Delayed Sternal closure following complex cardiac surgery in neonates

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Abstract

Background: Delayed sternal closure (DSC) is a well-established surgical intervention following complex congenital cardiac surgeries mitigating postoperative haemodynamic and respiratory instability. It is mostly used in neonates requiring prolonged cardiopulmonary bypass, aortic cross-clamp times or deep hypothermic circulatory arrest, predisposing to myocardial oedema or bleeding. Our study evaluates morbidity and mortality after DSC in neonates including superficial, deep sternal wound infections and requirement of surgical debridement.

Methods: Retrospective review of neonates who underwent DSC after cardiac surgery in a single centre from 2015 to 2021.

Results: 187 neonates were identified. Mean age and weight were 12.8 ± 6.8 days and 3.3 ± 0.5 kg, respectively. Mean days of opened chest were 3.8 ± 5.8 days. Two neonates (1.07%) required sternal wound debridement, whilst 19 cases (10.2%) had superficial wound infections. Mean ICU and hospital stay were 12.8 ± 16.6 and 25.9 ± 36.9 days. 30-days mortality occurred in 9 cases (4.8%). Univariate analysis indicated that DSC days (p= 0.01), ECMO (p= 0.000), aortic cross clamp time (p= 0.007) and CPB time (p=0.006) to be associated with 30-days mortality, whilst in multivariable analysis, only ECMO was significant (p= 0.002). RACHS-1 score was the only independent risk factor for sternal wound infection in univariate analysis (p =0.019) and multivariable analysis (p=0.05).

Conclusion: DSC is a safe therapeutic option following complex neonatal cardiac surgery, where cardiac compression by sternal approximation is not tolerated because of, myocardial oedema, haemodynamic instability or coagulopathy. Higher RACHS-1 score was associated with greater incidence of sternal wound infections.

Introduction

Delayed sternal closure (DSC) is a widely recognised surgical intervention aimed at mitigating postoperative haemodynamic and respiratory instability in paediatric patients following complex cardiac surgery [1]. Approximately 10% of paediatric cardiac patients leave the operating room with an open chest, with subsequent sternal closure performed after an average duration of three days [2–4].

It is most frequently indicated in complex cases involving prolonged cardiopulmonary bypass and aortic cross-clamping, which can potentially lead to intraoperative bleeding and myocardial oedema [5]. In such circumstances, sternal closure can trigger haemodynamic instability with reduction in cardiac output and diastolic filling [5]. Delayed chest closure can improve morbidity and mortality for patients following complex paediatric cardiac operations, by preventing the onset of haemodynamic instability.

However, DSC may predispose patients to sternal wound infections (SWI) and mediastinitis [6-9]. SWIs can be categorised into two types: superficial SWIs, managed conservatively with antibiotics, and deep SWIs which require surgical debridement. Albeit rare, severe complications such as sepsis, can be life-threatening [6]. Moreover, mortality rates in this critically ill patient subgroup vary considerably, ranging from 8 % to as high as 34% [1-6].

Considering the pros and cons of DSC, a lack of consensus exists within the literature concerning the indication for or timing of sternal closure in these patients. Moreover, different clinical series report variable morbidity and mortality rates associated with this procedure. A prevalence of 3.5-18.0 % for SWIs following delayed sternal closure has been documented in the literature [2–4, 6–15]. This retrospective review aims to evaluate the morbidity and mortality following delayed sternal closure in the neonatal population, focusing on the occurrence of superficial and deep sternal wound infections and the requirement of surgical debridement.

Material and methods

Study design and patient population

This study has been approved by Liverpool John Moores University Ethical committee (UREC reference number: 25/NAP/001). A retrospective data collection was performed for neonates who underwent DSC following congenital cardiac surgery via sternotomy from 2015 to 2021, at Alder Hey Children's Hospital, Liverpool, United Kingdom. Patients who are over 28 days of age and patients with incomplete data were excluded.

Variables including indication of DSC, time to sternal closure, mean paediatric intensive care unit (PICU), hospital stay duration, superficial & deep wound infections, 30-day mortality, sepsis and surgical risk according to the Risk Adjustment for Congenital Heart Surgery (RACHS-1) score, need for extracorporeal membrane oxygenation (ECMO) were extracted from our database. Data relating to incidence of SWI, surgical intervention and 30-day mortality were double checked by another author.

