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Original Research

Early and Mid-Term Outcomes of Delayed Sternum Closure Strategy in Adult Cardiac Surgery: A Single-Center Experience

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Abstract

Background: Delayed sternum closure is a crucial strategy in the management of hemodynamic instability after weaning from cardiopulmonary bypass. This study aimed to evaluate our outcomes with this technique in light of the literature. **Methods**: We retrospectively reviewed the data of all the patients who developed postcardiotomy hemodynamic compromise and intraaotic balloon pump was inserted between November 2014 to January 2022. Patients were divided into two groups: primary sternal closure group, and delayed sternum closure group. Patients' demographic data, hemodynamic parameters, and postoperative morbidities were recorded. **Results**: Delayed sternum closure was performed in 16 patients with an incidence of 3.6%. The most common indication was hemodynamic instability in 14 patients (82%), followed by arrhythmia in 2 patients (12%) and diffuse bleeding in 1 patient (6%). The mean time to sternum closure was 21 ($\pm$7) hours. Three patients died (19%), $p > 0.999$. The median follow-up period was 25 months. Survival analysis revealed that the survival rate was 92%, $p = 0.921$. Deep sternal infection was observed in one patient with (6%), $p > 0.999$. multivariate logistic regression analysis revealed that end-diastolic diameter [odds ratio (OR) 4.5, 95% CI (1.19–17), $p = 0.027$], right ventricle diameter [OR 3.9, 95% CI (1.3–10.7), $p = 0.012$] and aortic clamp time [OR 1.16, 95% CI (1.02–1.12), $p = 0.008$] were independent risk factors for delayed sternum closure. **Conclusions**: Elective delayed sternal closure is a safe and effective method for treating postcardiotomy hemodynamic instability. It can be performed with a low incidence of mortality and sternal infections.

Keywords

delayed sternum closure; open sternum; cardiac surgery; cardiopulmonary bypass; hemodynamics

Introduction

The concept of delayed sternum closure (DSC) following adult cardiac surgery was first described by Riahi *et al.* [1] in 1975. Although it is a common therapeutic maneuver in pediatric population after congenital heart surgery, it has a reported incidence of 1% – 4% in adult patients [2,3].

Cardiopulmonary bypass (CPB) has several unfavorable effects that lead to vascular tone loss, leukocyte extravasation, and capillary fluid leakage, which eventually leads to myocardial and pulmonary edema [4]. Although sternal closure may result in a slight reduction in cardiac index (CI) and a slight increase in central venous pressure and/or pulmonary artery pressure due to right atrial and ventricular compression, the surgeon can proceed to close the chest if hemodynamic stability is maintained. However, in some patients, cardiac compression by sternal closure might cause hemodynamic instability, particularly in patients with poor myocardial functions due to ischemia, reperfusion, and even in the presence of good cardiac performance with poor myocardial preservation [5,6]. In rare cases, sternal closure causes trapping of lung parenchyma or limitation of lung expansion, resulting in increased airway pressure. Those patients may benefit from DSC management. Furnary *et al.* [6] demonstrated that reopening the sternum improves low cardiac output state by increasing cardiac output and systolic systemic pressure without significant change in cardiac filling pressures. However, it has been avoided due to the increased risk of sternal infections with prolonged open sternum [5,7].

The only way to examine the true outcomes of this technique is by randomizing patients with hemodynamic instability into two groups; patients with or without delayed sternal closure. However, it would be unethical to perform such an analysis. Therefore, previous studies were either observational studies without comparison groups [8–11] or studies that included a control group of patients with primary sternal closure (PSC) who did not develop the same condition of hemodynamic compromise before weaning from CPB [2,4,5,12], which do not reflect the true efficacy of this procedure. In the present study, we presented our

