Association of Intraoperative Factors with Difficult Weaning from Cardiopulmonary Bypass Among Patients with Preserved Left Ventricular Ejection Fraction Who Underwent Coronary Artery Bypass Grafts

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Abstract

OBJECTIVE: To determine the incidence and the associated intraoperative factors that contribute to difficult weaning from cardiopulmonary bypass (CPB) among coronary artery bypass graft (CABG) patients with preserved left ventricular ejection fraction (LVEF).

METHODS: This study was a prospective observational cohort study conducted at a specialty center from September 1, 2019, to May 15, 2020. It included adult patients diagnosed with coronary artery disease (CAD) admitted for elective CABG under the CABG Z-Benefit Package, with an LVEF of greater than 50%. After institutional review board approval, data on consecutive patients scheduled for elective, isolated CABG and meeting the inclusion criteria were prospectively collected and analyzed. Descriptive or qualitative statistics was used to summarize the demographic and clinical characteristics of the patients.

RESULTS: Data from 52 patients who met the inclusion criteria were included in the analysis, with 17.3% (n = 9/52) meeting the criteria for difficult weaning from CPB. Of these nine patients, nine (100%) required use of more than one inotrope and/or vasopressor, and two of the nine (22.22%) needed to return to CPB after coming off. Of those patients with nondifficult weaning from CPB, 74.44% (n = 32/43) used a single inotrope, and 42.26% (n = 11/43) successfully separated from CPB without any need for pharmacological support. Among the various parameters assessed, logistic regression analysis showed that every unit increase in base deficit after release of aortic cross-clamp increased the odds of having difficult separation from CPB by 40.21%. Patients who received nicardipine were also 7.8 times more likely to have difficult separation from CPB.

CONCLUSION: In this study of patients with preserved left ventricular function undergoing CABG surgery, we identified two intraoperative variables associated with difficult weaning from CPB: (1) base deficit at release of aortic cross-clamp and (2) the use of nicardipine infusion.

INTRODUCTION

Weaning from cardiopulmonary bypass (CPB) encompasses the period of gradual withdrawal and removal of extracorporeal circulation. Therapeutic decisions regarding hemodynamic and surgical optimization are compressed within a few critical minutes to prevent myocardial injury while transitioning from full mechanical support to spontaneous cardiac activity. Currently, there are no specific criteria defining "difficult to wean" situations.

Ventricular function is impaired following CPB. This may occur even in patients with normal preoperative ventricular function[4] and can be the result of inadequate revascularization, poor ischemic protection, or myocardial reperfusion injury.[5.]

In literature, different terminologies are used to describe weaning from CPB that required significant pharmacological and mechanical support. Some of the descriptive terms used include "difficult separation from CPB," "low cardiac output state," and "low cardiac output syndrome."

An analysis by McKinlay et al[7] of 1009 patients undergoing coronary artery bypass graft (CABG) found six independent predictors of inotrope support, which was required for 39% of the cohort during weaning. These six variables were cross-clamp time, wall motion score index, reoperation, concomitant mitral valve repair or replacement, moderate to severe mitral regurgitation, and left ventricular ejection fraction (LVEF) of less than 35%.

Inability to wean off CPB despite maximal support with a low cardiac index and evidence of end-organ dysfunction is also known as low cardiac output syndrome. Its prevalence ranges from 0.2% to 6% and is associated with increased postoperative morbidity and mortality, increasing hospital length of stay and resource utilization.[1,2]

A multicenter retrospective study done by Denault et al[3] found that difficult and complex weaning from CPB was associated with mortality after cardiac surgery, independent of the impact of inotropic use on postoperative outcomes.

Although risk assessments predicting perioperative or long-term mortality rates are vital in managing coronary artery disease (CAD) patients requiring CABG, an assessment of which patients would have difficult weaning from CPB shall provide good insights to the perioperative management by the cardiac anesthesiologist.

This study aimed to determine the incidence and the associated intraoperative factors that contribute to difficult weaning from CPB among CABG patients with preserved LVEF.