Endpoints

The primary endpoints of this study were the superficial and deep sternal wound infection and mediastinitis rates with the need for sternal wound debridement rate. Superficial SWIs were defined as inflammatory changes confirmed with wound swabs. Deep SWIs were confirmed if the muscular layers were affected. Mediastinitis is defined as a positive pathogen identified by culture swabs affecting the mediastinum and the sternum. Secondary endpoints involved evaluating associated morbidity such as sepsis, intensive care and hospital stay duration and 30-day mortality rates.

Indication for DSC

The decision to delay sternal closure is determined preoperatively for operations like the Arterial Switch Operation for transposition of the great arteries and the Norwood procedure for hypoplastic left heart syndrome. In other instances, it is decided intraoperatively in case of myocardial oedema and myocardial distention from a variety of clinical conditions like low cardiac output, arrhythmias, respiratory failure needing high ventilation pressures. Coagulopathy with the need to leave the chest packed with swabs is a further indication or in patients with postoperative circulatory support through central ECMO. Also, we adopt the DSC policy in the case of pulmonary artery banding (PAB) for single ventricle circulation or in case of septal defects (Multiple VSDs, Apical VSD or complete AVSD not closable in conjunction with hypoplastic aortic arch repair under circulatory arrest), as we have experienced, in such cases, that the PAB will need further adjustments few days after surgery. We use intravenous (IV) Cefuroxime (Cephalosporin) during the days of opened chest, and we tend to continue it for 2 doses after chest closure. In case of cephalosporin or penicillin allergy, we use IV Teicoplanin plus IV gentamicin as an alternative to cefuroxime and we continue them for 2 doses after chest closure.

Surgical techniques:

Our approach to open chest treatment encompasses various techniques depending on the surgeon's preference. In cases who went out of theatre on ECMO, we utilise silastic membrane that is sutured to the skin with continuous 5/0 polypropylene sutures, then we further cover it with 2 layers of antimicrobial drape (Ioban 3M).

In non-ECMO cases, we utilise different techniques based on the individual surgeon's preference which can be:

1- silastic membrane that is sutured to the skin with continuous 5/0 polypropylene sutures, then we further cover it with 2 layers of antimicrobial drape (Ioban 3M).

2- Direct skin closure using subcuticular Monocryl sutures, leaving the sternal edges open. Then, covering the wound with sterile dressing.

3- Sterile dressings over a small size swab left in the chest.

4- Antimicrobial drape (Ioban 3M) alone over the open chest with 1 small swab left inside the chest.

5- Few cases needed the use of sternal bridge to keep the sternal edges apart with a piece of chest drain tube sutured to the sternal edges to prevent compression to the heart or RV-PA conduit. Then a silastic membrane is sutured to the skin edges covered by a sterile dressing.

Upon chest closure, any dressing is removed in a sterile fashion, to expose the sternum removing retained swabs, mediastinal cavity washout with warm saline solution, followed by standard sternotomy closure in layers using 2/0 PDS for the sternum, 3/0 Vicryl for the muscle and subcutaneous layers, and 5/0 Monocryl for subcuticular skin closure. We do all our chest closures in ICU including those who need ECMO weaning and decannulation. We do not use

GORE-TEX membrane to cover the heart routinely. Its use is a surgeon's preference. In case of needing to cover the heart or great vessels, suturing a ePTFE 0.1 mm membrane (Gore-Tex) to the pericardial edges with polypropylene 5/0 interrupted sutures is done at the time of chest closure in ICU.

Regarding the cases who had sternal wound infection:

Out of the two cases who required wound revision and debridement in the operation room, the first patient exhibited sternal dehiscence on examination and had positive mediastinal wound swab cultures. The second patient developed signs of a deep sternal wound infection, characterised by a high C-reactive protein, pyrexia, positive blood cultures and chest swab cultures, as well as purulent material on swabs covering the midline sternotomy incision with sternal dehiscence.

However, in cases of superficial wound infection, we managed it conservatively with antibiotics based on the culture and sensitivity results and regular dressings. If the baby needed frequent dressing change because of superficial discharge, we tend to use PICO negative pressure wound dressing and we change it every 5-7 days.

Statistical analysis

Categorical data was reported as frequencies and proportions. Mean and standard deviation were used to express quantitative data. Univariate and multivariable regression analyses were conducted to identify risk factors for sternal wound infection and 30-day mortality. The level of significance was considered at p value < 0.05. Statistical analyses were conducted with SPSS Version 27.0 (SBSS Inc, Chicago, IL).