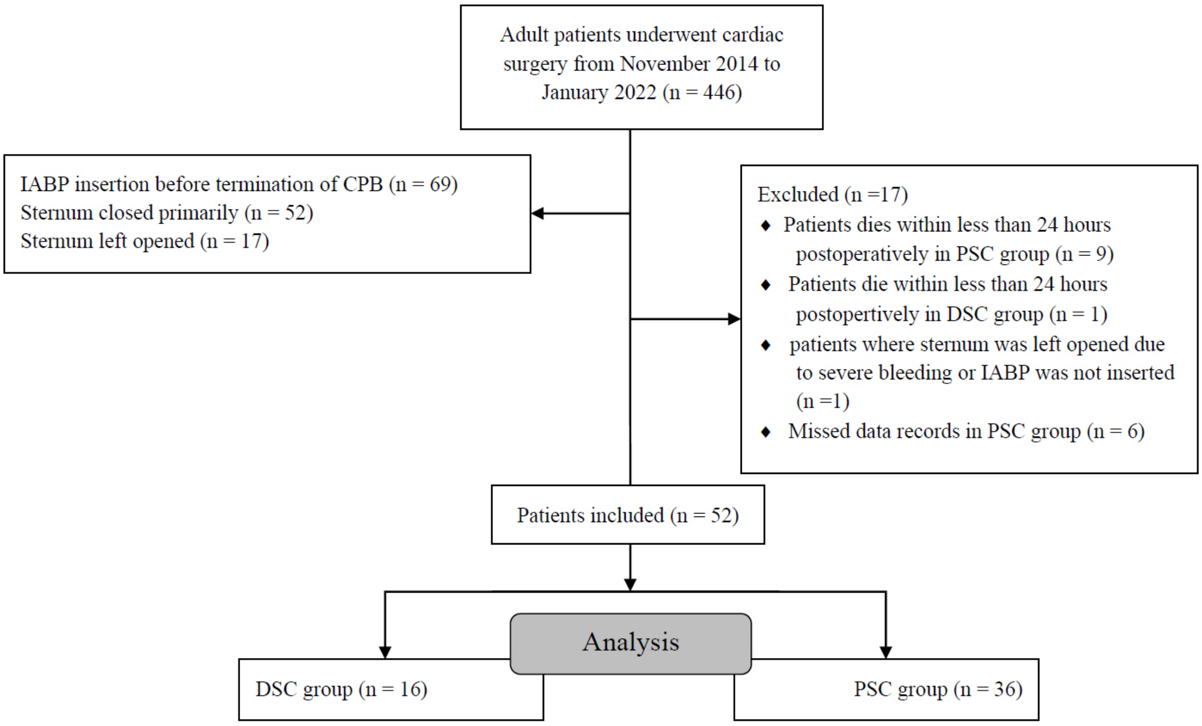

Fig. 1. Flowchart of the study design.

experience with DSC over 7 years to examine the early and mid-term outcomes in comparison with patients who exhibited hemodynamic instability on the termination of CPB, yet the sternum was closed primarily. To our knowledge, a similar analysis was not performed in previous studies.

Materials and Methods

Study Design

The study was conducted by reviewing the data of 446 patients who underwent cardiac surgeries from November 2014 to January 2022. Inclusion criteria were: (1) patients over 18 years old, (2) all the patients who received intra-aortic balloon pump (IABP) intraoperatively and were shifted to the intensive care unit (ICU) with primary sternum closure or their sternums left opened, Exclusion criteria were as follows: (1) patients die within 24 hours postoperatively, (2) missing records, (3) patients who underwent a thoracotomy procedure, (4) patients where IABP was inserted pre- or post-operatively, (5) patients where IABP was not inserted, (6) patients with intractable bleeding. We divided the patients into two groups: patients with primary sternum closure (PSC) and patients who were managed with delayed sternum closure procedure (DSC) (Fig. 1).

Along with demographic data, preoperative comorbidity factors, procedure type, EuroSCORE II, echocardiographic features (left ventricular ejection fraction (LVEF), systolic pulmonary artery pressure (SPAP), end systolic diameter (ESD), end diastolic diameter (EDD), right ventricular diameter (RVD)), aortic clamp time, CPB time, length of intensive care unit (ICU) and hospital stay, postoperative lactate and mean arterial pressure (MAP) values at different time points, and postoperative results were recorded. The primary endpoint was 30-day mortality from all causes. Secondary endpoints included mediastinitis or sternum wound infection, bleeding amount, blood products transfusion rates, ICU and hospital length of stay. The analysis includes the pre- and intra-operative predictors of delayed sternum closure. All surgeries were performed by the same team of heart surgeons.

Surgical Procedure

Standard anesthesia, cardiopulmonary bypass, and surgical methods were performed. In the majority of patients, intermittent cold blood cardioplegia with hypothermia and antegrade-retrograde cardioplegia was used for myocardial protection, and only two patients received del Nido cardioplegia. IABP insertion was applied for all the study participants except for one patient whose sternum was left open due to severe bleeding and therefore excluded from the study.

Indications for Delayed Sternum Closure

DSC was performed if all attempts to maintain hemodynamic stability failed. Optimization of preload and afterload, inotropic support and IABP insertion were all applied to stabilize the patient. In all patients, hemodynamic instability was the main reason for DSC, which was defined as MAP ≤50 mmHg or systolic arterial pressure ≤80 mmHg. This instability emerged in some patients during the trial of chest closure, however, not all patients had trial closure and the sternum was left open electively according to the surgeon's preference. Cardiac edema, arrhythmias, and diffuse bleeding with hemodynamic compromise were other considerations for leaving the sternum open.

Technique and Maintenance of DSC

The temporary closure of the sternal wound was achieved by a sterile 1000 mL layer of a saline bag which was fashioned to fit the open sternum and then sutured to the skin by a continuous suture. This was followed by a second cover of a laparotomy pad and a steri-drape plastic film over it (Fig. 2).

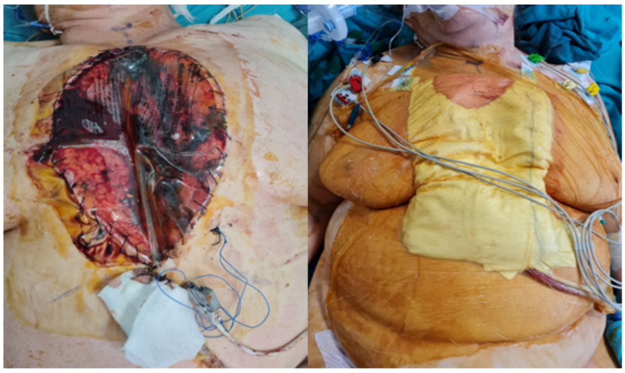

Fig. 2. The technique of temporary closing of the sternal wound.