METHODS

This study was a prospective observational cohort study. The study was conducted at a specialty center from September 1, 2019, to May 15, 2020. This study included patients diagnosed with CAD, 19 years or older, admitted for elective CABG under the CABG Z-Benefit Package, with an LVEF of greater than 50%. Excluded from the study were patients with preoperative inotropic support and intra-aortic balloon pump (IABP), patients with concomitant valvular heart disease and/or aortic aneurysm requiring repair, and patients referred for off-pump CABG and/or minimally invasive CABG surgery.

Withdrawal Criteria

An intraoperative decision to perform concomitant valvular and/or aortic aneurysm repair would render the patient ineligible for the study.

Sample Size Calculation

A minimum of 48 patients was required for this study based on 26% difficult separation from bypass,[3] 5% level of significance, and 12.5% desired half-width of the confidence interval (CI).[8]

Study Maneuver

After institutional review board approval, data on consecutive patients scheduled for elective, isolated CABG and meeting the inclusion criteria were prospectively collected and analyzed.

Baseline preoperative data collected included patient age, sex, EuroSCORE II, comorbidities (hypertension, diabetes mellitus, chronic kidney disease, hyperlipidemia, angina, history of stroke), time interval from preoperative myocardial infarction to CABG, history of percutaneous coronary intervention done and time interval between procedure and CABG, coronary angiogram findings (number of vessels, left main involvement), echocardiography data (LVEF, right ventricular fractional area change, presence of pulmonary hypertension), and preoperative drug therapy (angiotensin-converting enzyme inhibitor, nitrates, beta blockers, digitalis, calcium-channel blockers, diuretics, amiodarone, anticoagulants).

Intraoperative data were collected from the anesthesia and perfusionist record. These include baseline hemodynamic status, base deficit, Svo_2, partial pressure of carbon dioxide (Pco_2), venoarterial gradient (CO_2 gap), CPB time, aortic cross-clamp time, successful weaning off CPB time, lowest bypass hematocrit, number of packed red blood cell (PRBC) transfused, inotropes given and timing (ie, when the drug was started), use of other medications (nitroglycerin, nicardipine, amiodarone, insulin), initial rhythm after aortic cross-clamp release, and presence of defibrillation and/or cardioversion or atrioventricular pacing.

The following standard-of-care procedure is done among elective CABG procedures. Aspirin and clopidogrel were discontinued as per the CABG Z-Benefit Protocol. All other maintenance cardiovascular medications were continued until the morning of surgery. Anesthesia induction and maintenance were upon the discretion of the attending anesthesiologist. Inotropic and vasopressor support was implemented by the anesthesia care team as clinically indicated.

All patients underwent nonpulsatile, hypothermic (30º–32º) CPB. Perfusion pressure was maintained with pump flow rates of 2 to 2.5 L/min per m^2 throughout CPB. The pump was primed with crystalloid, and serial hematocrit was kept at 25% with PRBC transfusion as necessary. Arterial and venous blood gas, electrolytes, and ACT were monitored every 30 minutes and after release of the aortic cross-clamp. Venous oxygen was determined to have been kept at more than 70%. Cardioplegia infusion frequency was given per protocol and as deemed by the surgeon. At the end of CPB, the patients will be actively rewarmed to 36º.

Patients who required either two or more inotropic support or the use of IABP or who had a failed attempt at weaning from CPB were categorized as difficult to wean from CPB; the association of intraoperative variables with nondifficult and difficult weaning from CPB groups was analyzed.

For this study, inotropic support pertains to any dose of epinephrine, norepinephrine, dobutamine, and milrinone.

- Nondifficult weaning from CPB: no support or only one vasoactive agent or inotrope was required during weaning off CPB.
- Difficult weaning from CPB: shall mean any of the following events:
  (a) use of two or more inotropic and/or vasopressors
  (b) failure to wean from CPB on the first attempt
  (c) need for mechanical support to get off CPBComplete revascularization: all stenotic vessels are revascularized
- CPB time: time in minutes from the start of CPB to successful weaning off CPBAortic cross-clamp time: time in minutes from the application of aortic cross-clamp to release of aortic cross-clamp
- Release of cross-clamp to off CPB: time in minutes from the release of aortic cross-clamp to successful weaning of CPB

Statistical Analysis

Descriptive or qualitative statistics was used to summarize the demographic and clinical characteristics of the patients. Frequency and proportion were used for categorical variables, median and interquartile range for non–normally distributed continuous variables, and mean and SD for normally distributed continuous variables.