Results

Demographic data

Over a 6-year period, 1896 patients were identified and screened of which 187 neonates were included in our patient cohort. Mean age and weight at operation were 12.8 ± 6.8 days and 3.3 ± 0.5 kg, respectively. Mean aortic cross clamp time and CPB time were 102.8 ± 52.5 and 183 ± 81 minutes, respectively. Mean RACHS-1 Score was 4 ± 1.05. Arterial Switch Operation, with or without Ventricular Septal Defect (VSD) repair 70 (37.4%), Hypoplastic Aortic Arch Repair (HAA) 49 (26.2%), Norwood operation 30 (16.0%) comprised the most frequent operations performed in the DSC cohort as depicted in *Figure 1*.

Mean days of open chest were 3.8 ± 5.8 days. Only 2 patients (1.07%) needed sternal wound debridement in theatre for deep sternal wound infections, whilst 19 cases (10.2%) had superficial wound infections managed conservatively with antibiotics. Mean days of wound infection was 10.76 ± 6.65 days and the 2 cases who needed wound revision and debridement was at the 7th and 17th day after chest closure.

Mean ICU and hospital stay were 12.8 ± 16.6 and 25.9 ± 36.9 days respectively. Pre-operative ECMO was required in 1 neonate (0.5%). Intra-operative ECMO was required in 6 cases (3.2%), whilst 21 patients (11.2%) needed post-operative ECMO. 52 cases (27.8%) required further chest explorations. 30-day hospital mortality occurred in 9 cases (4.8%). 24 neonates (12.8%) developed sepsis within 30 days of primary operation. Demographic data has been summarised in *Table 1*.

Regression analysis

Univariate regression analysis showed that the RACHS-1 score (p=0.019, 95% CI -0.047-0.178) was found to be significantly associated with sternal wound infections as described in Table 2. Furthermore, DSC days (p=0.011, 95% CI -0.19 - -0.003), ECMO (p =0.000, 95% CI 0.251-0.465), aortic cross clamp time (p=0.007, 95% CI 0.000- 0.003) and CPB time (p=0.006, 95% CI -0.002-0.000) were found to be significantly associated with 30-days mortality, in the univariate regression analysis, which has been depicted in Table 3.

On multivariate analysis, the RACHS-1 score was found to be the one significant independent risk factor for sternal wound infections, p= 0.05, 95% CI 0.995-4.012 as described in Table 4. In addition, ECMO was found to be the sole significant risk factor for 30-day mortality, (p=0.002, 95% CI 0.000-0.122). Multivariate analysis for 30-day mortality is shown in Table 5.

Discussion

Median sternotomy with delayed sternal closure has become standard practice in selected subgroup of patients needing to optimise postoperative recovery. This strategy proves particularly advantageous in case of haemodynamic or respiratory instability, myocardial oedema and dilation, when coagulopathy and bleeding require packing of the chest or the necessity for central ECMO support. For some subgroup of patients, the decision of leaving the chest open is taken preoperatively, like in case of ASO for TGA, or following the Norwood Procedure for HLHS. In other cases, when is likely that additional procedures need to be performed, like tightening a PAB, the DSC is adopted. Adopting a DSC policy is not without risks, for instance patients with prolonged CPB time, low cardiac output, or coagulopathy needing transfusion are recognised be at higher risk for sternal wound infections [1].

Furthermore, SWIs have been associated with longer postoperative stays, as well as increasing the cost of stay due to the requirement for prolonged ventilation [6].

A significant challenge in comparing our findings with existing literature lies in the lack of standardization in defining infection subtypes. Variability in the criteria used to classify superficial and deep wound infections across studies introduces potential inconsistencies and may account for some of the observed differences in reported incidence rates [6-16].

There exists a variance in the reported incidence rates of sternal wound infections in patients with DSC. Some retrospective series have found superficial SWI rates as (6.7-9.7%) and deep SWIs as (3.9-10.5%), respectively[1, 6, 16]. Whilst others have reported no significant association between DSC and an increase in surgical site infections. Von Stumm et al described 7.3% superficial SWI rate in a 358 paediatric cohort but no deep SWIs requiring surgical debridement[1]. Furthermore, Yang et al reported a 9.7% surgical site infection rate in neonates post DSC, of which there were 28 cases of mediastinitis[16]. Our retrospective study demonstrates similar superficial SWI rates, 10.2%, whilst our deep SWI rate is considerably lower, 1.07%.

