications for cardiac surgery, are managed surgically by coronary artery bypass grafting (CABG) or valve repair/replacement when medical therapy alone cannot adequately control myocardial ischemia, ventricular dysfunction, or hemodynamic compromise.

Conventional cardiac surgery, performed through a full median sternotomy, provides excellent surgical exposure but is associated with substantial tissue trauma, blood loss, prolonged ventilation, extended intensive care unit (ICU) stay, delayed mobilization, and sternal wound complications. Minimally invasive cardiac surgery (MICS) encompassing mini-thoracotomy, partial sternotomy, thoracoscopic, robotic-assisted, and minimally invasive extracorporeal circulation techniques aims to reduce these access-related effects while preserving procedural safety and efficacy⁴. Meta-analytic evidence broadly supports reduced blood loss and transfusion, shorter ventilation and ICU stay, and earlier mobilization with MICS^{4,5,6}, but findings are not uniform: some large, randomized syntheses report no significant difference in ventilation time, reintervention, or mortality⁷, and evidence on inotropic support, intra-aortic balloon pump (IABP) requirement, and re-exploration for bleeding remains sparse and inconsistently reported across studies^{8,9}.

Pragmatic measures of early postoperative recovery were mechanical ventilation duration and stay in the ICU. To evaluate the level of inotropic support and IABP use following surgery, they were added as well as re-exploration for bleeding as a clinically relevant postoperative complication that could extend the need for ventilation and ICU care. These outcomes are affected by patient characteristics, complexity of the procedure, peri-operative management and institutional practice and may not be interpreted as causative differences between surgical groups^{10,11}. These latter three outcomes have been reported particularly inconsistently: the largest randomized synthesis of minimally invasive extracorporeal circulation found no overall reduction in inotrope or IABP requirement⁹, whereas a large single-center coronary bypass cohort reported significantly lower postoperative IABP use after minimally invasive surgery¹², and appropriate prophylactic IABP support in selected high-risk patients has itself been described as beneficial rather than indicative of inferior care¹³. Comparing these outcomes together, rather than in isolation, was intended to provide a more coherent picture of early recovery than existing single-endpoint studies¹⁴.

By reducing mechanical ventilation times, hospital and ICU stays and the cost of hospitalization, minimally invasive cardiac surgery is more efficient of recovery than sternotomy, despite the higher upfront procedural costs¹⁵. In Pakistan, where MICS remains less widely practiced and ICU capacity is a limited and costly resource, prolonged postoperative recovery has direct implications for bed availability, cost, and access to timely surgical care for other patients¹⁶. International findings, generated largely under standardized enhanced-recovery pathways, may not generalize to Pakistani patient profiles, perioperative practices, or resource constraints, and locally generated evidence comparing early recovery across both surgical approaches is lacking.

This study therefore aimed to compare early postoperative recovery outcomes such as ventilation time, ICU stay, inotropic and IABP requirement, and re-exploration for bleeding between adult patients undergoing MICS and conventional cardiac surgery at a single tertiary-care cardiac center in Pakistan, and to examine factors associated with prolonged ventilation and to identify independent predictors of short ICU stay after adjusting for sex, diabetes mellitus, and hypertension. We hypothesized that MICS would be associated with more favorable early recovery across these domains than conventional surgery.