In the ICU, all patients were kept on mechanical ventilation and sedated by midazolam (1–2 cc intravenous injection (i.v)) which was applied intermittently in case the patient was agitated, or by morphine (5 mg intramuscular injection (i.m)). Loop diuretics were used to achieve negative fluid balance. Patients who were not closed within the first 24 hours underwent reexploration and mediastinal irrigation (this was applied only to one patient). A broad-spectrum antibiotic prophylaxis was administered immediately after shifting to the ICU and maintained after the sternum was closed; in the majority of patients, tazobactam and piperacillin or meropenem were administered according to the recommendation of infectious disease specialist.

The timing of sternal closure was determined by evaluation of the inotrope levels, improved hemodynamic parameters, decrease in lactate levels, correction of coagulation defects, resolution of myocardial edema and improvement of contractility by inspections of the heart. In all patients, sternal closure was routinely performed in the ICU under strict aseptic measures. Repeated irrigation with rifampicin or gentamycin solution and warm isotonic saline and cleaning of sternal and skin edges with diluted betadine solution was performed. The sternum was reapproximated by sternal wires followed by closure of the skin incision with close attention to hemodynamic response.

Follow-Up

All patients were clinically followed up at three, six, and twelve months following the surgery, as well as at yearly intervals. The most recent information was obtained by calling the patient. The follow-up ended on April 2022 and was totally completed. The event investigated was survival.

Statistical Analysis

Descriptive statistics are presented as mean with SD or median with IQR for numerical variables, while frequencies and percentages are used for the categorical variables. The distribution of variables was assessed by Kolmogorov-Smirnov and Shapiro-Wilk's tests. For analytical statistics, Independent samples t-test, Mann-Whitney Test, Paired samples test and Wilcoxon Signed Ranks test were used to compare numerical variables between two groups based on the normality assumption, while Pearson Chi-Square test or Fisher's Exact test were used to compare two categorical variables. Log-Rank test was used to evaluate survival between DSC and PSC groups and demonstrated by Kaplan-Meier's curve. Univariate and multivariate logistic regression analysis were performed to determine independent predictors for DSC. Models of Multiple logistic regression analysis were performed using the 'Enter' method, Hosmer-Lemeshow goodness-of-fit test was used to assess the suitability of the model. The data were analysed using IBM SPSS statistics (version 25, Armonk, NY, USA) predictive analytics software. p-value < 0.05 was considered statistically significant.

Results

Demographic and Clinical Characteristics

A total of 52 patients, 39 males (75%) and 13 females (25%), who underwent cardiac bypass surgery and met the study criteria, were included (Table 1). The mean age was 62.3 (±11.15). In DSC group the body mass index (BMI) of patients was higher (median, IQR = 30, 1.12) than the BMI in patients in the PSC group (median, interquartile range (IQR) = 28, 1.4), $p = 0.002$. The most common comorbidities were hypertension (HT) (42%), smoking (36%), hyperlipidemia (HL) (35%), diabetes milletus (DM) (35%), new myocardial infraction (MI) (23%), and chronic obstructive pulmonary disease (COPD) (10%), with no significant difference between the groups except for the DM, which incidence was higher in the DSC group, $p = 0.029$.

Table 1. Baseline characteristics and comparison between groups.