Independent-samples t test, Mann–Whitney *U* test, and Fisher exact/χ^2 test was used to determine the difference of mean, rank, and frequency, respectively, between patients who had nondifficult separation from CPB and those who had difficult weaning from CPB.

Odds ratio and corresponding 95% CIs from binary logistic regression were computed to determine significant predictors of difficult weaning from CPB. All statistical tests will be two-tailed.

Shapiro–Wilk was used to test the normality of the continuous variables. Missing variables were neither replaced nor estimated. Null hypothesis was rejected at $\alpha = 0.05$ of significance. STATA 13.1 (StataCorp, College Station, Texas) was used for data analysis.

Ethical Considerations

The study was conducted in compliance with the ethical principles set forth in the Declaration of Helsinki and the National Ethical Guidelines for Health and Health-Related Research of 2017. Prior to study initiation, there was a review and approval of the study protocol and informed consent and subsequent amendments by the institutional ethics review board. The researcher adheres to the provisions of the Data Privacy Act of 2012.

RESULTS

Data from 52 patients who met the inclusion criteria were included in the analysis, with 17.3% (n = 9/52) meeting the criteria for difficult weaning from CPB. Of these nine patients, nine (100%) required use of more than one inotrope and/or vasopressor, and two of the nine (22.22%) needed to return to CPB after coming off. Of those patients with nondifficult weaning from CPB, 74.44% (n = 32/43) used a single inotrope, and 42.26% (n = 11/43) successfully separated from CPB without any need for pharmacological support.

Preoperative Variables

Table 1 shows that there were no significant differences in the preoperative characteristics between these two groups of patients in terms of age (57.72 ± 8.25 vs 55.33 ± 12.91, P = 0.48), body mass index (27.49 vs 27.65, P = 0.91), and gender (P = 0.91). Both groups were characterized as low risk by definition of the EuroSCORE II classification (1.03 ± 0.57 vs 1.06 ± 0.59, P = 0.86). There were also no significant differences in the patients' preoperative comorbid conditions and their preoperative drug therapies.

There was no significant difference in the preoperative cardiac lesions in terms of the number of occluded epicardial vessels (P = 1.0) and left main coronary artery involvement (P = 1.0). The following echocardiographic parameters were also similar in both groups: left ventricular function (LVEF 62.50% ± 7.77% vs 64.88% ± 8.86%, P = 0.41), right ventricular fractional area change (50.39% ± 6.32% vs 43.25% ± 13.93%, P = 0.08), presence of wall motion abnormalities (51.28% vs 16.67%, P = 0.19), and presence of pulmonary hypertension (15.79% vs 0, P = 0.56).

Pre-CPB Intraoperative Variables

Intraoperative variables are given in Table 2. There was no significant difference in the variables observed during the pre-CPB period. Hemodynamic parameters between the two groups were similar, with mean cardiac output of 5.14 ± 1.8 vs 4.53 ± 1.01 (P = 0.58) and cardiac index of 2.94 ± 1.01 vs 2.42 ± 0.54 (P = 0.40) within normal limits. Baseline base deficit (1 [interquartile range {IQR}, 0–2] vs 2 [IQR, 0–4], P = 0.16), Svo_2 (75% [IQR, 74%–78%] vs 82% [IQR, 74%–75%], P = 0.54), and hematocrit (0.35 ± 0.05 vs 0.36 ± 0.05, P = 0.55) were also similar between the two groups. Pco_2

