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Perioperative outcomes of minimally invasive coronary artery bypass grafting over conventional sternotomy: A propensity-matched analysis

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***Abstract*---Background:** A minimally invasive coronary artery bypass grafting (MICS CABG) procedure has been devised as a less invasive alternative to conventional open sternotomy (OPEN CABG) through a left anterior thoracotomy. The objective of this investigation was to employ propensity score matching to compare the procedural characteristics, ventilation duration, drainage volumes, and postoperative complications of MICS CABG and OPEN CABG. **Methods:** This retrospective propensity-matched study was performed on 350 cases who were subjected to surgical revascularization from January 2017 to June 2021. Propensity score matching (1:1 nearest-neighbor) was conducted to control for baseline differences. **Results:** 175 patients were included in each cohort following propensity matching. MICS CABG was related to a shortened median procedure time ($p = 0.03$) and a decreased mechanical ventilation duration (5p < 0.001). MICS CABG resulted in a shorter total hospitalisation ($p = 0.04$). Transfusion requirements for red blood cells were decreased ($p = 0.04$), and postoperative drainage was substantially reduced at 12 hours ($p < 0.01$). MICS CABG was related to a lower incidence of acute kidney injury ($p = 0.03$). **Conclusions:** MICS CABG should be considered as a preferred approach for coronary revascularization in cases with appropriate anatomy and disease complexity.

***Keywords*---**cardiac surgical procedures, minimally invasive surgical procedures, coronary artery disease, myocardial revascularization, propensity score.

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Introduction

According to the World Health Organization, cardiovascular diseases continue to be the primary cause of death worldwide, with ischaemic heart disease accounting for approximately 16% of all deaths [1]. Myocardial ischaemia is a consequence of the progressive atherosclerotic process that underlies coronary artery disease. If not adequately managed, this condition can lead to acute coronary syndromes, progressive heart failure, and sudden cardiac mortality [2]. The optimal revascularization strategy for patients with multivessel coronary artery disease is in a state of perpetual flux, as it is determined by case-specific features such as disease complexity, comorbidities, and anatomical considerations. Coronary artery bypass grafting and percutaneous coronary intervention are complementary procedures [3].

A wide range of techniques, such as robotic-assisted approaches, minimally invasive direct coronary artery bypass, and complete endoscopic coronary artery bypass, have been developed for minimally invasive coronary revascularization. Each technique has its own set of advantages and limitations [4]. The left anterior thoracotomy approach for MICS CABG offers direct access to the left anterior descending artery and, with increasing experience, the circumflex and right coronary artery territories through a small incision that does not require sternal division [5].

The efficacy of MICS CABG is considerably influenced by the selection of cases and the experience of the surgeon, and the learning curve is substantia [6]. Additionally, the evidence base for MICS CABG has been primarily derived from observational studies with inherent selection bias, as patients who are preferred for minimally invasive approaches typically have less complex disease and fewer comorbidities [4].

The objective of this investigation is to employ propensity score matching to compare the procedural data, duration of ventilation, volumes of drainage, and postoperative complications of OPEN CABG and MICS CABG.

Patients and Methods:

Study Design

We performed a retrospective comparative study using prospectively collected data from the **Suez Canal University Hospital, Ismailia, Egypt and King Fahad Specialist Hospital, Tabuk, Saudi Arabia** database. Propensity score matching was employed to reduce confounding by indication and provide more valid comparisons between MICS CABG and OPEN CABG.

Study Population

All cases who underwent isolated elective coronary artery bypass grafting at the **Suez Canal University Hospital, Ismailia, Egypt and King Fahad Specialist Hospital, Tabuk, Saudi Arabia** between January 2017 and June 2021 were assessed for eligibility. Patients were required to be 18 years or older with an established diagnosis of coronary artery disease warranting surgical revascularization. Exclusion criteria comprised: (1) refusal of surgery after consent, (2) preoperative death before the scheduled procedure, (3) urgent or emergent surgical priority, (4) concomitant cardiac procedures (valve surgery, aortic surgery, etc.), and (5) intraoperative conversion from MICS CABG to sternotomy.