	Overall	DSC	PSC	Mean difference (95% CI)	*p*-value
	n = 52	n = 16 (31%)	n = 36 (69%)		
Age (years), mean (±SD)	62.3 (±11.15)	63.75 (±8.4)	61.64 (±12.2)	2.11 (–4.7, 8.9)	0.058^{a}
Gender: n (%)					
Male	39 (75)	12 (75)	27 (75)	-	0.643^{d}
Female	13 (25)	4 (25)	9 (25)		
BMI (kg/m^2), median (IQR)	28.23 (2.32)	30 (1.12)	28 (1.4)		**0.022**^{b}
Comorbidity factors: n (%)					
HL	18 (35)	7 (43.8)	11 (30.6)		0.356^{c}
HT	22 (42)	8 (50)	14 (38.9)		0.454^{c}
DM	18 (35)	9 (56.3)	9 (25)	-	**0.029**^{c}
COPD	5 (10)	1 (6)	4 (11)		>0.999^{d}
Smoking	19 (36)	8 (50)	11 (30.6)		0.179^{c}
New MI	12 (23)	4 (25)	8 (22)		>0.999^{d}
Priority of procedure: n (%)					
Elective	35 (67)	11 (68.8)	24 (66.7)	-	0.882^{c}
Urgent	17 (33)	5 (31.3)	12 (33)		
Type of procedure: n (%)					
CABG	43 (82.7)	12 (75)	31 (86)		
CABG+MVR+Tc repair	4 (7.7)	2 (12.5)	2 (5.6)		
Mitral valve repair	2 (3.8)	1 (6.3)	1 (2.8)		0.634^{d}
AVR	2 (3.8)	1 (6.3)	1 (2.8)		
TVR	1 (1.9)	0	1 (2.8)		
Preop. creatinine (mg/dL), mean (±SD)	0.92 (±0.2)	0.92 (±0.2)	0.93 (±0.2)	–0.014 (–0.14, 0.11)	0.828^{a}
Postop. creatinine (mg/dL), mean (±SD)	1.17 (±0.4)	1.1 (±0.3)	1.21 (±0.4)	–0.106 (–0.33, 0.11)	0.340^{a}
Echocardiography					
LVEF (%), median (IQR)	50 (9.1)	49.7 (14)	50 (15)	-	0.697^{b}
SPAP (mmHg), median (IQR)	33.2 (6)	29.5 (16)	33.2 (5)	-	>0.999^{b}
ESD (cm), mean (±SD)	3.5 (±0.6)	3.4 (±0.5)	3.6 (±0.6)	–0.22 (–0.56, 0.11)	0.183^{a}
EDD (cm), mean (±SD)	4.9 (±0.7)	5.2 (±0.7)	4.8 (±0.6)	0.47 (0.06, 0.87)	**0.025**^{a}
RVD (cm), median (IQR)	3.1 (0.4)	3.3 (0.2)	3.1 (0.33)	-	**<0.001**^{b}
Euroscore II (%), median (IQR)	1.09 (0.75)	1.39 (1.16)	0.90 (0.53)		**0.011**^{b}
Intraoperative features, median (IQR)					^{b}
Aortic clamp time (minute)	80 (25)	101.8 (21)	76.4 (11)	-	**0.001**
CPB time (minute)	132 (46)	203.4 (51)	125.3 (10)	-	**<0.001**
MV time (hour), median (IQR)	36.4 (26)	42.3 (20)	28.7 (24)	-	**0.001**^{b}
IABP weaning time (day), median (IQR)	5 (1)	5 (0)	5.9 (2)	-	0.137^{b}
Total blood drainage (mL). p.o. 24 hour	868.2 (333)	1033 (121)	868.2 (238)	-	**0.015**^{b}
Blood transfusion					
PRBCs transfusion (unit), median (IQR)	3.6 (2)	4.1 (1)	3 (2)	-	**0.007**^{b}
FFP transfusion (unit), mean (±SD)	6.2 (±2.3)	8 (±1.8)	5.4 (±2.1)	2.65 (1.44, 3.85)	**<0.001**^{a}
Postop. Platelets (×10^9 L), mean (±SD)	124.8 (±50)	104 (±28.1)	134.2 (±55)	–30.4 (–53.6, –7.2)	**0.011**^{a}
Atrial fibrilation, n (%)	9 (17)	2 (12.5)	7 (19)	-	0.704^{d}
Stroke, n (%)	7 (13.5)	3 (18)	4 (11)	-	0.662^{d}
Sternal wound infection/mediastinitis, n (%)	4 (7.7)	1 (6)	3 (8)	-	>0.999^{d}
ICU length of stay, median (IQR)	7 (2)	7.8 (4)	7 (2)	-	0.148^{b}
Hospital length of stay, median (IQR)	9 (10)	14.7 (5)	7 (8)	-	**0.004**^{b}
30-day Mortality, n (%)	9 (17)	3 (19)	6 (17)	-	>0.999^{d}

DSC, delayed sternum closure; PSC, primary sternum closure; HL, hyperlipidemia; HT, hypertension; DM, diabetes milletus; COPD, chronic obstructive pulmonary disease; MI, myocardial infraction; LVEF, left ventricle ejection fraction; SPAP, systolic pulmonary artery pressure; ESD, end-systolic diameter; EDD, end-diastolic diameter; RVD, right ventricle diameter; CPB, cardiopulmonary bypass; MV, mechanical ventilation; IABP, intraaortic balloon pump; PRBCs, packed red blood cells; FFP, fresh frozen plasma; MAP, mean arterial pressure; CABG, coronary artery bypass graft; MVR, mitral valve replacement; AVR, aortic valve replacement; Tc, tricuspid valve.

^{a} Independent Samples *t*-Test, ^{b} Mann-Whitney Test, ^{c} Pearson Chi-Square Test, ^{d} Fisher's Exact Test. Bold *p*-values indicate statistical significance.

Table 2. Comparison between multiple variables of patients with DSC.

	Median (IQR)		Difference (95% CI)	p-value
	Before sternum closure	After sternum closure	After-before	
Total blood drainage (mL)	1033.33 (121)	350 (38)	-	**<0.001**[a]
Urine output (cc/kg/h)	4.2 (1.2)	6.2 (3)	-	**0.005**[a]
Creatinine (mg/dL), mean (±SD)	1.12 (±0.29)	1.3 (±0.36)	0.17 (0.89, 0.26)	**0.001**[b]
Lactate level (mmol/L)	4.31 (1.05)	1.9 (0.2)	-	**<0.001**[a]
MAP (mmHg), mean (±SD)	73.5 (±4.9)	84 (±2)	10.4 (7.4, 13.5)	**<0.001**[b]

MAP, mean arterial pressure.