Table 1. Distribution of Preoperative Variables

	Nondifficult Weaning From CPB (n = 43)	Difficult Weaning From CPB (n = 9)	P Value
	Frequency (%); Mean ± SD; Median (IQR)		
Age, y	57.72 ± 8.25	55.33 ± 12.91	0.48
EuroSCORE II	1.03 ± 0.57	1.06 ± 0.59	0.86
NYHA class			
I	4.65 % (2)	0	1.0
II	95.35 (41)	100% (9)	
III			
IV			
Gender			
Male	79.07% (34)	100% (9)	0.3
Female	20.94% (9)	0	
BMI, kg/m^2	27.49 ± 3.40	27.56 ± 3.97	0.91
Diabetes mellitus	69.77% (30)	33.33% (3)	0.059
Hypertension	88.37% (38)	100% (9)	0.57
Chronic kidney disease	11.63% (5)	22.22% (2)	0.59
Chronic obstructive pulmonary disease	4.65% (2)	22.22% (2)	0.13
Hyperlipidemia	73.17% (30)	66.67% (6)	0.69
Angina	93.02% (40)	88.89% (8)	0.54
Preoperative myocardial infarction	46.51% (20)	55.56% (5)	0.54
<90 d	20% (4)	0	
≥90 d	80% (16)	100% (5)	
PCI	2.33% (1)	11.11% (1)	0.31
<90 d	0	0	
≥90 d	100% (1)	100% (1)	1.0
No. of vessels			1.0
1	0	0	
2	4.65% (2)	0	
3	93.35% (43)	100% (9)	
Left main involvement	36.59% (15)	33.33% (3)	1.00
Wall motion abnormalities	51.28% (20)	16.67% (1)	0.19
LVEF	62.50)% ± 7.77%	64.88% ± 8.86%	0.41
RVFAC	50.39% ± 6.32%	43.25% ± 13.93%	0.08
Pulmonary hypertension	15.79% (6)	0	0.56
Preoperative drug therapy			
ACE inhibitor	73.81% (31)	55.56% (5)	0.42
Nitrates	38.10 %(16)	55.56% (5)	0.46
β-Blockers	73.81% (31)	66.67% (6)	0.69
Digitalis	4.76% (2)	0	1.00
Calcium-channel blockers	19.51% (8)	22.22% (2)	1.00
Diuretics	9.52% (4)	11.11% (1)	1.00
Amiodarone	2.38% (1)	0	1.00
Aspirin	71.43% (30)	55.56% (5)	0.43
Clopidogrel	73.81% (31)	66.67% (6)	0.69
Statins	100% (42)	100% (9)	1.00

ACE=angiotensin-converting enzyme; BMI=body mass index; IQR= interquartile range; LVEF=left ventricular ejection fraction; PCI=percutaneous coronary intervention; RVFAC=right ventricular fractional area change.

Table 2. Intraoperative Variables

	Nondifficult Separation From CPB (n = 43)	Difficult Separation From CPB (n = 9)	P Value
	Frequency (%); Mean ± SD; Median (IQR)		
Pre–CPB period			
Postinduction hemodynamics			
CO	5.14 ± 1.80	4.53 ± 1.01	0.58
CI	2.94 ± 1.01	2.42 ± 0.54	0.40
Base deficit	1 (0–2)	2 (0–4)	0.16
Svo_2	75% (74%–78%)	75% (74%–75%)	0.54
Pco_2 venoarterial gradient	0.1 (0–4)	4.75 (3.5–6)	0.22
CBG	150.67 ± 58.73	122 ± 27.24	0.17
Hematocrit	0.35 ± 0.05	0.36 ± 0.05	0.55
No. of PRBC transfused			
0	100%	100%	
CPB period			
No. of grafts			
2	6.98% (3)	0	0.75
3	51.16 % (22)	55.56% (5)	
4	30.23% (13)	44.44% (4)	
5	11.63% (5)	0	
Complete revascularization	97.6% (43)	100% (9)	1.00
CPB time	125.65 ± 29.86	132.77 ± 17.44	0.49
Aortic cross-clamp time	99.76 ± 25.73	107 ± 20.26	0.39
Release of cross-clamp to off-CPB time	15.74 ± 9.42	18.44 ± 7.53	0.42
Lowest bypass hematocrit	0.25 ± 0.03	0.27 ± 0.06	0.23
No. of PRBC transfused			
0	44.19% (19)	55.56% (5)	0.22
1	34.88% (15)	22.22% (2)	
2	20.93% (9)	11.11% (1)	
3	0	11.11% (1)	
CBG	210.43 ± 51.66	199.33 ± 84.78	0.75
Svo_2			
At 1 h	78% (74–84%)	82% (73–88%)	0.59
At release of cross-clamp	75% (70–77%)	73% (70–76%)	0.92
Base deficit			
At 1 h	1.5 (0–4)	1 (0–3)	0.92
At release of cross-clamp	1 (0–2)	2.5 (2–5)	0.005
Initial rhythm on clamp release			0.74
Sinus rhythm	81.40% (35)	77.78% (7)	
Atrial fibrillation	0	0	
Junctional rhythm	0	0	
Ventricular tachycardia	4.65% (2)	0	
Ventricular fibrillation	13.95% (6)	22.22% (2)	