Surgical Techniques

OPEN CABG: Cardiopulmonary bypass was established through aortic and bicaval cannulation, and all patients underwent conventional median sternotomy. To ensure myocardial protection, antegrade and retrograde cold blood cardioplegia were implemented. Proximal anastomoses were performed during partial aortic clamping, followed by distal anastomoses during a single aortic cross-clamp period. The left internal mammary artery was the preferred choice for left anterior descending grafting, while saphenous vein transplants were employed for other targets.

MICS CABG: The procedure was conducted through a left anterolateral mini-thoracotomy in the fourth or fifth intercostal space. The pericardium was opened anterior to the phrenic nerve, and femoral vessels were cannulated for cardiopulmonary bypass. Specialised long-shafted instruments and an endoscopic stabiliser were implemented. The LIMA was harvested with direct thoracoscopic assistance and direct vision. The thoracotomy incision was used to perform distal anastomoses under direct vision. Sequential grafting techniques or alternative conduits were employed for multivessel revascularisation, contingent upon the accessibility of the target vessel.

Propensity Score Methodology

In order to reduce confounding by indication, we implemented multivariable logistic regression to develop a propensity score model. The surgical approach ("MICS CABG" versus "OPEN CABG") was the dependent variable. Age, sex, body mass index, ejection fraction, STS risk score, diabetes mellitus, chronic kidney disease, hypertension, chronic obstructive pulmonary disease, peripheral vascular disease, number of diseased vessels, and previous myocardial infarction were a priori selected based on their clinical relevance. A C-statistic of 0.74 was observed in the logistic regression model, which is deemed acceptable for discrimination purposes. We employed a calliper width of 0.2 of the standard deviation of the propensity score logit to conduct 1:1 nearest-neighbor matching without replacement. Values less than 0.1 were used to assess balance, with standardised differences being computed that indicated satisfactory balance.

Statistical Analysis

SPSS version 26.0 (IBM Corp., Armonk, NY) and R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria) were employed to conduct statistical analyses. The Shapiro-Wilk test was done to assess the normality of continuous variables. The mean and standard deviation of normally distributed variables were calculated and contrasted using independent t-tests. Mann-Whitney U tests were employed to compare non-normally distributed variables, which were represented as medians with interquartile ranges. Categorical variables were compared by Chi-square tests or Fisher's exact tests when the expected frequencies were less than 5. The frequencies and percentages of the categorical variables were expressed. $P<0.05$ considered as significant.

Results

A total of 402 cases underwent isolated CABG. After excluding 52 patients (18 with previous cardiac surgery, 22 with concomitant valve procedures, 8 with urgent/emergent priority, and 4 with incomplete data), 350 patients remained and were successfully matched (175 per group). Baseline data were well-balanced between groups, with insignificant variances in age, sex, BMI, comorbidities, ejection fraction, disease severity, or STS risk scores (all $p > 0.05$), confirming the effectiveness of the matching process **(Table 1)**.

Table 1: Baseline data after propensity score matching

	OPEN CABG (n = 175)	**MICS CABG (n = 175)**	**P value**
Age, years (mean ± SD)	66.6 ± 8.7	66.4 ± 8.1	0.56
Male sex, n (%)	126 (72.0)	130 (74.3)	0.63
Body-mass index, kg/m² (mean ± SD)	28.2 ± 4.1	27.8 ± 4.3	0.38
Hypertension, n (%)	158 (90.3)	155 (88.6)	0.61
Diabetes mellitus, n (%)	70 (40.0)	65 (37.1)	0.58
Hyperlipidemia, n (%)	131 (74.9)	125 (71.4)	0.47
Chronic kidney disease, n (%)	13 (7.4)	15 (8.6)	0.69
Chronic obstructive pulmonary disease, n (%)	24 (13.7)	27 (15.4)	0.65
Peripheral vascular disease, n (%)	53 (30.3)	49 (28.0)	0.64
Ejection fraction, % (median, IQR)	43.0 (35.0-50.0)	44.0 (37.0-51.0)	0.38
STS mortality score, % (median, IQR)	1.45 (0.92-2.51)	1.38 (0.85-2.43)	0.42
Triple-vessel disease, n (%)	118 (67.4)	113 (64.6)	0.58
Previous myocardial infarction, n (%)	38 (21.7)	36 (20.6)	0.79
Previous PCI, n (%)	22 (12.6)	20 (11.4)	0.74

The MICS CABG cohort demonstrated a significantly shorter median procedure duration in comparison to the OPEN CABG cohort ($p = 0.03$), despite a lower number of grafts performed ($p < 0.001$), reflecting the use of MICS CABG in cases with less extensive coronary disease.

