

Minimally Invasive Coronary Artery Bypass Grafting Reduces Postoperative Serum Lactate Level and Minimizes Associated Complications

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Abstract

Background: Postoperative lactate levels have been considered a marker of intraoperative ischemia, which can affect patients' prognosis. This study aims to compare the immediate postoperative complications due to high serum lactate levels of patients who had undergone coronary artery bypass graft (CABG) via minimally invasive cardiac surgery (MICS) vs. conventional median sternotomy (MS). **Methods:** A total of 111 MICS CABG patients were retrospectively analysed and compared with 3614 MS CABG patients from a mixed Asian population between January 2009 and June 2020. A generalized structural equation model (gSEM) was constructed and applied for data analysis, with the primary outcome of this study being high postoperative serum lactate levels (≥ 4 mmol/L) and its associated complications. The model considered patients' demographics, blood tests, Charlson co-morbidity index, and the type of operation. **Results:** There were no significant differences in the patients' preoperative profiles. The average postoperative serum lactate level in both groups was 3.2 mmol/L (range: 0.5 to 15.6 mmol/L). MICS patients had significantly lower postoperative lactate levels (coefficient: -1.1 ; 95% C.I.: -1.8 to -0.4 , p-value: 0.002). Moreover, a unit increase in lactate level was associated with a 12% increase in the odds of developing a new arrhythmia postoperatively (adjusted odds ratio: 1.1; 95% C.I.: 1.0 to 1.3, p-value: 0.048). **Conclusion:** MICS was associated with lower postoperative lactate levels and reduced metabolic stress, likely due to less trauma. Elevated lactate during CPB correlated with higher morbidity and mortality. Patients who are eligible for

both approaches may benefit more from the MICS approach.

Keywords

Minimally Invasive Cardiac Surgery, Coronary Artery Bypass, Serum Lactate, Open Heart Surgery, Clinical Outcomes, Complications

1. Introduction

Metabolic derangement, manipulation of the heart, and the use of prime solution in cardiopulmonary bypass (CPB) can elevate lactate levels to a certain extent [1]. Systemic hypoperfusion and tissue hypoxia can also increase serum lactate levels. Elevated blood lactate levels during CPB are associated with tissue hypoperfusion and can lead to postoperative complications, including postoperative arrhythmia [2]. Early intervention in response to high blood lactate levels may improve the outcomes for cardiac surgical patients.

Minimally invasive cardiac surgery has been increasingly adopted by cardiac surgeons worldwide since the first minimally invasive valve surgery in 1996 [3]. This approach is now also used for coronary artery bypass grafting (CABG), allowing surgery without traditional full sternotomy, which carries risks of wound healing complications, pain, and infection [4], particularly in diabetic patients, who represent a significant portion of CABG cases. In 2015, Shahzad *et al.* compared postoperative outcomes of minimally invasive direct coronary artery bypass (MIDCAB) with full sternotomy left anterior descending (LAD) artery revascularization, finding a higher incidence of wound infections in the full sternotomy group within 30 days, but no significant differences in other morbidities and mortalities between the groups [5]. Biglioli *et al.* also supported these positive findings, concluding that MIDCAB leads to shorter hospital stays and quicker recovery to preoperative baselines [6].

Elevated lactate levels are common after cardiac surgery and serve as a surrogate marker for intraoperative ischemia. Importantly, hyperlactatemia in this context may result from two distinct mechanisms: Type A hyperlactatemia, due to tissue hypoperfusion and oxygen delivery-demand mismatch (e.g., during CPB or low cardiac output states), and Type B hyperlactatemia, which arises from metabolic dysfunction unrelated to hypoxia—such as impaired hepatic clearance, drug effects (e.g., beta-agonists), or systemic inflammation [7]. Both types are relevant in the post-cardiac surgery setting, and recognizing the underlying cause is critical for timely and appropriate intervention.

High postoperative lactate levels are prognostic, being associated with complications, mortality, and length of stay (LOS). Complications such as stroke, acute myocardial infarction, arrhythmias, renal injury, and gut ischemia have been extensively studied by our group, emphasizing the need for further investigation into lactate management [7]-[9]. This study aimed to compare elevated blood lactate concentrations and immediate postoperative morbidity and mortality be-

tween conventional and minimally invasive coronary revascularization surgery.