METHODOLOGY

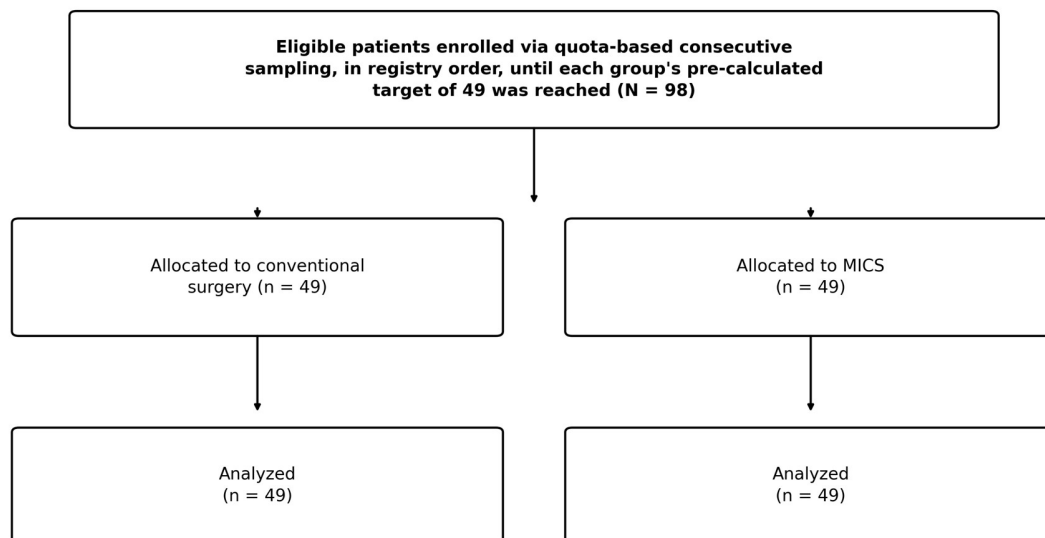
Study Design and Setting

This study used a quantitative, retrospective cohort design to compare early postoperative recovery outcomes between adult patients who underwent MICS and those who underwent conventional cardiac surgery at a single tertiary-care cardiac center in Pakistan. The participating hospital is a high-volume, urban referral center for complex cardiac disease with a dedicated cardiothoracic surgical unit, an intensive care unit, and standardized postoperative monitoring protocols, and it offers both conventional and minimally invasive surgical services. Data were drawn from the clinical records of patients operated on at this single center between November 2025 and May 2026.

Participants

Eligible participants were adults (≥ 18 years) who underwent CABG or valve surgery via conventional (median sternotomy) or minimally invasive access and were subsequently admitted to the ICU with documented recovery parameters. Patients were excluded if they underwent emergency or redo cardiac surgery, combined cardiac and major non-cardiac procedures, had incomplete postoperative outcome data, or died intraoperatively. Non-probability, consecutive sampling was used within each surgical-approach group: eligible patients were enrolled in the order they appeared in the hospital registry until the pre-calculated target of 49 patients per group (see Sample size) was reached in that group, yielding a final cohort of 49 conventional and 49 MICS patients. This quota-based consecutive approach, rather than open-ended enrollment of every eligible patient identified during the study period, accounts for the exact 1:1 balance between groups. Because counts of patients assessed beyond each group's quota cutoff were not separately logged during retrospective data extraction, the participant flow diagram (Figure 1) reports the totals that could be reliably verified from source records, patients enrolled up to the pre-calculated quota, and allocated to and analyzed in each surgical-approach group rather than a full assessed-for-eligibility and reason-coded exclusion breakdown.

Figure 1. Participant flow diagram



Verified counts of eligible patients enrolled via quota-based consecutive sampling and the numbers allocated to and analyzed in the conventional and MICS groups. Recruitment continued within each group, in registry order, until the pre-calculated quota of 49 patients per group was reached; a per-reason breakdown of patients assessed and not enrolled is not presented, as these counts were not separately recorded during retrospective chart review (see STROBE checklist, items 6b and 13a–13b).

Sample size

The required sample size was calculated in OpenEpi (version 3) using the sample size formula for comparing two means, based on expected means and standard deviations for a key continuous early-recovery outcome drawn from prior comparative literature 17, with a two-sided confidence level of 95%, power of 80%, and 1:1 allocation. This yielded a minimum requirement of 49 patients per group (total N = 98: 49 conventional, 49 MICS). Recruitment proceeded via consecutive sampling within each surgical-approach group separately, in registry order, until this per-group quota of 49 was reached, which is why the final cohort splits exactly 1:1 between approaches rather than reflecting the full, unequal number of eligible patients identified during the study period. This calculation was powered specifically for the primary continuous recovery outcome; it was not intended, and should not be interpreted, as providing adequate power for every binary secondary outcome or multivariable model reported in this study.

Data collection

Data were extracted using a structured, investigator-developed proforma from operative notes, anesthesia records, ICU charts, postoperative progress notes, and perfusion/hemodynamic records. Variables comprised demographic data (age, sex), clinical data (diagnosis, procedure type, surgical approach), intraoperative variables (cardiopulmonary bypass [CPB] use and duration, operative duration, estimated blood loss, transfusion, IABP use, temperature-management strategy), intra- and postoperative complications, and the outcome variables of interest such as ventilation time, ICU stay duration, inotropic support requirement, IABP requirement, and re-exploration. Content validity was established through literature-based instrument design and review by the research mentor and an experienced cardiac surgeon; reliability was supported by extraction from objective clinical records and independent double-checking of a subsample against source documents. Data were anonymized at extraction using unique study codes, double-entered into a password-protected electronic database, and checked for completeness and internal consistency, with discrepancies verified against source records.