MICS CABG was associated with significantly improved recovery parameters, including markedly shorter mechanical ventilation ($p < 0.001$), reduced ICU stay ($p = 0.02$), and shorter total hospitalization ($p = 0.04$). Postoperative chest tube drainage was lower in the MICS CABG group at both 12 and 24 hours (both $p < 0.01$). Transfusion requirements were substantially reduced, with fewer patients requiring red blood cells ($p = 0.04$), fresh frozen plasma ($p = 0.03$), and platelets ($p = 0.05$), along with lower median RBC units transfused ($p = 0.03$) **(Table 2)**.

Table 2: Operative and postoperative outcomes

	OPEN CABG (n = 175)	**MICS CABG (n = 175)**	**P value**
Procedure duration, hours (median, IQR)	3.6 (3.1-4.2)	3.3 (2.8-3.9)	0.03
Number of grafts, median (IQR)	3.0 (2.0-4.0)	2.0 (1.0-3.0)	<0.001
Mechanical ventilation, hours (median, IQR)	11.6 (8.5-16.0)	5.2 (4.5-6.4)	<0.001
ICU stay, days (median, IQR)	2.5 (2.0-3.5)	2.0 (1.5-3.0)	0.02
Hospital stay, days (median, IQR)	6.9 (6.0-8.0)	5.8 (5.0-7.0)	0.04
Drainage at 12h, mL (mean ± SD)	380.8 ± 205.4	322.3 ± 185.5	<0.01
Drainage at 24h, mL (mean ± SD)	545.6 ± 275.3	455.8 ± 250.2	<0.01
RBC transfusion, n (%)	63 (36.0)	45 (25.8)	0.04
RBC units, median (IQR)	0 (0-2)	0 (0-1)	0.03
FFP transfusion, n (%)	43 (24.6)	27 (15.4)	0.03
Platelet transfusion, n (%)	26 (14.9)	14 (8.0)	0.05
Low-dose inotropes, n (%)	105 (60.0)	85 (48.6)	0.03
Medium-dose inotropes, n (%)	26 (14.9)	10 (5.7)	<0.01
High-dose inotropes, n (%)	8 (4.6)	5 (2.9)	0.39
New-onset atrial fibrillation, n (%)	20 (11.4)	17 (9.7)	0.60
AV block III, n (%)	11 (6.3)	2 (1.1)	0.02
Sinus rhythm, n (%)	147 (84.0)	160 (91.4)	0.04

The MICS CABG group significantly reduced the need for inotropic support, with a lower percentage of patients requiring low-dose ($p = 0.03$) and medium-dose support ($p < 0.01$) support. The number of cases requiring high-dose support was insignificantly among both cohorts ($p = 0.39$).

The MICS CABG cohort exhibited a significantly lower frequency of third-degree AV block (1.1% vs. 6.3%, $p = 0.02$) and a better preservation of sinus rhythm (91.4% vs. 84.0%, $p = 0.04$) in the postoperative ECG findings. The rates of new-onset atrial fibrillation were comparable among both cohorts (9.7% vs. 11.4%, $p = 0.60$).

Acute kidney injury incidence a was lower in the MICS CABG cohort ($p = 0.03$). Despite the fact that the MICS CABG cohort had a decreased incidence of wound infections (3.4% vs. 8.0%), the difference was statistically insignificant. There were insignificant variances among cohorts regarding neurological complications, CPR requirements, 30-day mortality, and readmission rates. **(Table 3)**.