2. Methods

2.1. Patients' Characteristics

This study was a retrospective analysis of patients who underwent either MICS CABG or conventional sternotomy CABG by a single surgical team from January 2009 to June 2020, comprising a diverse, multi-racial Asian population. A total of 111 patients underwent MICS CABG, while 3,614 patients from the institution's database had conventional surgery (MS CABG). Patients were divided into high and low lactate groups based on postoperative serum lactate levels ≥ 4.0 mmol/L to examine associations with postoperative complications. In subgroup analysis, patients who underwent Minimally Invasive Direct Coronary Artery Bypass (MIDCAB) were compared to those with single or double vessel MS CABG, while multivessel MICS CABG patients were compared graft-for-graft with MS CABG patients.

2.2. Patients' Enrolment and Ethical Approval

Patients undergoing emergency CABG, requiring combined procedures, or with poor preoperative status—such as unstable hemodynamics from acute coronary occlusion after angioplasty, complications of acute myocardial infarction unmanageable by medication, or plasma lactate levels ≥ 2 mmol/L before CPB—were excluded. The study was approved by the Domain Specific Institutional Review Board, DSRB Reference #2019/00294 and #2020/00864, and a waiver for individual patient consent was obtained due to its retrospective nature. The Computerized Patient Support System (CPSS), established by the National University Hospital in 1998, served as a comprehensive medical registry for consolidating patient admissions, medications, and surgical histories. Data from the CPSS were integrated with REDCAP, a secure web platform for database management.

2.3. Operative Technique

In the MS group, conventional on-pump CABG with aorto-coronary anastomoses via aortic side-clamping was predominantly used, though some patients received off-pump or on-pump beating CABG. MICS CABG patients underwent either MIDCAB or multivessel grafting through a left anterior mini-thoracotomy. The left internal mammary artery (LIMA) was harvested in situ using electrocautery and ultrasonic dissection, aided by the Rultract® and Thoratrak™ retractors. MIDCAB, typically for single-vessel LAD stenosis, was performed off-pump, grafting the LIMA to the LAD with an Octopus™ stabilizer. Multivessel MICS CABG was done on either an arrested heart with a Chitwood® cross-clamp or a beating heart with stabilizers and peripheral CPB. For MS CABG, standard aortic and two-stage right atrial cannulation were used, while femoral cannulation was employed for MICS CABG. The CABG procedures prioritized the right coronary artery, followed by obtuse marginal, ramus, diagonal, and LAD, with LIMA as the

default conduit for the LAD and saphenous vein or radial artery grafts for other targets. All distal anastomoses were completed under direct vision with continuous 7 - 0 polypropylene sutures.

2.4. Lactate Measurement and Primary Outcomes

Before anesthesia induction, basal arterial lactate levels (T0) were measured from a central venous line sample. Intraoperatively, the durations of cardiopulmonary bypass (CPB) and aortic cross-clamp (AXT) were recorded. The highest lactate level from CPB, obtained from arterial blood gas analysis, was noted as T1. In the ICU, the highest lactate level in the first 24 hours was recorded as T2. A blood lactate level exceeding 4 mmol/L, as defined by Demers *et al.*, was considered high when measured at T2 [10]. The primary outcome was postoperative high serum lactate levels and their associated complications, including stroke, deep wound infection, myocardial infarction, dissection, new-onset arrhythmia, pleural effusion, atelectasis, pneumothorax, pericardial effusion, and multi-organ failure. Arrhythmias included atrial fibrillation, atrial flutter, supraventricular tachycardia, complete heart block, and ventricular fibrillation observed during the hospital stay.

2.5. Statistical Analysis

The results were analyzed using Stata MP V14 (Stata Corp, Texas, USA). A generalized structural equation model (gSEM) was applied for data analysis, and all statistical tests were performed with a 95% confidence interval (equivalent to a p-value of 0.05 in a two-sided test). The proposed model could estimate a predictor's direct and indirect effects on the outcome concurrently. The model accounted for patients' BMI, routine preoperative blood tests, Charlson co-morbidity index, urgency of operation, and type of operation. To compare lactate levels between patients who underwent MICS CABG and those who underwent full sternotomy, an independent samples t-test was conducted. To further explore the association between surgical approach and postoperative lactate levels while adjusting for potential confounding variables, a linear regression analysis was performed. Additionally, a multivariate logistic regression model was applied to examine the relationship between postoperative serum lactate levels and the occurrence of postoperative arrhythmias. This approach enabled the estimation of adjusted odds ratios while accounting for key covariates, including the type of surgery and preoperative atrial fibrillation status. For all computations, the significance level was set at $p < 0.05$.