[a] Wilcoxon Signed Ranks Test, [b] Paired Samples Test. Bold p-values indicate statistical significance.

The overall incidence of DSC was 3.6% (16/446), with 2.7% for isolated CABG, 0.4% for isolated valve procedures, and 0.4% for combined procedures (Fig. 3).

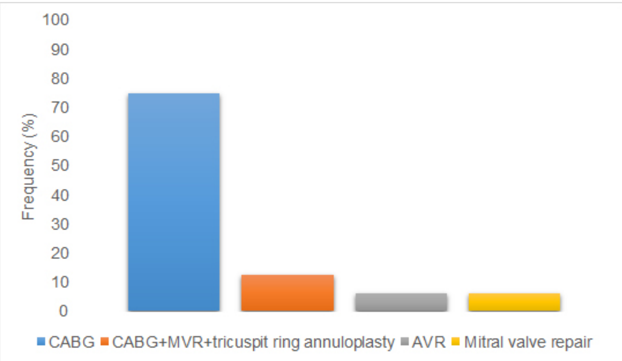

Fig. 3. Type of procedures managed with delayed sternum closure.

Echocardiographic Features

In DSC group end-diastolic diameter (EDD) and right ventricle diameter (RVD) were higher [mean = 5.2 (±0.7) cm, p = 0.025] and [median = 3.3 cm, $p < 0.001$], respectively, while there were no statistically significant differences between groups according to ejection fraction (EF), systolic pulmonary arterial pressure (SPAP) and end-systolic diameter (ESD).

Intraoperative Characteristics

The durations of aortic clamp time and CPB time were higher in DSC group [median =101.8 min, p = 0.001] and [median = 203.4 min, $p < 0.001$], respectively.

Postoperative Course

There was a statistically significant difference between groups regarding the mechanical ventilation time (median = 42.3 hours for DSC group vs 28.7 hours for PSC group, p = 0.001). In DSC group, the mean time to closure was 21 hours (±7) with a range of 14 to 40 hours. The total amount of blood drainage was higher in DSC group (median = 1033 mL, p = 0.015). Blood product transfusion rates were also higher in DSC group (median PRBCs = 4.1 units, p = 0.007, median FFP = 8 units, $p < 0.001$). The mean of postoperative platelet counts was lower in DSC [104 × 10^9 L (±28.1)] *vs.* [134.2 ×10^9 L (±55)] for PSC group, p = 0.011. There was no statistically significant difference between groups regarding postoperative atrial fibrillation or stroke.

In DSC group only one patient had mediastinitis (6%), while in PSC group, 3 patients (8%) developed sternal wound infection, however, there were no statistically significant differences between the groups. The ICU length of stay was comparable between the two groups, however, the hospital length of stay was higher in DSC group (median = 14.7, p = 0.004).

The in-hospital mortality within 30 days in DSC group was 19% (n = 3), while the mortality in PSC group was 17% (n = 6). However, there was no statistically significant difference between the groups.

Hemodynamic and Metabolic Data

In Table 2, we demonstrated changes in multiple variables in DSC group before and after sternum closure. The median of lactate levels was significantly lower after sternum closure (median = 1.9 mmol/L, $p < 0.001$), while mean values of mean arterial pressure (MAP) increased after sternum closure (mean = 84 mmHg, $p < 0.001$). We also recorded postoperative lactate values and MAP levels in different time intervals. For DSC group: (T1: postop. 1 hour after the operation or 1 hour after sternum closure, T2: postop. 6 hour, T3: postop. 12 hour, T4: 1 hour before sternum closure or postop. 24 hours after sternum closure). For PSC group: (T1: 1 hour after the operation, T2: postop. 6 hour, T3: postop. 12 hour, T4: postop. 24 hour). Lactate levels decreased from 6.3 mmol/L to 2.1 mmol/L until the time of sternum closure in less than 24 hours and remain at normal levels around 2 mmol/L after sternum closure, in PSC group lactate levels decreased gradually from 5.9 mmol/L until it reaches the normal levels after 24 hours, while MAP values changed in a direct fashion to the filling pressures in both groups. Changes in lactate and MAP

Table 3. Comparison of patients' lactate levels and MAP values at different time points.