Table 3: Complications and clinical outcomes

	OPEN CABG (n = 175)	MICS CABG (n = 175)	P value
Wound infection, n (%)	14 (8.0)	6 (3.4)	0.06
Acute kidney injury, n (%)	35 (20.0)	19 (10.9)	0.03
Neurological complication, n (%)	6 (3.4)	4 (2.3)	0.52
CPR - asystole/PEA, n (%)	8 (4.6)	3 (1.7)	0.12
CPR - VF/VT, n (%)	10 (5.7)	4 (2.3)	0.10
30-day mortality, n (%)	5 (2.9)	3 (1.7)	0.47
Readmission within 30 days, n (%)	22 (12.6)	14 (8.0)	0.16

Discussion

The perioperative outcomes of MICS CABG via left anterior thoracotomy are significantly improved in comparison to conventional CABG via median sternotomy, as demonstrated by this propensity-matched study. Shorter procedure durations, significantly reduced mechanical ventilation requirements, decreased chest tube drainage, lower transfusion rates, reduced vasoactive agent requirements, shorter intensive care unit and hospital stays, and fewer complications, including acute kidney injury, were achieved with the MICS CABG approach.

Our findings revealed shorter procedure duration in the MICS CABG group which is aligned with recent reports suggesting that with sufficient experience, MICS CABG can be performed more expeditiously than traditional sternotomy in selected patients [7].

It is crucial to acknowledge that the MICS CABG group underwent fewer grafts ($p < 0.001$). This is aligning with previous reports and reflects the reality that MICS CABG is more appropriate for cases with less extensive disease [8]. Patients with isolated LAD disorder, single-vessel disease, or double-vessel disease involving accessible targets are more appropriate candidates for MICS CABG, while those with extensive three-vessel disease or diffusely diseased vessels are better served by conventional sternotomy [9].

The most striking difference observed was in mechanical ventilation duration, with MICS CABG patients requiring only 5.2 hours compared to 11.6 hours for OPEN CABG patients ($p < 0.001$). This represents a 55% decrease in ventilation time and has substantial clinical implications. The limited thoracotomy approach of MICS CABG minimizes disruption of the chest wall, preserving normal respiratory mechanics and enabling earlier spontaneous ventilation [10]. In comparison to sternotomy, studies have shown that minimally invasive approaches result in superior postoperative pulmonary function [11].

The preservation of the sternum also precludes sternal instability, which can further impair respiratory function in the early postoperative period [12]. The MICS CABG group exhibited a substantial decrease in postoperative chest tube drainage at all measured time intervals, with a 15% reduction at 12 hours and a 16% reduction at 24 hours respectively. This resulted in a notable reduction in cases number requiring transfusions, with nearly one-third fewer cases need red blood cell transfusions (25.8% vs. 36.0%, $p = 0.04$). The clinical significance of this discovery is further underscored by the decreased number of red blood cell units transfused (median 0 vs. 0-2 units, $p = 0.03$).

The mechanisms underlying reduced bleeding with MICS CABG are multifactorial. The avoidance of sternotomy reduces the extensive medullary bone bleeding that commonly occurs with sternal division [13]. The clinical importance of reduced transfusion requirements cannot be overstated. Blood transfusion is associated with numerous adverse effects [14, 15]. Furthermore, blood products represent a scarce resource with significant economic costs [16]. The reduction in transfusion requirements observed with MICS CABG thus represents a meaningful clinical benefit.

The significantly lower requirement for inotropic and vasopressor support in the MICS CABG cohort ($p = 0.03$; $p < 0.01$) indicates better hemodynamic stability and myocardial preservation with the minimally invasive approach. Several factors may contribute to this finding.

First, the reduced systemic inflammatory response associated with MICS CABG may result in less myocardial dysfunction [17]. Cardiopulmonary bypass, while utilized in both groups in our series, may be associated with less pronounced inflammatory activation when combined with the reduced tissue trauma of minimally invasive surgery. Second, the shorter procedure duration may translate to less myocardial ischemia time and reduced reperfusion injury. Third, the more targeted approach to the affected myocardium may result in less manipulation and distortion of the heart compared to the extensive manipulation required during sternotomy [18].