3. Results

The study included 111 patients in the MICS CABG group, 3,614 in the MS CABG group, and 64 in the MIDCAB group (Figure 1). For matched subgroups, there were 64 patients each in the MIDCAB and MS CABG groups for single/double-vessel cases, and 46 patients each in the MICS CABG and MS CABG groups for multi-vessel cases. MIDCAB patients were matched with single/double-vessel MS

CABG patients due to the limited number of single-vessel procedures performed. All patients underwent isolated CABG.

Table 1 presents preoperative clinical characteristics, showing no significant differences between groups in age, gender, race, smoking status, diabetes, hypertension, or ejection fraction. However, hyperlipidaemia was less common in the MICS CABG group, and those patients had a higher incidence of previous percutaneous coronary intervention (PCI). Overall, the groups were well-matched regarding most preoperative characteristics. **Table 2** summarizes perioperative and postoperative outcomes. Most cases were elective, with higher proportions of off-pump procedures in the MICS CABG and MIDCAB groups compared to MS CABG. CPB time and AXT were generally shorter for MICS CABG, although multi-vessel cases had significantly longer durations (145.5 ± 70.6 vs. 104.3 ± 48.4 , $p = 0.005$). The MICS CABG group also had a shorter postoperative length of stay (LOS) compared to MS CABG. Conversion to median sternotomy occurred in a small percentage of MICS CABG cases (10.9% in matched multi-vessel cases and 6.3% overall).

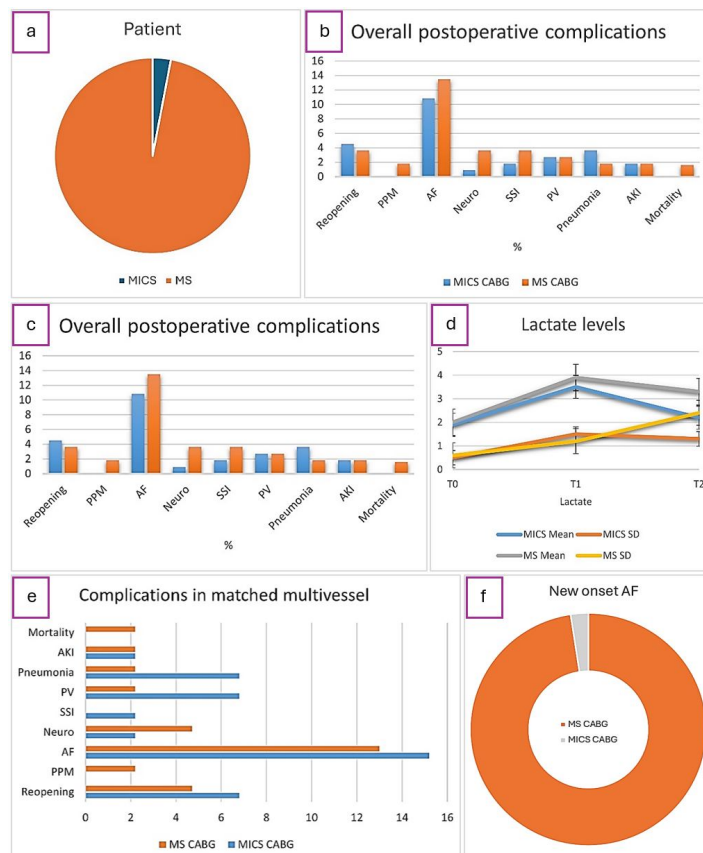


Figure 1. Patients' clinical characteristics (a) Distribution of MICS and MS CABG in the study population; (b) Overall postoperative complications in the study groups showing higher incidence of AF, neurological complication and death in MS CABG; (c) Comparison of complication in the matched groups in single/double vessel CABG; (d) Changes in the lactate levels in the perioperative period; (e) Comparison of complication in the matched groups in multivessel CABG; (f) Incidence of new onset AF was significantly higher in MS-CABG group.

Table 1. Patient's preoperative clinical characteristics.