Statistical analysis

Analyses were performed in IBM SPSS Statistics version 26.0. Normality of continuous variables was assessed with the Shapiro–Wilk test; normally distributed variables are presented as mean $\pm$ standard deviation and non-normally distributed variables as median (interquartile range, IQR). Categorical variables are presented as frequencies and percentages. Between-group comparisons used the independent-samples t-test or Mann–Whitney U test for continuous variables, as appropriate, and the chi-square test for categorical variables with adequate expected cell counts; Fisher's exact test was used for categorical outcomes with low event frequency (IABP use and re-exploration). Effect sizes (r for Mann–Whitney comparisons) were calculated and interpreted using Cohen's benchmarks.

Two multivariable binary logistic regression models (enter method) were built to identify independent predictors of prolonged ventilation (>48 hours) and short ICU stay (<3 days); both outcomes were coded as binary variables (1 = outcome present, 0 = outcome absent), and both models were adjusted for sex, diabetes mellitus, hypertension, and surgical approach. For categorical predictors, the reference category was male (for sex), diabetes mellitus present (for diabetes mellitus), hypertension present (for hypertension), and MICS (for surgical approach); adjusted odds ratios therefore express the odds of the outcome for female vs male, no diabetes vs diabetes, no hypertension vs hypertension, and conventional vs MICS, respectively. Model fit was assessed with the Hosmer–Lemeshow test and Cox & Snell/Nagelkerke R^2 . Statistical significance was set at $p < 0.05$; p -values close to this threshold (including $p = 0.05$) are reported and interpreted as continuous evidence of association rather than classified strictly as "significant" or "not significant."

Ethical considerations

Ethical approval was obtained from the Institutional Review Board of The Operating Room Global (TORG-IRB; approval reference TORG-IRB/2026/032501; protocol ID TORG-IRB-20260325-01) on 06 May 2026, and the study was conducted in accordance with the Declaration of Helsinki and applicable national guidelines for biomedical research in Pakistan. It was a retrospective review of clinical records generated during routine care between November 2025 and May 2026, no prospective data collection, patient contact, or change to clinical management occurred at any point; retrospective abstraction of the relevant medical records began only after IRB approval, and no data were analyzed prior to that date. All direct identifiers were removed at extraction, and each participant was assigned a unique, non-identifying study code; data were stored on a password-protected, encrypted device in accordance with institutional and national data-protection regulations.

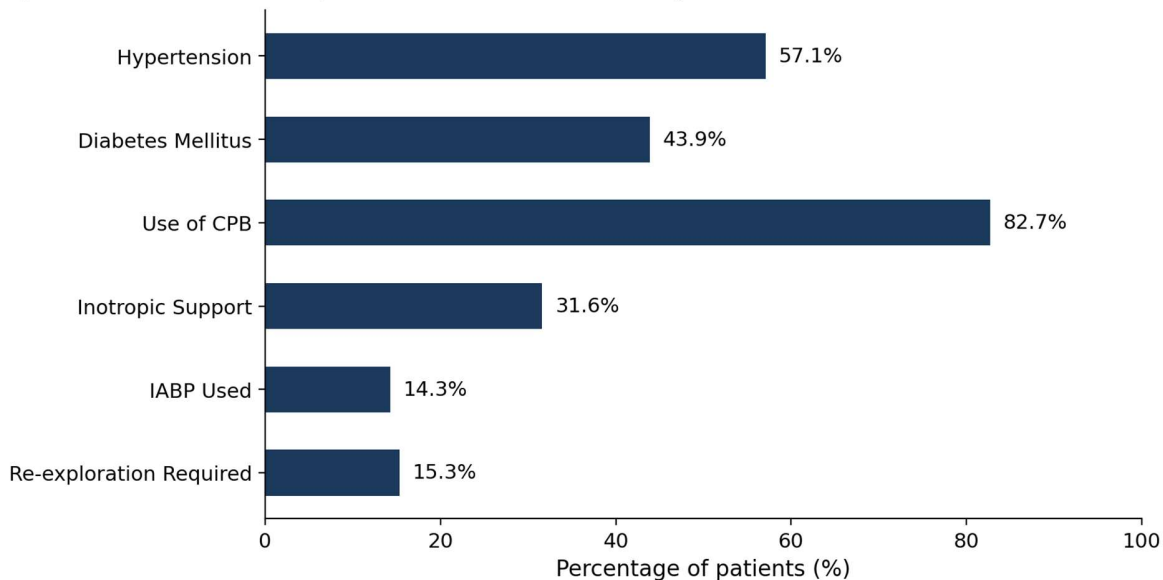
RESULTS

Demographical characteristics

Ninety-eight adult patients were included: 49 (50.0%) underwent conventional surgery and 49 (50.0%) underwent MICS. The cohort comprised 64 males (65.3%) and 34 females (34.7%), with an even split between coronary artery disease (49, 50.0%) and valvular heart disease (49, 50.0%), and between CABG (49, 50.0%) and valve surgery (49, 50.0%). Hypertension was present in 56 patients (57.1%) and diabetes mellitus in 43 (43.9%). Overall clinical characteristics are summarized in Table 1 and Figure 2.