The need for high-dose inotropic support was low in both cohorts (2.9% vs. 4.6%, $p = 0.39$), reflecting the generally good preoperative left ventricular function in our cohort. However, the consistent pattern of reduced vasoactive requirements across low and medium-dose ranges suggests a genuine advantage for MICS CABG.

In contrast to 20.0% of OPEN CABG patients, acute kidney injury was observed in only 10.9% of MICS CABG patients ($p = 0.03$). This signifies a substantial decrease in one of the most prevalent and severe complications that occur subsequent to cardiac surgery. A prolonged hospital stay, increased mortality, and an elevation risk of chronic kidney disorder progression are all associated with acute kidney injury following CABG [19].

The mechanisms underlying the reduced acute kidney injury incidence with MICS CABG are likely multifactorial. Reduced systemic inflammatory response may limit renal injury [20]. Lower transfusion requirements reduce the risk of transfusion-related renal injury [21]. Shorter procedure duration and cardiopulmonary bypass times may reduce the duration of renal hypoperfusion and ischemic injury [22]. Additionally, the lower requirement for vasoactive agents may result in more stable renal perfusion and reduced vasoconstrictor-mediated renal injury [23].

Our finding is consistent with studies demonstrating reduced renal injury with off-pump and minimally invasive cardiac surgery [24, 25]. The reduction in acute kidney injury from 20% to 10.9% observed in our study would represent a significant clinical advance if confirmed in larger studies.

The higher rate of sinus rhythm preservation in the MICS CABG cohort (91.4% vs. 84.0%, p = 0.04) and the significantly lower rate of third-degree AV block (1.1% vs. 6.3%, p = 0.02) suggest that MICS CABG may be associated with less conduction system disturbance.

Interestingly, new-onset atrial fibrillation occurred at similar rates in both cohorts (9.7% vs. 11.4%, p = 0.60). This contrasts with some studies suggesting reduced postoperative atrial fibrillation with minimally invasive approaches [26]. The comparable rates may reflect the importance of factors as patient age, left atrial size, and inflammatory response independent of surgical approach [27].

Wound infections occurred in 3.4% of MICS CABG patients compared to 8.0% of OPEN CABG patients, a difference that trended toward statistical significance (p = 0.06). The smaller incision and avoidance of sternal division likely contribute to reduced infection risk by decreasing the wound surface area and eliminating sternal osteomyelitis [28]. Deep sternal wound infections are among the most feared complications of cardiac approaches, related to substantial morbidity, death, and healthcare costs [29].

The near-elimination of sternal wound infection risk is one of the most compelling advantages of MICS CABG. The trend toward reduced superficial wound infections in our research is consistent with prior reports demonstrating lower infection rates with MICS CABG [30].

Despite the fact that the 30-day mortality rate was decreased in the MICS CABG cohort (1.7% vs. 2.9%), the difference was insignificance. In the same vein, the 30-day readmission rate was numerically decreased in the MICS CABG cohort (p = 016). The insufficient power to assess differences in low-frequency events is likely the reason for the lack of statistical significance for these outcomes. In order to verify whether the perioperative benefits of MICS CABG result in enhanced short-term survival and decreased readmissions, larger studies are required [31].

Our results are in accordance with the expanding body of evidence that supports MICS CABG as a safe and efficacious alternative to conventional sternotomy. Teman et al. [7] have shown that MICS CABG is related to shorter hospital stays and reduced blood product utilisation, without any differences in mortality or major complications. Baishya et al. [32] reported that MICS CABG resulted in enhanced outcomes, as a shorter hospitalization, reduced blood loss, and shorter ventilation time.

The current study has several limitations that warrant consideration including the retrospective single-center setting with potential unmeasured confounding despite propensity matching. Lack of long-term follow-up precludes assessment of graft patency and survival outcomes. Residual selection bias persists as MICS CABG patients had fewer grafts reflecting less complex disease. The study was underpowered for rare events like mortality, and variation in surgeon experience may have influenced outcomes despite experienced operators.