Tabbutt and Özker et al reported a 19% mortality rate following paediatric DSC [6, 17]. Hurtado-Sierra et al reported mortality as 22.4% with patients a RACHS- 1 score ≥ 3 posing a higher risk of mortality [3]. Our study shows a considerably lower 30-day mortality rate of 4.8%. 30-day mortality may be attributed to nosocomial infections. 12.8% of our neonates developed sepsis within 30 days of admission, significantly lower than Elassal et al, 54.1% in a paediatric cohort [18]. Infection rates are reported to be higher in patients with prolonged ICU stay [18]. Our study depicts an association between prolonged ICU stay and the risk of SWIs on univariate analysis. Our ICU and hospital stay 12.8 (SD 16.6) and 25.9 (SD 36.9) respectively is higher than other neonatal cohorts; Yang et al report a ICU and hospital length of stay in their SWI as 11.64 (SD 2.6) and 22.26 (SD 4.3), respectively[16].

On univariate analysis, cardiopulmonary bypass time, prolonged DSC time and aortic cross clamp time were significantly associated with 30-day mortality. Cardiac surgery-related morbidity has been primarily attributed to the use of cardiopulmonary bypass. This can be explained by the fact that extracorporeal circulation can induce a systemic inflammatory response, trauma, ischemia and reperfusion injury, endothelial dysfunction, and activation of the coagulation cascade [19-22]. Prolonged cross-clamp time has also been shown to be an independent predictor of 30-day mortality in the literature, similar to our findings [25]. Furthermore, aortic cross clamp time of more than 60 mins with a 91.2% higher probability of sternal wound infections. Our study, on the other hand, did not found such association [16].

Our retrospective study found one significant association between a higher RACHS-1 score and risk of SWIs on multivariable analysis. The majority of our DSC cohort had undergone arterial switch operations and hypoplastic aortic arch repairs with high RACHS-1 scores of 4, similar to several other series [6, 24, 25]. This may be explained as more complex operations with higher RACHS-1 scores are more likely to lead to myocardial oedema, coagulopathy and haemodynamic instability, increasing the risk of infection.

Application of ECMO was a significant risk factor for 30-day mortality in our multivariable analysis, similar to previous reports[26]. Gupta et al in a 998 paediatric cohort describe a 48.1% survival rate to hospital discharge with ECMO, with a mortality rate increasing by 12% every day after 7 days of veno-arterial ECMO use[26].

Timing of sternal closure is still a matter of controversy. Riphagen et al. recommends DSC within 24 hours to lower rates of nosocomial infections and ventilator associated complications[24]. However, premature closure of the sternum can lead to repeated DSCs leading to more deleterious effects than a prolonged period of DSC[7]. Our study reports a DSC time of 3.8 (SD 5.8) days, comparable to the existing literature averaging at 3 days[17, 18]. Furthermore, our study reports no association between DSC time and risk of SWI. This is contradictory to previous retrospective studies which reported a higher incidence of infection with longer periods of open chest[2, 27]. This demonstrates the importance of avoiding premature closure of the sternum as premature closure may lead to further attempts at reopening the chest[7, 18].

Limitations

It is important to note that although several retrospective studies have been referenced, their outcomes cannot be generalised or used as a basis for comparison due to the significant variance in reported mortality and morbidity. Limitations of our study include it being retrospective and a single centre. Moreover, different surgical delayed sternal closure protocols exist within our surgeons' group.

Conclusion

Delayed sternal closure (DSC) represents an efficacious surgical approach for the management of complex cardiac surgery in the paediatric population. Reassuringly, our findings reveal minimal incidence of sternal wound infection associated with delayed sternal closure in these high-risk cases. High RACHS-1 score was the only independent risk factor for sternal wound infection in univariate analysis (p =0.019) and multivariable analysis (p=0.05). DSC facilitates PAB adjustment in high-risk complex cases. Moreover, DSC allows quick access to initiate postoperative lifesaving ECMO in this critical group of patients.

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Competing interests

All authors declare no conflict of interest. No authors have any personal or institutional financial interests related to any content of this manuscript.