Table 1. Baseline demographic and clinical characteristics of the study cohort (N = 98)

Variable	Value (N = 98)
Age, years, mean $\pm$ SD	55.45 $\pm$ 8.65
Sex, male, n (%)	64 (65.3)
Sex, female, n (%)	34 (34.7)
Body mass index, kg/m ² , mean $\pm$ SD	26.07 $\pm$ 2.88
Ejection fraction, %, mean $\pm$ SD	53.11 $\pm$ 8.30
Diagnosis – coronary artery disease, n (%)	49 (50.0)
Diagnosis – valvular heart disease, n (%)	49 (50.0)
Procedure – CABG, n (%)	49 (50.0)
Procedure – valve surgery, n (%)	49 (50.0)
Surgical approach – conventional, n (%)	49 (50.0)
Surgical approach – MICS, n (%)	49 (50.0)
Hypertension, n (%)	56 (57.1)
Diabetes mellitus, n (%)	43 (43.9)
Operative duration, min, mean $\pm$ SD	201.65 $\pm$ 43.50
Cardiopulmonary bypass time, min, mean $\pm$ SD	76.40 $\pm$ 43.63
Estimated blood loss, mL, mean $\pm$ SD	385.30 $\pm$ 143.03
Intraoperative fluid balance, mL, mean $\pm$ SD	1688.02 $\pm$ 496.14
Intraoperative complications, n (%)	18 (18.4)
Bleeding, n (%)	8 (8.2)
Arrhythmia, n (%)	6 (6.1)
Hemodynamic instability, n (%)	4 (4.1)
Postoperative inotropic support, n (%)	31 (31.6)
Postoperative IABP requirement, n (%)	14 (14.3)
Postoperative re-exploration, n (%)	15 (15.3)

Figure 2. Distribution of key clinical variables in the study cohort (N = 98)

Percentage of patients in the overall cohort (N = 98) with hypertension, diabetes mellitus, use of cardiopulmonary bypass (CPB), postoperative inotropic support, intra-aortic balloon pump (IABP) use, and re-exploration.

Table 2 shows the conventional and MICS groups comparable in age, preoperative ejection fraction, and CPB time. However, the MICS group had a significantly higher body mass index (BMI) (26.74 ± 3.01 vs 25.38 ± 2.60 kg/m², $p = 0.019$) and longer operative duration (222.65 ± 42.05 vs 180.65 ± 33.98 minutes, $p = 0.001$), whereas the conventional group had significantly greater estimated blood loss (465.92 ± 136.23 vs 302.67 ± 94.05 mL, $p < 0.001$) and intraoperative fluid balance (median 1844.00 [IQR 684.00] vs 1392.00 [IQR 420.50] mL, $p = 0.001$).

Table 2. Baseline and perioperative characteristics by surgical approach (N = 98)

Parameter	Conventional (n = 49)	MICS (n = 49)	p-value
Age, years, mean $\pm$ SD	55.71 $\pm$ 9.60	55.18 $\pm$ 7.67	0.763
Body mass index, kg/m ² , mean $\pm$ SD	25.38 $\pm$ 2.60	26.74 $\pm$ 3.01	0.019
Ejection fraction, %, mean $\pm$ SD	51.84 $\pm$ 8.38	54.40 $\pm$ 8.09	0.129
Operative duration, min, mean $\pm$ SD	180.65 $\pm$ 33.98	222.65 $\pm$ 42.05	0.001
Estimated blood loss, mL, mean $\pm$ SD	465.92 $\pm$ 136.23	302.67 $\pm$ 94.05	<0.001
CPB time, min, median (IQR)	82.00 (49.00)	92.00 (71.00)	0.157
Intraoperative fluid balance, mL, median (IQR)	1844.00 (684.00)	1392.00 (420.50)	0.001

Note. Values are mean $\pm$ SD, except CPB time and intraoperative fluid balance, which are reported as median (IQR) owing to non-normal distribution. p-values are from independent samples t-tests for normally distributed variables and Mann–Whitney U tests for non-normally distributed variables.

Intraoperatively, complications occurred in 18 patients (18.4%): bleeding (8, 8.2%), arrhythmia (6, 6.1%), and hemodynamic instability (4, 4.1%). Postoperatively, 31 patients (31.6%) required inotropic support, 14 (14.3%) required IABP, and 15 (15.3%) required re-exploration.