Variables	Unmatched				Matched				Overall SDM (%)
	Overall		P- value	SDM (%)	Single/Double-ves- sel		Multi-vessel		
	MICS CABG (N = 111)	MS CABG (N = 3614)			MIDCA B (N = 64)	MS CABG (N = 64)	MICS CABG (N = 46)	MS CABG (N = 46)	
Age (yr), mean ± SD	59.8 ± 9.7	59.4 ± 7.7	0.737	-15.2	58.3 ± 9.8	57.7 ± 7.9	60.9 ± 9.4	61.0 ± 8.0	< 10
Male (%)	98 (88.3)	3191 (88.4)	1.000	-16.2	55 (85.9)	54 (84.4)	43 (93.5)	43 (93.5)	0
Race (%)	-	-		-	-	-	-	-	-
• Chinese	76 (67.6)	2474 (68.5)		28.4	41 (64.1)	37 (57.8)	34 (73.9)	27 (58.7)	0
• Indian	13 (11.7)	423 (11.7)	0.990	-28.4	8 (12.5)	12 (18.8)	4 (8.7)	6 (13)	0
• Malay	18 (16.2)	586 (16.2)		28.4	12 (18.8)	14 (21.9)	7 (15.2)	10 (21.7)	0
• Others	4 (3.6)	131 (3.6)		-28.4	3 (4.7)	1 (1.6)	1 (2.2)	3 (6.5)	0
Smokers (%)	26 (23.4)	846 (23.4)	1.000	45.6	16 (25)	19 (30.2)	26 (56.5)	25 (54.3)	< 10
Diabetes (%)	46 (41.1)	1725 (47.7)	0.418	-27	27 (42.2)	25 (39.1)	19 (41.3)	13 (28.3)	-12.8
Hypertension (%)	82 (73.9)	2898 (80.2)	0.338	0.38	47 (73.4)	50 (78.1)	36 (78.3)	41 (89.1)	< 10
Hyperlipidae- mia (%)	91 (82)	3353 (92.8)	0.025	-25.6	55 (85.9)	55 (85.9)	33 (71.7)	38 (82.6)	< 10
Renal disease (%)	9 (8.1)	98 (2.7)	0.135	22.5	8 (12.5)	2 (3.1)	1 (2.2)	3 (6.5)	< 10
COPD (%)	3 (2.7)	33 (0.9)	0.175	0.48	1 (1.6)	0	0	1 (2.2)	< 10
CVD (%)	12 (10.8)	391 (10.8)	1.000	0.96	8 (12.5)	9 (14.1)	2 (4.3)	1 (2.2)	0
Previous PCI (%)	37 (33.3)	749 (20.7)	0.049	-22.8	20 (31.1)	16 (25)	17 (37)	11 (23.9)	< 10
PVD (%)	3 (2.7)	33 (0.9)	0.622	-36.9	1 (1.6%)	0	1 (2.2)	1 (2.2)	-11.1
EF, mean ± SD	54.9 ± 11	55.3 ± 12	0.778	-16.8	55.4 ± 11.9	53.2 ± 12.6	53.7 ± 10.3	53.7 ± 10.9	< 10
EF category (%)	-	-		-18.4	-	-	-	-	< 10
• Good (≥ 50%)	87 (78.4)	2865 (79.3)		45.6	50 (78.1)	48 (75)	35 (76.1)	34 (73.9)	45.6
• Fair (30 - 49%)	20 (18)	619 (17.1)	0.984	-34.4	11 (17.2)	12 (18.8)	10 (21.7)	12 (26.1)	-34.4
• Poor (< 30%)	4 (3.6)	130 (3.6)		-35.9	3 (4.7)	4 (6.3)	1 (2.2)	0	-35.9
Preop IABP (%)	0	98 (2.7)	0.247	-15.8	0	4 (6.3)	0	4 (8.7)	< 10
Preop NYHA ≥II (%)	52 (46.8)	1400 (38.7)	0.278	36.4	29 (45.3)	21 (32.8)	22 (47.8)	18 (39.1)	< 10
EuroSCORE II, mean ± SD	1.31 ± 1.28	1.28 ± 1.16	0.850	56.4	1.31 ± 1.49	1.38 ± 1.43	1.29 ± 0.92	1.37 ± 0.95	< 10

CABG = coronary artery bypass grafting; CVD = cerebrovascular disease; COPD = chronic obstructive pulmonary disease; EF = ejection fraction; EuroSCORE = European System for Cardiac Operative Risk Evaluation; IABP = intra-aortic balloon pump; MICS CABG = minimally invasive CABG; MIDCAB = minimally invasive direct coronary artery bypass; MS = median sternotomy; NYHA = New York Heart Association; PCI = percutaneous coronary intervention; PVD = peripheral vascular disease; SD = standard deviation; SDM = standard Mean Difference.