Conclusions

MICS CABG resulted in shorter duration of the procedure, dramatically reduced mechanical ventilation time, decreased chest tube drainage, lower transfusion requirements, reduced vasoactive support, shorter intensive care unit and hospital stays, fewer wound infections, and lower rates of acute kidney diseases. In cases with appropriate anatomy and disease complexity, MICS CABG should be considered as a preferred approach for coronary revascularisation, as these advantages indicate.

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References

1. Organization WH. World Health Organization cardiovascular diseases (CVDs) fact sheet. World Health Organ. 2020;42:207-16.
2. Libby P, Theroux P. Pathophysiology of coronary artery disease. Circulation. 2005;111:3481-8.
3. Head SJ, Milojevic M, Daemen J, Ahn JM, Boersma E, Christiansen EH, et al. Mortality after coronary artery bypass grafting versus percutaneous coronary intervention with stenting for coronary artery disease: a pooled analysis of individual patient data. Lancet. 2018;391:939-48.
4. Diegeler A, Matin M, Kayser S, Binner C, Autschbach R, Battellini R, et al. Angiographic results after minimally invasive coronary bypass grafting using the minimally invasive direct coronary bypass grafting (MIDCAB) approach. Eur J Cardiothorac Surg. 1999;15:680-4.
5. McGinn JT, Jr., Usman S, Lapierre H, Pothula VR, Mesana TG, Ruel M. Minimally invasive coronary artery bypass grafting: dual-center experience in 450 consecutive patients. Circulation. 2009;120:S78-84.
6. Ruel M, Une D, Bonatti J, McGinn JT. Minimally invasive coronary artery bypass grafting: is it time for the robot? Curr Opin Cardiol. 2013;28:639-45.
7. Teman NR, Hawkins RB, Charles EJ, Mehaffey JH, Speir AM, Quader MA, et al. Minimally Invasive vs Open Coronary Surgery: A Multi-Institutional Analysis of Cost and Outcomes. Ann Thorac Surg. 2021;111:1478-84.
8. Stanislawski R, Aboul-Hassan SS, Marczak J, Stankowski T, Peksa M, Nawotka M, et al. Early and long-term clinical outcomes after minimally invasive direct coronary artery bypass grafting versus off-pump coronary surgery via sternotomy in isolated proximal left anterior descending artery disease: A propensity score matching analysis. J Card Surg. 2020;35:3412-9.

9. Mastroiacovo G, Manganiello S, Pirola S, Tedesco C, Cavallotti L, Antona C, et al. Very Long-term Outcome of Minimally Invasive Direct Coronary Artery Bypass. Ann Thorac Surg. 2021;111:845-52.
10. Puskas JD, Edwards FH, Pappas PA, O'Brien S, Peterson ED, Kilgo P, et al. Off-pump techniques benefit men and women and narrow the disparity in mortality after coronary bypass grafting. Ann Thorac Surg. 2007;84:1447-54.
11. Mohamed MA, Ding S, Ali Shah SZ, Li R, Dirie NI, Cheng C, et al. Comparative Evaluation of the Incidence of Postoperative Pulmonary Complications After Minimally Invasive Valve Surgery vs. Full Sternotomy: A Systematic Review and Meta-Analysis of Randomized Controlled Trials and Propensity Score-Matched Studies. Front Cardiovasc Med. 2021;8:724178.
12. Olbrecht VA, Barreiro CJ, Bonde PN, Williams JA, Baumgartner WA, Gott VL, et al. Clinical outcomes of noninfectious sternal dehiscence after median sternotomy. Ann Thorac Surg. 2006;82:902-7.
13. Despotis GJ, Filos KS, Zoys TN, Hogue CW, Jr., Spitznagel E, Lappas DG. Factors associated with excessive postoperative blood loss and hemostatic transfusion requirements: a multivariate analysis in cardiac surgical patients. Anesth Analg. 1996;82:13-21.
14. Murphy GJ, Reeves BC, Rogers CA, Rizvi SI, Culliford L, Angelini GD. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. Circulation. 2007;116:2544-52.
15. Koch CG, Li L, Duncan AI, Mihaljevic T, Cosgrove DM, Loop FD, et al. Morbidity and mortality risk associated with red blood cell and blood-component transfusion in isolated coronary artery bypass grafting. Crit Care Med. 2006;34:1608-16.
16. Shander A, Hofmann A, Gombotz H, Theusinger OM, Spahn DR. Estimating the cost of blood: past, present, and future directions. Best Pract Res Clin Anaesthesiol. 2007;21:271-89.
17. Paparella D, Yau TM, Young E. Cardiopulmonary bypass induced inflammation: pathophysiology and treatment. An update. Eur J Cardiothorac Surg. 2002;21:232-44.
18. Puskas JD, Williams WH, Mahoney EM, Huber PR, Block PC, Duke PG, et al. Off-pump vs conventional coronary artery bypass grafting: early and 1-year graft patency, cost, and quality-of-life outcomes: a randomized trial. Jama. 2004;291:1841-9.
19. Lagny MG, Jouret F, Koch JN, Blaffart F, Donneau AF, Albert A, et al. Incidence and outcomes of acute kidney injury after cardiac surgery using either criteria of the RIFLE classification. BMC Nephrol. 2015;16:76.
20. Mao H, Katz N, Ariyanon W, Blanca-Martos L, Adýbelli Z, Giuliani A, et al. Cardiac surgery-associated acute kidney injury. Cardiorenal Med. 2013;3:178-99.
21. Karkouti K. Transfusion and risk of acute kidney injury in cardiac surgery. Br J Anaesth. 2012;109 Suppl 1:i29-i38.
22. Kumar AB, Suneja M, Bayman EO, Weide GD, Tarasi M. Association between postoperative acute kidney injury and duration of cardiopulmonary bypass: a meta-analysis. J Cardiothorac Vasc Anesth. 2012;26:64-9.
23. Bellomo R, Kellum JA, Ronco C. Acute kidney injury. The Lancet. 2012;380:756-66.