Postoperative recovery outcomes by surgical approach

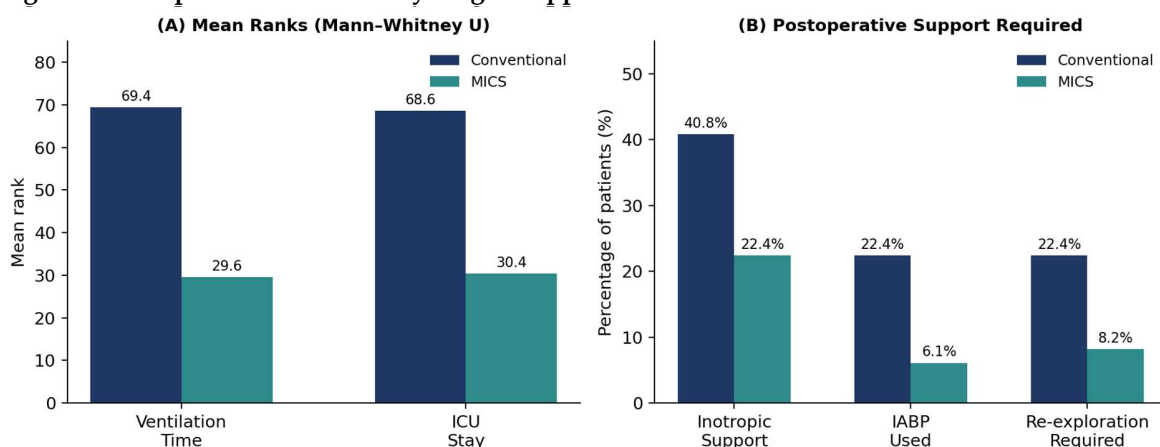
Ventilation time and ICU stay were both non-normally distributed (Shapiro–Wilk $p < 0.001$ and $p = 0.006$, respectively) and were therefore compared using the Mann–Whitney U test. MICS was associated with significantly shorter ventilation time (mean rank 29.61 vs 69.39; $U = 226.00$, $Z = -6.925$, $p < 0.001$, $r = 0.42$) and significantly shorter ICU stay (mean rank 30.37 vs 68.63; $U = 263.00$, $Z = -6.664$, $p < 0.001$, $r = 0.65$) than conventional surgery, representing with large effects (Table 3, Figure 3A).

Postoperative support requirements followed a broadly consistent pattern (Table 3, Figure 3B). Because IABP use and re-exploration were both low-frequency outcomes, group differences for these two variables were evaluated with Fisher's exact test. IABP use was significantly less frequent after MICS (3/49, 6.1%) than after conventional surgery (11/49, 22.4%; Fisher's exact $p = 0.040$). Re-exploration for bleeding was also less frequent after MICS (4/49, 8.2%) than after conventional surgery (11/49, 22.4%), but this difference did not reach statistical significance (Fisher's exact $p = 0.090$). Inotropic support (11/49, 22.4% vs 20/49, 40.8%; $\chi^2(1) = 3.822$, $p = 0.051$) showed the same direction of benefit without reaching significance. Effect sizes (0.20–0.23) indicated small-to-modest associations for these three comparisons, consistent with a pattern of directionally favorable but not uniformly statistically significant differences.

Table 3. Early postoperative recovery outcomes by surgical approach (N = 98)

Outcome	Conventional (n = 49)	MICS (n = 49)	Test statistic	p-value
Ventilation time, mean rank	69.39	29.61	$U = 226.00$, $Z = -6.925$, $r = 0.42$	<0.001
ICU stay, mean rank	68.63	30.37	$U = 263.00$, $Z = -6.664$, $r = 0.65$	<0.001
Inotropic support, n (%)	20 (40.8)	11 (22.4)	$\chi^2(1) = 3.822$	0.051
IABP use, n (%)	11 (22.4)	3 (6.1)	Fisher's exact test	0.040
Re-exploration, n (%)	11 (22.4)	4 (8.2)	Fisher's exact test	0.090

Figure 3. Postoperative outcomes by surgical approach



(A) Mean ranks for ventilation time and ICU stay (Mann–Whitney U test); lower mean rank indicates shorter duration. (B) Percentage of patients requiring inotropic support, IABP, or re-exploration, by surgical approach (conventional vs MICS).