	Median (IQR)			*p*-value*
		DSC (Before sternum closure)	PSC	
Lactate levels (mmol/L), median (IQR)				
T1	5.7 (2)	6.5 (0.99)	5.7 (2.7)	0.262
T3	3.4 (2.3)	3 (0.55)	5 (2.1)	**0.005**
T4	2.1 (1.1)	2.05 (0.35)	2.8 (1.07)	**0.047**
MAP (mmHg), median (IQR)				
T1	68 (8)	62.7 (4)	70.3 (7)	**0.005**
T3	74 (5)	72 (3)	74.6 (5)	0.710
T4	80 (3)	82.2 (2)	79.6 (3)	**0.036**
Urine output (cc/kg/h). p.o 1 hour	4.2 (1.5)	4.2 (1.2)	4.5 (1.4)	0.395
		DSC (After sternum closure)	PSC	*p*-value*
Lactate levels (mmol/L), median (IQR)				
T1	4.5 (3.8)	1.9 (0.47)	5.7 (2.6)	**<0.001**
T3	3.3 (3.2)	1.8 (0.12)	5 (3)	**<0.001**
T4	2 (1.3)	1.5 (0.08)	2.8 (1.07)	**<0.001**
MAP (mmHg), median (IQR)				
T1	70 (17)	85 (3)	70.3 (7)	**<0.001**
T3	74.5 (13)	85 (2)	74.6 (5)	**<0.001**
T4	70 (17)	85 (2)	70 (7)	**<0.001**
Urine output (cc/kg/h). p.o 1 hour	4.6 (2.7)	6.2 (3)	4.5 (1.4)	**0.001**

DSC, delayed sternum closure; PSC, primary sternum closure; MAP, mean arterial pressure.

* Mann-Whitney Test. Bold *p*-values indicate statistical significance.

levels at these time intervals were depicted in Figs. 4,5. respectively. The statistical significance of the variations in these parameters in different time intervals was shown in Table 3.

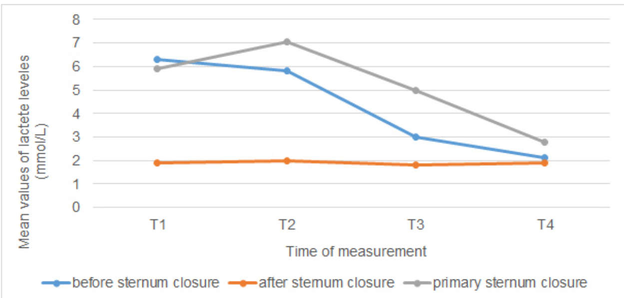

Fig. 4. Changes in lactate levels at different time intervals.

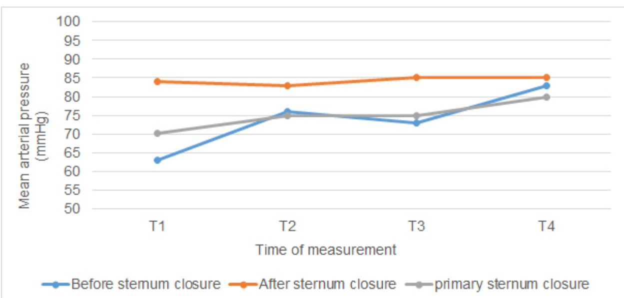

Fig. 5. Changes in MAP values at different time intervals.

Predictive Factors of DSC

The results of univariate and multivariate analysis are shown in Table 4, in univariate analysis, the following factors were found to be significant predictors for DSC: DM [OR 3.9, 95% CI (1.11–13.4), p = 0.033], EDD [OR 2.9, 95% CI (1.09–7.95), p = 0.033] and aortic clamp time [OR 1.05, 95% CI (1.01–1.08), p = 0.007]. For multivariate analysis we built 2 models, in model 1, the analysis revealed that EDD [OR 4.5, 95% CI (1.19–17), p = 0.027], RVD [OR 3.9, 95% CI (1.3–10.7), p = 0.012] and aortic clamp time [OR 1.16, 95% CI (1.02–1.12), p = 0.008] were independent risk factors for DSC. In model 2, aortic clamp time, RVD and EDD were also independent risk factors for DSC, while reduced EF (EF $\leq$40%) was not found to be a predictive risk factor for DSC in both models.

Survival Analysis for Both Groups

Out of 52 patients, 43 patients were discharged. In-hospital survival for DSC group was 81% (13/16) *vs.* 83% (30/36) survival rate for PSC group. The median time of follow-up was 25 months ranging from 2 to 89 months. The overall survival rate in DSC group was 92% and in PSC group was 93%, the mean survival time in DSC was [82.4 months, 95% CI (69.9, 94.8)] while in PSC group, the mean survival time was [80.4 month, 95% CI (72.9, 87.8)], the analysis revealed no statistically significant difference, p = 0.921 (Fig. 6).

Table 4. Results of univariate and multivariate logistic regression analyses testing the association between delayed sternum closure and clinical characteristics.