Table 2. Intra-operative and postoperative outcomes.

Variables	Unmatched				Matched				Overall SDM (%)
	Overall		P-value	SDM (%)	Single/ Double-vessel		Multi-vessel		
	MICS CABG (N = 111)	MS CABG (N = 3614)			MIDCAB (N = 64)	MS CABG (N = 64)	MICS CABG (N = 46)	MS CABG (N = 46)	
Operative urgency (%)	-	-	-	-	-	-	-	-	-
• Elective (%)	98 (88.3)	2995 (82.9)	0.339	28.4	64 (100)	64 (100)	39 (84.8)	39 (84.8)	< 10
• Urgent (%)	13 (11.7)	619 (17.1)		-28.4	0	0	7 (15.2)	7 (15.2)	< 10
CABG category (%)	-	-		-	-	-	-	-	-
• Off-pump (%)	56 (50.5)	65 (1.8)	<0.001	-68.4	54 (84.4)	7 (10.9)	1 (2.2)	3 (6.5)	0
• On-pump beating (%)	33 (29.7)	66 (1.8)		16.2	8 (12.5)	3 (4.7)	26 (56.5)	1 (2.2)	0
• Cardioplegic arrest (%)	22 (19.8)	3483 (96.4)		54.2	2 (3.1)	54 (84.4)	19 (41.3)	42 (91.3)	0
CPB (min), mean ± SD	131.2 ± 42.7	136.3 ± 46.1	0.620	10	-	-	145.5 ± 70.6	104.3 ± 48.4	< 10
AXT (min), mean ± SD	64.7 ± 13.1	80.5 ± 23.7	0.037	16.2	-	-	59.1 ± 15.7	52.9 ± 20	< 10
Length of procedure, mean ± SD	286.3 ± 85.1	272.8 ± 69.6	0.240	0	234.3 ± 57.5	239 ± 49.2	359.7 ± 63.1	233.5 ± 36.3	< 10
Postop LOS, median (IQR)	6 (2)	228 (3)	<0.001	10.2	5 (2)	7 (5)	6 (5.7)	7 (2.25)	< 10
Conversion to MS (%)	7 (6.3)	-	-	-28.2	2 (3.1)	-	5 (10.9)	-	-12.6
Reopening (%)	5 (4.5)	130 (3.6)	1.000	15.8	2 (3.1)	4 (6.3)	3 (6.8)	2 (4.7)	< 10
Permanent pacemaker (%)	0	65 (1.8)	0.386	12.6	0	1 (1.6)	0	1 (2.2)	< 10
New-onset AF (%)	12 (10.8)	488 (13.5)	0.701	12.4	5 (7.8)	8 (12.5)	7 (15.2)	6 (13)	-18.4
Postoperative IABP (%)	2 (1.8)	148 (4.1)	0.002	-62.8	1 (1.6)	0	1 (2.2)	0	< 10
Neuro-complications* (%)	1 (0.9)	131 (3.6)	0.375	-28.2	0	2 (3.1)	1 (2.2)	2 (4.7)	< 10
Surgical site infections (%)	2 (1.8)	130 (3.6)	0.687	24.8	1 (1.6)	1 (1.6)	1 (2.2%)	0	-36.8
Non-surgical infections# (%)	3 (2.7)	65 (1.8)	1.000	-18.6	1 (1.6)	2 (3.1)	1 (2.2)	1 (2.2)	< 10
Prolonged ventilation (%)	3 (2.7)	98 (2.7)	1.000	-16.4	0	3 (4.7)	3 (6.8)	1 (2.2)	< 10
Pneumonia (%)	4 (3.6)	66 (1.8)	0.687	-36.2	1 (1.6)	3 (4.7)	3 (6.8)	1 (2.2)	< 10
Pleural effusion drainage (%)	0	65 (1.8)	1.000	11.2	0	1 (1.6)	0	0	< 10
Acute renal injury (%)	2 (1.8)	65 (1.8)	0.631	28.8	1 (1.6)	5 (7.8)	1 (2.2)	1 (2.2)	-12.4