Multivariable Analysis of Factors Associated with Prolonged Ventilation and Short ICU Stay

Two multivariable logistic regression models, adjusted for sex, diabetes mellitus, hypertension, and surgical approach, were fitted for prolonged ventilation (>48 hours) and short ICU stay (<3 days) (Table 4 and Figure 3). The model for prolonged ventilation was not statistically significant overall (omnibus $\chi^2 = 6.404$, $df = 4$, $p = 0.171$; Nagelkerke $R^2 = 0.146$) but showed adequate fit (Hosmer–Lemeshow $\chi^2 = 10.288$, $p = 0.245$). At the default 0.50 classification cutoff, the model correctly classified 91.8% of cases, but sensitivity was 0%, specificity was 100%, and negative predictive value (NPV) was 91.8%; positive predictive value (PPV) was not estimable because no cases were classified as prolonged ventilation. After adjustment, conventional surgical approach showed an association with higher odds of prolonged ventilation; however, the estimate was imprecise (AOR = 8.59, 95% CI 1.00–73.88, $p = 0.050$), and the overall model was not statistically significant. Sex (AOR = 0.72, 95% CI 0.12–4.34, $p = 0.724$), diabetes mellitus (AOR = 0.64, 95% CI 0.14–2.98, $p = 0.569$), and hypertension (AOR = 1.52, 95% CI 0.32–7.22, $p = 0.598$) were also not significant predictors.

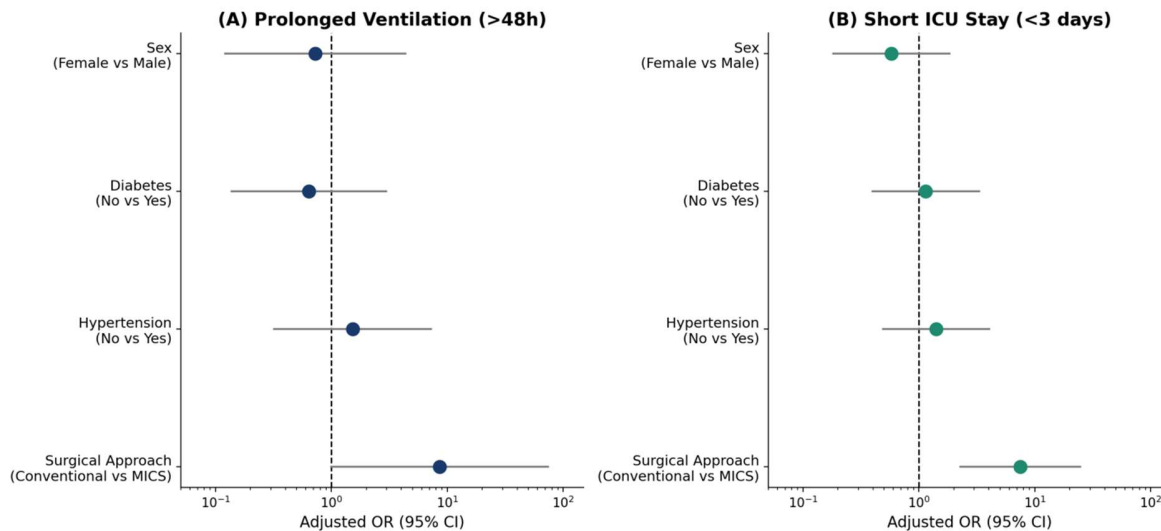
The model for short ICU stay was statistically significant (omnibus $\chi^2 = 15.319$, $df = 4$, $p = 0.004$; Nagelkerke $R^2 = 0.218$), with good fit (Hosmer–Lemeshow $\chi^2 = 5.863$, $p = 0.663$). At the default 0.50 classification cutoff, it correctly classified 76.5% of cases, but sensitivity was 0%, specificity was 100%, and NPV was 76.5%; PPV was not estimable because no cases were classified as having a short ICU stay. Surgical approach was the only significant independent predictor (AOR = 7.47, 95% CI 2.28–24.55, $p = 0.001$); sex (AOR = 0.58, 95% CI 0.18–1.83, $p = 0.350$), diabetes mellitus (AOR = 1.14, 95% CI 0.40–3.30, $p = 0.803$), and hypertension (AOR = 1.41, 95% CI 0.49–4.02, $p = 0.526$) were not significantly associated with ICU stay duration. Because short ICU stay (<3 days) reflects earlier not delayed recovery, a higher AOR for this outcome indicates a greater likelihood of the faster-recovery outcome, not a greater risk of a complication.

Table 4 Multivariable logistic regression analysis for predictors of prolonged ventilation and short ICU stay

Predictor (reference group)	Prolonged ventilation (>48 h) AOR (95% CI), p	Short ICU stay (<3 days) AOR (95% CI), p
Sex (female vs male)	0.72 (0.12–4.34), $p = 0.724$	0.58 (0.18–1.83), $p = 0.350$
Diabetes mellitus (no vs yes)	0.64 (0.14–2.98), $p = 0.569$	1.14 (0.40–3.30), $p = 0.803$
Hypertension (no vs yes)	1.52 (0.32–7.22), $p = 0.598$	1.41 (0.49–4.02), $p = 0.526$
Surgical approach (conventional vs MICS)	8.59 (1.00–73.88), $p = 0.050$	7.47 (2.28–24.55), $p = 0.001$

Note. AOR = adjusted odds ratio; CI = confidence interval. Both outcomes were coded as binary (1 = outcome present, 0 = outcome absent). Reference categories: male (sex), diabetes mellitus present (diabetes mellitus), hypertension present (hypertension), and MICS (surgical approach). Models adjusted for sex, diabetes mellitus, hypertension, and surgical approach (enter method).