(continuation of Table 2)

Defibrillation/cardioversion			0.41
0	81.40 (35)	77.78% (7)	
1	16.28% (7)	11.11% (1)	
2	0	0	
≥3	.33% (1)	11.11% (1)	
Atrioventricular pacing	2.33% (1)	0	1.00
Inotrope/vasopressor use and period of initiation			
Dobutamine	72.09 % (31)	100% (9)	0.09
Pre-CPB	41.94% (13)	44.44% (4)	0.43
Start of CPB	3.23% (1)	0	
Weaning	54.84% (17)	44.44% (4)	
Off-CPB	0	11.11% (1)	
Epinephrine	2.33% (1)	44.44% (4)	0.02
Pre-CPB	0	0	0.40
Start of CPB	0	0	
Weaning	0	75% (3)	
Off-CPB	100% (1)	25% (1)	
Milrinone	0	0	-
Pre-CPB			
Start of CPB			
Weaning			
Off-CPB			
Norepinephrine	0	55.56% (5)	0.00
Pre-CPB		60% (2)	-
Start of CPB			
Weaning		20% (1)	
Off-CPB		20% (1)	
Vasopressin	0	0	-
Pre-CPB			
Start of CPB			
Weaning			
Off-CPB			
NTG	76.74% (33)	55.56% (5)	0.22
Pre-CPB	87.88% (29)	100% (5)	1.00
Start of CPB	9.09% (3)		
Weaning	3.03% (1)		
Off-CPB	0		
Nicardipine	9.30% (4/43)	44.44% (4/9)	0.023
Pre-CPB	0	75% (3)	0.14
Start of CPB	25% (1)		
Weaning	25% (1)	25% (1)	
Off-CPB	50% (2)		
Amiodarone	0	11.11% (1)	0.17
Insulin drip	4.88% (2)	0	1.00

CI=cardiac index; CO=cardiac output; CPB=cardiopulmonary bypass; IQR=interquartile range; NTG=nitroglycerin; Pco_2=partial pressure of carbon dioxide; PRBC=packed red blood cell; Svo_2=mixed venous oxygen saturation.

venoarterial gradient was higher in the difficult weaning group (0.1 [IQR, 0–4] vs 4.75 [IQR, 3.5–6], P = 0.22), but showed no statistical significance. No transfusion with PRBC was done prior to initiation of CPB.

On-CPB Intraoperative Variables

There was no significant difference between the nondifficult and difficult weaning from CPB groups in terms of the number of grafts anastomosed (P = 0.75), CPB time (125.65 ± 29.86 minutes vs 132.77 ± 17.44 minutes, P = 0.49), aortic cross-clamp time (99.76 ± 25.73 minutes vs 107 ± 20.26 minutes, P = 0.39), and time from release of aortic cross-clamp to coming off CPB (15.74 ± 9.42 minutes vs 18.44 ± 7.53 minutes, P = 0.42). The lowest bypass hematocrit during CPB for the nondifficult weaning was lower (25% vs 27%) but showed no significant difference (P = 0.23). There was also more blood transfusions in the group with nondifficult separation from CPB, but this also showed no significant difference (P = 0.22).