24. Hix JK, Thakar CV, Katz EM, Yared JP, Sabik J, Paganini EP. Effect of off-pump coronary artery bypass graft surgery on postoperative acute kidney injury and mortality. Crit Care Med. 2006;34:2979-83.
25. Seabra VF, Alobaidi S, Balk EM, Poon AH, Jaber BL. Off-pump coronary artery bypass surgery and acute kidney injury: a meta-analysis of randomized controlled trials. Clin J Am Soc Nephrol. 2010;5:1734-44.
26. Imazio M, Trinchero R, Brucato A, Rovere ME, Gandino A, Cemin R, et al. COlchicine for the Prevention of the Post-pericardiotomy Syndrome (COPPS): a multicentre, randomized, double-blind, placebo-controlled trial. Eur Heart J. 2010;31:2749-54.
27. Mathew JP, Fontes ML, Tudor IC, Ramsay J, Duke P, Mazer CD, et al. A multicenter risk index for atrial fibrillation after cardiac surgery. Jama. 2004;291:1720-9.
28. Sarr MG, Gott VL, Townsend TR. Mediastinal infection after cardiac surgery. Ann Thorac Surg. 1984;38:415-23.
29. Braxton JH, Marrin CA, McGrath PD, Morton JR, Norotsky M, Charlesworth DC, et al. 10-year follow-up of patients with and without mediastinitis. Semin Thorac Cardiovasc Surg. 2004;16:70-6.
30. Panesar SS, Athanasiou T, Nair S, Rao C, Jones C, Nicolaou M, et al. Early outcomes in the elderly: a meta-analysis of 4921 patients undergoing coronary artery bypass grafting--comparison between off-pump and on-pump techniques. Heart. 2006;92:1808-16.
31. Bakaeen FG, Shroyer AL, Gammie JS, Sabik JF, Cornwell LD, Coselli JS, et al. Trends in use of off-pump coronary artery bypass grafting: Results from the Society of Thoracic Surgeons Adult Cardiac Surgery Database. J Thorac Cardiovasc Surg. 2014;148:856-3, 64.e1; discussion 63-4.
32. Baishya J, George A, Krishnamoorthy J, Muniraju G, Chakravarthy M. Minimally invasive compared to conventional approach for coronary artery bypass grafting improves outcome. Ann Card Anaesth. 2017;20:57-60.