Risk factor	Univariate		Multivariate			
			Model 1		Model 2	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Age (y)	1.02 (0.96–0.17)	0.526	-	-	-	-
Sex (female)	1 (0.25–3.89)	>0.999	0.7 (0.09–5.8)	0.752	-	
DM	3.9 (1.11–13.4)	**0.033**	2.8 (0.48–15.8)	0.249	-	-
New MI	1.16 (0.29–4.6)	0.826	1.9 (0.33–11.6)	0.447		-
BMI (kg/m^2)	1.15 (0.97.1.37)	0.110	1.5 (0.15–14.1)	0.677	-	-
EF ≤40%	0.66 (0.18–2.51)	0.549	0.99 (0.16–6.1)	0.993	0.8 (0.15–4.7)	0.853
EDD (cm)	2.9 (1.09–7.95)	**0.033**	4.5 (1.19–17)	**0.027**	5.2 (1.27–21.5)	**0.022**
ESD (cm)	0.44 (0.13–1.47)	0.183	-	-	0.28 (0.051–1.6)	0.156
RVD (cm)	1.52 (0.72–3.21)	0.270	3.9 (1.3–10.7)	**0.012**	3.2 (1.23–8.5)	**0.017**
Aortic clamp time (min)	1.15 (1.01–1.08)	**0.007**	1.16 (1.02–1.1)	**0.008**	1.16 (1.02–1.1)	**0.003**

OR, odds ratio; CI, confidence interval; BMI, body mass index; DM, diabetes milletus; MI, myocardial infraction; EDD, end diastolic diameter; ESD, end systolic diameter; RVD, right ventricle diameter. Bold *p*-values indicate statistical significance.

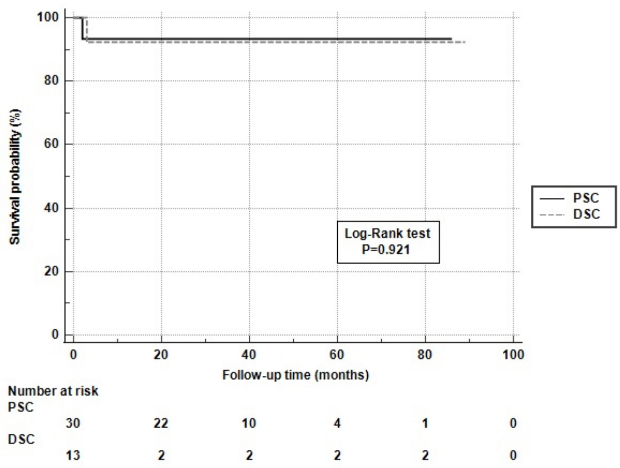

Fig. 6. Cumulative survival probabilities. Kaplan-Meier estimate of survival comparing the two groups.

Discussion

Cardiopulmonary bypass induces a complex sequence of events that have the potential to produce tissue edema and dysfunction including myocardial and pulmonary edema [4]. in some cases that require prolonged CPB, sternal closure causes severe hypotension and may lead to hemodynamic changes including a reduction in cardiac index and stroke volume index [13]. These changes may require inotrope agents adjustment, fluid administration, or reopening of the chest and reassessment. Patients who do not tolerate chest closure, delayed sternal closure can be performed on the following postoperative day. This technique prevents the sternum from compressing the heart, minimizes the risk of tamponade, and allows for mediastinal re-exploration if necessary. This study was designed to evaluate the outcome of using DSC with IABP in patients who developed postcardiotomy hemodynamic instability in comparison with those who had PSC with IABP.

In the present study, 3.6% of our patients required DSC procedure, which is similar to recent studies that report an incidence between 3.5–5% [2,5,14], while other studies reported slightly lower incidences ranging between 1–2% [9,12,15] in adult patients. The most common indication for DSC in our center was hemodynamic instability and cardiac edema, followed by arrhythmia and diffuse bleeding, these indications were consistent with previous studies [5,6].

Hospital survival in our study was 81% for patients who had DSC. This exceeds the survival rates in previous studies, which ranged from 52% to 72% [2,7,12,14]. Wong *et al.* [11] and Christenson *et al.* [3] reported comparable survival rates of 84% and 79% respectively. The survival rate after discharge was also high in this cohort of patients, the follow-up time ranged between 2 to 89 months and the overall survival was 92%, Calafiore *et al.* [4] in his study reported that a two-year survival rate was 48% (±9), another study by Christenson *et al.* [3] reported a survival rate of 73% at 5 years. A broad variety of mortality rates were reported, which might be explained by a wide variation of preoperative and intraoperative risk factors, as well as the complexity of the procedures. Yasa *et al.* [12] reported a mortality rate of 27%, Boeken *et al.* [5] also in his large series of 179 patients reported an overall mortality of 29%, other studies reported higher rates of mortality over 30% [9,14,16]. On contrary, few studies with different numbers of patients and a variety of procedures reported less overall mortality rates of 16% and 10% [11,17]. Hospital mortality in our study was 19% (3/16) for DSC group and 17% (6/36) for PSC. The common cause of mortality in both groups was low cardiac output. As a matter of fact, the mortality rate in PSC group is much higher than DSC group. However, we excluded patients who died in the immediate postoperative period as most of the data needed for the analysis would not be available. There were 9 more patients whose sternum was closed primarily died within 24 hours, while only one patient whose sternum was left open died within 24 hours, subsequently, the overall mortality in PSC group is 33% (15/45), and in DSC group is 23% (4/17). Although there is still no statistically significant difference between the groups regarding mortality rates, we think that those patients who died in the immediate postoperative period might be saved if the sternum was left open. This fact cannot be emphasized more, since a randomised study would be unethical, and the decision to leave the sternum open as a clinical judgment is crucial. Based on our review of available data, previous studies have not conducted such an analysis, which limits our evaluation of these findings; however most previous reports revealed that mortality was higher in patients with DSC if EF is low with a prolonged duration of high dose inotropic support, closure is delayed more than six days, requirement of hemodialysis or sternal wound infection develops [2,5,7,11]. None of our patients developed renal failure and the sternum closure time was less than 1 day in the majority of patients. Other studies revealed that the presence of IABP [5,7] or VAD [6] was independently associated with in-hospital mortality. In the present study all patients in both groups were in critical condition and insertion of IABP was necessary to be able to wean from CPB.