Continued

30-day mortality (%)	0	58 (1.6)	1.000	-16.4	0	1 (1.6)	0	1 (2.2)	< 10
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AF = atrial fibrillation; AXT = aortic cross-clamp time; CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass time; IABP = intra-aortic balloon pump; IQR = interquartile range; LOS = length of stay; MICS CABG = minimally invasive CABG; MIDCAB = minimally invasive direct coronary artery bypass; MS = median sternotomy; SDM = standard mean difference; * = neuro-complications comprise permanent stroke, transient ischemic attack, and delirium; # = non-surgical infections comprise urinary tract infection and/or sepsis.

The average postoperative serum lactate level was 3.1 ± 2.2 mmol/L (range: 0.5 – 15.6). Patients who underwent MICS CABG had significantly lower postoperative lactate levels (T2) compared to those who had full sternotomy (2.2 ± 1.3 mmol/L vs. 3.3 ± 2.4 mmol/L, $p < 0.001$). Confirmatory analysis indicated that MICS patients had a significantly lower postoperative lactate level (coefficient: -1.2 mmol/L; 95% CI: -1.8 to -0.5; $p = 0.001$). Multivariate logistic analysis showed a significant association between postoperative serum lactate level and postoperative arrhythmia development, even after adjusting for the type of operation and preoperative atrial fibrillation (AF) status. Each unit increase in lactate level was associated with a 12% increase in postoperative arrhythmia incidence (adjusted odds ratio: 1.1; 95% CI: 1.0 to 1.3; $p = 0.048$). However, there was no significant evidence indicating a lower risk for cardiac death ($p = 0.640$) or postoperative arrhythmia development ($p = 0.539$) with MICS.

4. Discussion

Revascularization through conventional median sternotomy is highly invasive, but this can be circumvented by the less traumatic MIDCAB approach, which also provides aesthetic benefits to patients. It is important to understand that the MIDCAB technique for CABG has a steep learning curve and should only be performed by surgeons with adequate training. Furthermore, MIDCAB should be carried out only in centers with sufficient patient volumes to keep surgeons proficient in the technique. The development of lactic acidosis after cardiac surgery is associated with poorer clinical outcomes [10]-[12]. Ju *et al.* found that hyperlactatemia within 24 hours post-cardiac surgery was a risk factor for non-obstructive mesenteric ischemia [11]. A study by Nagai *et al.* also demonstrated that systemic acidosis after reperfusion for STEMI was a significant determinant of the development of VT/VF post-reperfusion [12] [13]. These findings are consistent with studies examining the prognostic value of postoperative serum lactate levels in the context of non-cardiac surgeries.

Our study results are consistent with findings from other institutions. Patients in the minimally invasive CABG group were expected to have lower postoperative serum lactate levels because the operation is less traumatic and shorter in duration. This may be partly due to the fact that patients undergoing full sternotomy CABG typically require multiple vessel grafting. Since single-vessel disease is more often treated using the minimally invasive approach by the surgical team, it is un-

likely that a group of full sternotomy patients would have single-vessel disease. This is reflected in the small number of single-vessel cases in the full sternotomy group, as shown in **Table 1**. Although MICS is less traumatic and typically shorter, multi-vessel MICS cases take longer due to limited surgical exposure, complex heart manipulation, and the need for specialized instruments. The confined field makes grafting multiple targets technically demanding and time-intensive compared to full sternotomy. Additionally, the steep learning curve and patient-specific anatomical challenges further extend operative times. With greater experience and improved techniques, these durations are expected to decrease.

CPB is widely used in cardiac surgeries, including CABG, valve repair/replacement, congenital defect repair, and correction of great vessel abnormalities [14]. CPB oxygenates and recirculates blood diverted from the heart and lungs during surgery [15]. Surgical verifications and hemodynamic optimization occur in the critical first minutes, requiring close communication between surgeons, anesthesiologists, and perfusionists [16]. Cardioplegic arrest induces anaerobic metabolism, producing lactate. Persistent lactate release during reperfusion indicates delayed recovery of aerobic metabolism, potentially leading to depressed myocardial function [17]-[19].