Figure 3 Adjusted odds ratios for predictors of prolonged ventilation and short ICU stay



Adjusted odds ratios (95% confidence interval, log scale) from multivariable logistic regression for (A) prolonged ventilation (>48 h) and (B) short ICU stay (<3 days). The dashed vertical line marks an odds ratio of 1 (no effect); estimates whose confidence interval crosses this line are not statistically significant.

DISCUSSION

This retrospective cohort study compared early postoperative recovery between MICS and conventional cardiac surgery in 98 Pakistani adults. Consistent with our hypothesis, MICS was associated with significantly shorter ventilation time and ICU stay and significantly lower IABP use, while inotropic support and re-exploration showed the same direction of benefit without reaching conventional significance. After adjustment for sex, diabetes mellitus, and hypertension, surgical approach remained the only independent predictor of short ICU stay and approached significance for prolonged ventilation.

The reduction in ventilation time with MICS ($r = 0.42$) aligns with observational and single-center evidence reporting earlier extubation with minimally invasive or enhanced-recovery pathways^{15,18,19}. It contrasts, however, with the two largest randomized syntheses in the field, which found no significant difference in ventilation time^{7,20}. A plausible explanation is that these meta-analyses pooled predominantly isolated valve procedures performed within standardized, protocol-driven pathways, where extubation timing is governed more by institutional fast-track protocols than by incision size, whereas the present study combined CABG and valve surgery at a single Pakistani center without a uniform enhanced-recovery or zero-ICU pathway, so differences attributable to surgical trauma itself may remain more visible.

The reduction in ICU stay (large effect, $r = 0.65$) was the most robust finding of this study and the outcome most consistently supported across the literature, including the largest randomized synthesis⁷ and observational and matched studies^{15,19}. This convergence across study designs, settings, and procedure types is consistent with reduced ICU dependency being an association with MICS rather than an artifact of case selection, and is compatible with a surgical stress and recovery model in which reduced access trauma is linked to faster physiological stabilization; as with all findings in this retrospective cohort, however, this remains an association rather than evidence of a causal mechanism.

The significantly lower rate of IABP use after MICS (6.1% vs 22.4%) replicates findings from a large coronary bypass cohort in which minimally invasive off-pump surgery was associated with lower postoperative IABP use, even after propensity matching, attributed partly to greater operative efficiency¹². This contrasts with the largest randomized

synthesis of minimally invasive extracorporeal circulation, which found no overall reduction in IABP or inotrope requirement⁹, a discrepancy that likely reflects a difference in comparator: that synthesis evaluated perfusion strategy (minimally invasive extracorporeal circulation versus conventional bypass) rather than surgical access route, whereas the present study, like Lei et al.¹², compared surgical approach directly, capturing the combined effect of smaller incisions and reduced operative trauma on hemodynamic stability. It is also worth noting that prophylactic or adjunctive IABP use in selected high-risk patients may itself reflect appropriate support rather than inferior care¹³, underscoring the importance of interpreting group differences in IABP use as a marker of perioperative course rather than of quality.

In the adjusted regression models, surgical approach was the only significant independent predictor of short ICU stay and approached significance for prolonged ventilation, while sex, diabetes mellitus, and hypertension were not significant in either model (Table 4). This differs somewhat from studies emphasizing patient-level risk factors, such as ejection fraction or comorbidity burden, as primary drivers of delayed recovery, and suggests that in this cohort, technique-related factors outweighed the baseline patient characteristics measured. The relatively modest, explained variance (Nagelkerke R^2 14.6–21.8%) indicates that unmeasured intraoperative variables such as operative time, blood loss, transfusion, and perfusion strategy likely account for additional variance not captured by this model.

An important contextual finding is that the MICS group had a significantly higher mean BMI and longer operative duration than the conventional group, factors typically associated with greater technical difficulty and, if anything, expected to disadvantage the MICS group. Despite this less favorable profile, the MICS group still showed significantly lower blood loss, shorter ventilation and ICU stay, and lower IABP use. This pattern is compatible with the observed differences being associated with surgical approach rather than a more favorable baseline risk profile, although, given the retrospective, non-randomized design, residual confounding by unmeasured variables cannot be excluded and a causal relationship cannot be established. This is broadly consistent with reports of preserved recovery benefit with minimally invasive approaches despite comparable or higher baseline risk^{18,21}.