One of the major obstacles to wide acceptance of DSC strategy is the anticipated risk of deep sternal infections, which increases the mortality rate in those critically ill patients. The overall rate of sternal wound infections in those patients was reported as 5.4% [18], while sternal infection rates for patients undergoing routine cardiac operations ranged from 1% to 2% [14]. In our analysis, it is worth noting that the incidence of sternal wound infections or mediastinitis following DSC was not statistically different from that of controls with PSC. Although the majority of the patients in DSC group had higher BMI and a higher rate of insulin-dependent DM, we observed mediastinitis in only one patient out of 16 (6%). None of the patients had sternal dehiscence or bloodstream infection. this might be explained by our strategy to administer broad-spectrum antibiotics as early as possible, the prolonged duration of prophylaxis and the short time until sternal closure in most cases. In line with our study, Boeken *et al.* [2] reported the use of broad-spectrum antibiotics in the majority of patients who received piperacillin-tazobactam, and mediastinitis was observed in 10 patients out of 212 (5%). Other series with different medications or strategies like VAC therapy did not encounter any signs of sternal infections [10,16].

Various methods have been described to keep the sternum open including self-retaining retractor, steri-drape film coverage, silicone membrane, bovine pericardial patch, stenting by syringes appropriately cut, sterile blood bag, and primary skin closure [4,6,12,19,20]. In our series we used a sterile layer of 1000 mL saline bag, which was sutured to the skin, this was followed by a second layer of laparotomy pad and a steri-drape plastic film over it. The benefits are that it is readily accessible and inexpensive, in addition, it is non-porous and reduces the risk of infection.

The timing of sternal closure is a critical choice that should be made with caution, as early closure might result in failure and recurrent cardiac dysfunction due to ongoing myocardial edema. While prolonged time to closure may expose the patient to increased risk of mortality [7,11] and sternal infections [9], some previous studies reported that they were unable to close the sternum before the 3rd postoperative day [7,11,21], and patients who were successfully closed were patients who required a low amount of inotropic support and in negative fluid balance [2,7]. In our study, the sternum was closed on a subsequent postoperative day in all of the patients except for one patient (mean time to closure was 21 hours ± 7). The success of timing of closure in our series could be demonstrated by considerable improvements in mean arterial pressures and blood lactate levels. Furthermore, the temporary hemodynamic changes around the sternal closure time, which improved after 12 to 24 hours are consistent with other studies [3,6,7].

Based on our literature review, patients with increased ventricular diameters, particularly right ventricle, pulmonary hypertension, reduced EF, and renal dysfunction were more susceptible to DSC [4,7], also the type and complexity of the procedure might be associated with increased risk of DSC [3]. In our univariate logistic regression analysis, we found that DM, increased EDD and aortic clamp time were significantly associated with the need for DSC, while in multivariate analysis, the most independent risk factors for DSC were, increased aortic clamp time, right ventricular diameter and end-diastolic diameter. These factors remained significant in both models in multiple logistic regression analysis despite controlling for other potential factors such as reduced EF, new MI, female gender, DM, and BMI. Two previous studies have found that prolonged CPB time and intraoperative blood transfusion were significant predictors of DSC [8,10]. Identifying the risk factors associated with this cohort of patients could improve the outcome and allow for the management of the postoperative course properly.

Limitations and Strengths

This study is a retrospective study with a small sample size and reflects a single-center experience, which might have impacted our outcomes regarding this strategy, however, we include all the patients with and without sternum closure who developed hemodynamic instability on termination of CPB and temporary mechanical circulatory support was used. Such analysis was not performed in previous studies, which limits the true interpretation of the findings.

Conclusions

In conclusion, delayed sternal closure strategy is a safe and effective technique for managing critically ill patients with refractory myocardial or pulmonary dysfunction that precludes weaning from CPB. It can be performed with a low incidence of mortality and sternal infections. We believe that this technique should be considered without reluctance, in addition to placement of IABP as early as possible, as it might increase the opportunity of survival in those patients.

Abbreviations

DSC, delayed sternum closure; PSC, primary sternum closure; IABP, intraaortic balloon pump; MAP, mean arterial pressure; CPB, cardiopulmonary bypass.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

SA designed the study. SA and ÖHM collected and analyzed the data. FÇ writing the original draft. FÇ and HE served as scientific advisors. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the local ethical committee and conforms to the provisions of the Declaration of Helsinki. Number: 2017-KAEK-189_2022.05.26_3, date: 26.05.2022.

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Conflict of Interest

The authors declare no conflict of interest.

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