SvO_2 taken at 1 hour of CPB (median, 78% [IQR, 74%–84%] vs 82% [IQR, 73%–88%]; P = 0.59) and during release of cross-clamp (median, 75% [IQR, 70%–77%] vs 73% [IQR, 70%–76%]; P = 0.92) showed no significant difference. Base deficit taken at 1 hour showed no significant difference between the two groups (median, 1.5 [IQR, 0–4] vs 1 [IQR, 0–3]; P = 0.92). After release of cross-clamp, however, base deficit showed a significant difference (P = 0.005), with median base deficit in the nondifficult group of 1 (IQR, 0–2) and in the difficult weaning group of 2.5 (IQR, 2–5).

Ventricular fibrillation occurred at 22.22% in the difficult weaning group compared with 13.95% in the nondifficult group (13.95%) and more incidence of need for defibrillation to convert to sinus rhythm, with both parameters showing no statistical significance (P = 0.74, P = 0.41).

Inotrope and Vasopressor Use

Dobutamine was used less in the nondifficult group (72.09% vs 100%), but showed no significance (P = 0.09). The timing of dobutamine initiation also did not show any significance (P = 0.43). In the nondifficult group, 41.94% initiated dobutamine in the pre-CPB period, and 54.84% started dobutamine during weaning. In the difficult weaning group, 44.44% started dobutamine during the pre-CPB period, and 44.44% used dobutamine during weaning from CPB. Epinephrine (44.44%) and norepinephrine (55.56%) were the most commonly added drugs to dobutamine in difficult weaning from CPB.

Other Drugs

Nitroglycerin was used more in the nondifficult weaning group (76.74% vs 55.56%, P = 0.22). Nicardipine, on the other hand, was used more often in the difficult separation group (44.44%) compared with the nondifficult group (9.3%) and showed statistical significance at P = 0.023.

Table 3. Factors Associated With Difficult Separation From Cardiopulmonary Bypass in CABG Patients With Preserved LVEF

Parameters	Crude OR (95% CI)	P Value
Base deficit after release of aortic cross-clamp	1.40	0.041
Nicardipine	7.8	0.016

CI=confidence interval; OR=odds ratio.

Logistic Regression

Logistic regression analysis showed that every unit increase in base deficit after release of aortic cross-clamp increased the odds of having difficult separation from CPB by 40.21%. Patients who received nicardipine were also 7.8 times more likely to have difficult separation from CPB.

DISCUSSION

Scores commonly used in cardiac surgery to stratify perioperative risk of the patient consider only preoperative variables and fail to account for intraoperative events. Among these intraoperative variables, the level of pharmacological and mechanical support during weaning from CPB is a critical factor.[3,10] Therefore, identification of factors that predict difficult weaning is important for cardiac anesthesiologists.

In this study, we looked at the incidence of difficult weaning from CPB in a low-risk cardiac surgical population. We have identified two intraoperative factors associated with difficult weaning from CPB: (1) base deficit after release of aortic cross-clamp (*P* = 0.005) and (2) the use of nicardipine infusion (*P* = 0.023).

There is a 17.3% incidence of difficult weaning from CPB in this study. The lower incidence of this study could be attributed to the fact that our study population is limited to low-risk patients undergoing elective CABG surgery with good left ventricular function.

In the study by Denault et al,[3] age, previous myocardial infarction, depressed ejection fraction, mitral surgery, previous cardiac surgery, and CPB duration were observed as independent predictors of complex CPB separation. In contrast, our study did not show age, previous myocardial infarction, and CPB duration to be associated with difficult weaning because the two groups we compared were almost homogenous in their demographic characteristic and cardiac risk factors.

It was observed that 17.3% had difficult weaning from CPB. Two main factors were found to be significantly influencing the process of weaning from CPB.

The first factor to be associated with difficult weaning from CPB is the base deficit after release of aortic cross-clamp. Base deficit is an indicator of pure metabolic acidosis. Hugot et al[11] cited experimental animal studies by Davis and colleagues, which showed base deficit to have a high correlation with other indicators of tissue hypoxia, such as lactate, and indicators of tissue oxygenation, such as arteriovenous oxygen differences and central venous oxygen saturation.

Hugot et al[11] observed that the value of base deficit measured during the first hour after cardiac surgery under CPB was correlated with the length of intensive care unit (ICU) stay. Zante et al[12] likewise found severely reduced base excess (base deficit) at ICU admission in a cohort of post–cardiac surgery patients to be predictive of ICU mortality.