This study's principal strength is its integrated assessment of five recovery domains within a single comparative cohort powered for its primary continuous recovery outcomes, generated from routine clinical practice at a Pakistani tertiary-care center, a setting largely absent from the existing comparative literature, which is dominated by high-income-country data^{7,14}. Several limitations should nonetheless be considered. The retrospective cohort design with non-probability, consecutive sampling limits control of confounding and precludes firm causal inference. While the sample size was adequate for the primary continuous outcomes, it was likely underpowered for the lower-base-rate binary outcomes (inotropic support, re-exploration). The regression models explained only 14.6–21.8% of outcome variance, indicating that unmeasured intraoperative factors were not captured. Only early postoperative recovery was assessed; longer-term outcomes such as functional recovery, readmission, and quality of life were outside the scope of this study¹⁴. Finally, as data were drawn exclusively from a single Pakistani tertiary-care center, findings may not generalize to other centers, lower-throughput settings, or non-tertiary settings. The high apparent classification accuracy should therefore be interpreted cautiously: at the 0.50 cutoff, both models classified all observations into the majority (negative) outcome category, yielding 0% sensitivity despite the reported overall accuracy.

Several recommendations follow from these findings for practice, policy, education, and future research. Multidisciplinary case selection and postoperative monitoring protocols that account for surgical approach should be considered when determining an appropriate patient population for cardiac surgical teams pursuing MICS for coronary artery disease or valvular heart disease^{19,21}. Hospital administrators and health policymakers should consider introducing MICS within tertiary cardiac centers as a viable strategy to reduce critical-care burden, provided there is capacity to invest in surgeon training, compatible perfusion equipment, and ICU resource planning²². In education, structured training and simulation-based credentialing programs for trainees and practicing surgeons are needed to support the safe adoption of minimally invasive approaches, alongside ongoing professional education on realistic, evidence-based recovery expectations. Future research should prioritize larger, multicenter, prospective studies with standardized enhanced-

recovery protocols to confirm the borderline findings for inotropic support and re-exploration, incorporate unmeasured intraoperative factors such as blood loss, transfusion, and perfusion strategy into multivariable models, and extend follow-up beyond the immediate postoperative period to capture functional recovery, readmission, and quality of life¹⁴. Cost-effectiveness analyses comparing MICS with conventional approaches within Pakistani healthcare settings would further strengthen the evidence base for future policy decisions.

CONCLUSION

In this Pakistani cohort of 98 adults treated at a single tertiary-care cardiac center, minimally invasive cardiac surgery was associated with significantly shorter ventilation time and ICU stay and significantly lower IABP requirement than conventional surgery, with inotropic support showing the same non-significant direction of benefit and re-exploration showing a similar but weaker directional pattern that did not reach statistical significance (Fisher's exact $p = 0.090$). Surgical approach was the only independent predictor of short ICU stay after adjustment for sex, diabetes mellitus, and hypertension, and this association persisted despite a less favorable baseline profile (higher BMI) in the MICS group. As this was a retrospective, single-center observational study, these findings should be interpreted as an association rather than proof of a causal benefit of MICS. They provide context-specific, hypothesis-generating evidence, largely consistent with international data, in support of the continued and cautious adoption of minimally invasive approaches in Pakistani tertiary cardiac centers, while highlighting the need for larger, prospective, multicenter studies to confirm effects on inotropic support and re-exploration and to evaluate longer-term outcomes.

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DECLARATIONS

Conflict of Interest

The authors declare no conflicts of interest relevant to the content of this manuscript.

Use of Artificial Intelligence

During the preparation of this manuscript, the authors used an AI-based language model (Claude, Anthropic) to assist with drafting, restructuring, and formatting the manuscript from the authors' original dissertation data and analysis, and to reformat the reference list. The AI tool was not used to collect, generate, analyze, or interpret study data or results; all data, statistical results, and scientific interpretations originate from the authors' own research. The authors reviewed and edited the AI-assisted content and take full responsibility for the accuracy, integrity, and originality of the final manuscript.

AUTHOR CONTRIBUTIONS (CREDIT)

Fatima Jaweria: Project administration, Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing original draft. Myada A. Ibrahim: Supervision & review & editing. Zia Un Nisa: Writing, review & editing. Saman Aziz: Writing, review & editing. Muhammad Muzammil Ramzan: Writing, review & editing. All authors approved the final manuscript and take responsibility for the integrity of the work.

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