Maintaining body temperature, acid-base balance, arterial inflow, venous outflow, and blood pressure is crucial during CPB [20]-[24]. Acid-base imbalances arise from lactic acid or pyruvic acid production, leading to elevated blood lactate levels and metabolic acidosis, particularly in critically ill patients experiencing systemic hypoperfusion and tissue hypoxia [25]-[27]. This condition represents type A lactic acidosis, caused by an imbalance between tissue oxygen supply and demand. Several studies have indicated that blood lactate concentration is a prognostic marker in patients with circulatory shock following open heart surgery. CPB facilitates adequate systemic oxygenation and perfusion during cardiac procedures.

Identifying predictors of morbidity and mortality is crucial for managing cardiac surgery patients. While preoperative factors are key to risk stratification, intraoperative events such as surgical technique, myocardial protection, and CPB can influence postoperative outcomes [28]-[30]. In our series more frequent use of CPB in the MS group vs. the MICS group most likely a one major confounder. Monitoring these factors during surgery and intervening early may improve results. The relationship between hyperlactatemia and postoperative complications is significant for cardiac surgeons, as elevated lactate during CPB may indicate intraoperative tissue hypoperfusion. This study aimed to evaluate the link between elevated lactate levels during CPB and perioperative morbidity and mortality.

Limitations

The study's retrospective design carries inherent limitations, including potential bias in patient selection due to preoperative status and the single-center experi-

ence, which limits generalizability. A major limitation is the significant imbalance in the use of cardiopulmonary bypass between the MICS and full sternotomy groups, with a higher proportion of on-pump procedures in the latter. Since cardioplegic arrest and bypass are known contributors to lactate elevation, this discrepancy represents a key potential confounder that likely influenced the primary outcome. However, the consistency in surgical technique and perioperative care provided by the same team enhances the internal validity of the findings. Furthermore, lactate levels were not serially trended over the first 24 hours postoperatively, which could have provided additional insight into the dynamics of lactate clearance. Additionally, patient groups were not subdivided by the number of grafts or use of cardiopulmonary bypass, partly due to the small number of minimally invasive CABG cases, as the technique was recently introduced at the National University Heart Center, Singapore.

5. Conclusion

In conclusion, patients undergoing MICS had significantly lower postoperative lactate levels, likely due to reduced surgical trauma and less frequent use of cardioplegic arrest. A peak blood lactate level of 4.0 mmol/L or higher during CPB is linked to an increased risk of perioperative morbidity, including low output syndrome, pulmonary complications, renal dysfunction, and wound infections. Elevated lactate during CPB was linked to higher perioperative morbidity and mortality, highlighting the impact of surgical approach on metabolic stress. The more frequent use of CPB in the MS group is a key confounder. Despite technical challenges, multivessel MICS offers metabolic and cosmetic advantages when performed by experienced teams. These findings support its broader adoption and reinforce the value of intraoperative lactate monitoring as a prognostic tool. Further multicenter studies are needed to validate these outcomes.

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Ethics Statement

The study received approval from the Domain Specific Review Board (DSRB), National Health Care Group, under Reference number: # DSRB: 2019/00294 and #2020/00864. Given the retrospective nature of the study, the requirement for informed consent was waived.

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Data Availability Statement

The data used in this investigation is available upon request. The study's corresponding author can be contacted if anyone is interested in requesting access to the data.

Author Contributions

Study conceptualization, Z.O., J.A., S.L., G.C., T.K., and F.S.; Methodology, F.S., and Z.O., Software, Z.O., J.A., S.L., and FS; Validation, J.A., S.L., G.C., and F.S.; Formal analysis, S.L., Z.O., and F.S.; Data curation, Z.O., and F.S.; Writing—original draft preparation, Z.O., J.A., S.L., G.C., T.K., and F.S.; Writing—review and editing, Z.O., J.A., S.L., G.C., T.K., and F.S.; Resources, G.C., T.K., and F.S.; Supervision, F.S., and T.K.; Project administration, F.S.; Funding acquisition, T.K., and F.S. All authors have read and agreed to the final version of the manuscript.

Disclosure

The early data from this project was presented at the 27th Annual Congress of the ATCSA 2017, Australia. The abstract for the conference was published in the Heart, Lung and Circulation Journal, Special Issue on the conference, Volume 27, Supplement 3, Pages S501-S600 (2018),

<http://dx.doi.org/10.1016/j.hlc.2018.04.145>.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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