In our study, base deficit was taken after the release of aortic cross-clamp, where reperfusion of the myocardium after the ischemic insult occurs. Base deficit may reflect the adequacy of myocardial protection during the ischemic time. The metabolic acidosis during CPB could also be iatrogenic in nature. Liskaser et al[13] studied the role of pump prime in metabolic acidosis during CPB and concluded that transient metabolic acidosis is derived from the effect of pump prime fluid on acid–base balance. The type of pump prime and cardioplegia has not been included in this study and might have contributed to the metabolic acidosis seen after release of aortic cross-clamp. However, base deficit taken 1 hour after institution of CPB was not shown to be statistically significant between the two groups; thus, the base deficit taken after release of aortic cross-clamp may be more reflective of the degree of myocardial protection rather than the type of pump prime and cardioplegia.

There is, however, no stringent protocol for the correction of base deficits, and oftentimes it depends on the clinical decision of the attending anesthesiologist. Correction of metabolic acidosis with sodium bicarbonate generates intracellular carbon dioxide and is often associated with a reduction in systemic vascular resistance. Clearance of the increased carbon dioxide via membrane oxygenator takes 5 to 10 minutes.[14]

A limitation of our study is the failure to check if correction of metabolic acidosis was done and whether enough time for clearance of increased carbon dioxide was given. It is possible that these factors may also have contributed to the difficulty in weaning off-CPB. This finding highlights the importance of obtaining a metabolic panel after the release of aortic cross-clamp, which shall help identify correctable factors with significant impact on the weaning process.

Another finding in this study is that the use of nicardipine infusion was found to be associated with difficult separation from CPB. The authors postulate that because of a longer half-life, the administration of nicardipine infusion might have contributed to the decreased systemic vascular resistance during weaning from CPB, which necessitated the addition of a vasopressor drug. This finding, however, should be interpreted with caution because of the small number and lack of control in the use of nicardipine in this study.

Monaco et al[10] cited in their review that owing to a longer half-life compared with clevidipine, a dihydropyridine calcium-channel blocker with a fast onset and offset, nicardipine is not routinely used in the setting of cardiac surgery. Clevidipine, however, is not available in our setting.

Transthoracic echocardiography (TEE) is not routinely used in our institution for elective, low-risk CABG surgery without associated valvular problems. The use of TEE, in conjunction with hemodynamic variables, can identify adequacy of deairing of cardiac chambers, diagnose hypovolemia, and assess left and right ventricular function. TEE is also the cornerstone in diagnosing etiology of failure to wean from CPB in normovolemic conditions and in the absence of structural or dynamic abnormalities.[10] Although this may be a limitation for our study, it also reflects real-world, decision-making processes during weaning from CPB in low-resource settings.

Although it has been established that difficult weaning from CPB in a high-risk cardiac surgical cohort correlated with morbidity and mortality, additional studies need to be done to identify if difficult separation from CPB in low-risk cardiac surgeries is also associated with morbidity and mortality. Larger trials are needed to validate our results and help establish guidelines and protocols on weaning from CPB.

LIMITATIONS

Our analysis is limited first by its observational, nonrandomized, single-center design. Our results may thus have limited external validity. Second, our subjects were enrolled consecutively as they presented for surgery. However, time constraints on the researchers' ability to strictly enforce enrollment of subjects as such might have introduced a selection bias. Third, initiation of inotropes, vasopressors, and vasodilators during the intraoperative course is at the discretion of the attending cardiac anesthesiologist; therefore, selection bias cannot be discounted. Another important limitation of the study is the lack of intraoperative TEE, which could have given anesthesiologists additional information to guide decision-making in the appropriate use of inotropes, vasopressors, and volume during weaning from CPB.

CONCLUSION

Weaning from CPB encompasses a short period where critical decisions are made to safely transition the patient from mechanical circulation to spontaneous, sustained cardiac activity. In this low-risk cardiac surgical population, patients with preserved left ventricular function undergoing CABG surgery, we identified two intraoperative variables associated with difficult weaning from CPB: (1) base deficit at release of aortic cross-clamp and (2) the use of nicardipine infusion.

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