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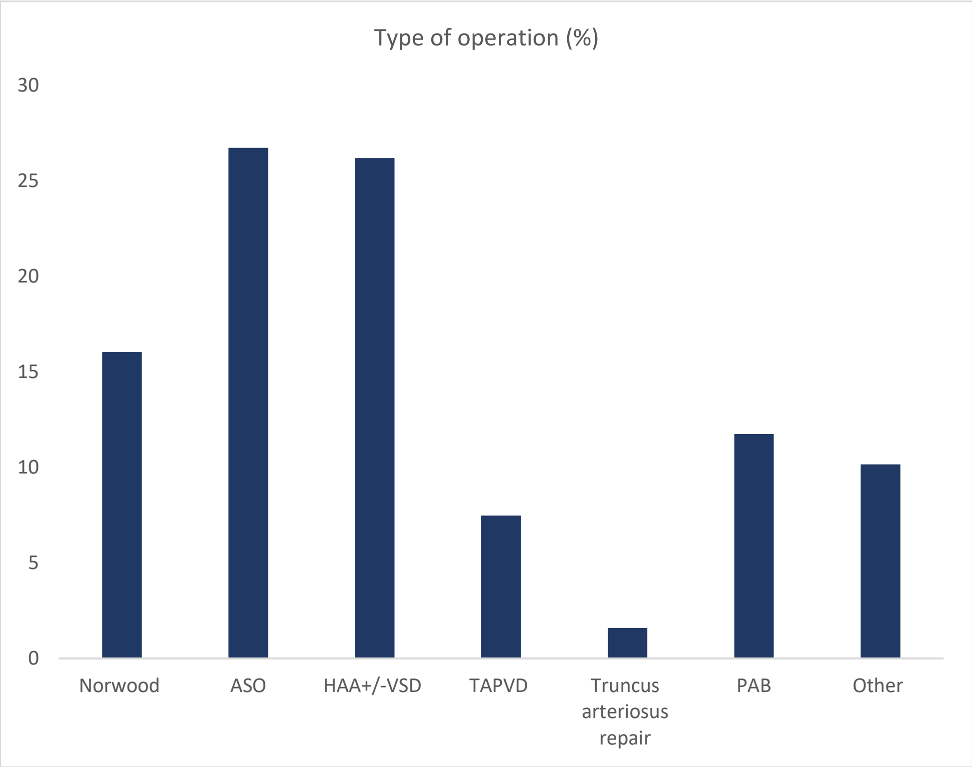
Figures:

Figure 1: Types of operations (%). ASO: Arterial Switch operation, HAA +/- VSD: Hypoplastic aortic arch repair with or without ventricular septal defect repair, TAPVD: Total anomalous pulmonary venous drainage repair, PAB: pulmonary artery banding



Tables:

Table 1: Demographic data

Variables	All cases (n = 187)
Age at operation in days (mean, SD)	12.86 ± 6.45
Female gender (N, %)	59 (31.6%)
RACHS-1 score (mean, SD)	4 ± 1.05
Weight at surgery in kg (mean, SD)	3.33 ± 0.48
ICU stay in days (mean, SD)	12.75 ± 16.57
Hospital stay in days (mean, SD)	25.93 ± 36.88
Time to DSC in days (mean, SD)	3.81 ± 5.80
Pre-operative ECMO (N, %)	1 (0.5%)
Operative ECMO (N, %)	6 (3.2%)
Postoperative ECMO (N, %)	21 (11.2%)
Cardiopulmonary bypass time in minutes (mean, SD)	183.1 ± 80.94
Aortic cross clamp time in minutes (mean, SD)	102.75 ± 52.50
30-day mortality (N, %)	9 (4.3 %)
Sepsis (N, %)	24 (12.8%)
Chest explorations (N, %)	52 (27.8%)

Table 2: Univariate logistic regression analysis for dependent variable, sternal wound infections. CI= confidence interval. The bold values show statistical significance (p <0.05).

Variables	p-value	95% C.I.	
Age at operation (days)	.139	-.006	.007
Sex	.168	-.156	.027
Weight at operation	.462	-.129	.059
ICU days	.987	-.003	.003
DSC days	.074	-.025	.001
ECMO	.299	-.248	.077
RACHS-1 (surgical risk score)	**.019**	.009	.101
Aortic cross clamp time	.388	-.003	.001
CPB time	.07	.000	.003
Number of chest explorations	.251	-.047	.178

Table 3: Univariate logistic regression analysis for dependent variable, 30- day mortality rate. CI= confidence interval. The bold values show statistical significance (p <0.05).

Variables	p-value	95% C.I.	
Age at operation (days)	.583	-.005	.003
Sex	.833	-.067	.054
Operative weight	.845	-.068	.056
ICU days	.207	-.003	.001
DSC days	**.011**	-.019	-.003
ECMO	**.000**	.251	.465
RACHS-1 (surgical risk score)	.665	-.037	.024
Aortic cross clamp time	**.007**	.000	.003
CPB time	**.006**	-.002	.000
Number of chest explorations	.215	-.027	.121

Table 4: Multivariable logistic regression analysis for risk factors of sternal wound infections among neonates undergoing DSC post cardiac surgery. CI= confidence interval. The bold values show statistical significance (p <0.05).

Variables	p-value	95% C.I.	
Age at operation (days)	.722	.925	1.120
Sex	.237	.607	7.533
Weight at operation	.49	.158	2.417
ICU days	.82	.964	1.048
DSC days	.211	.768	1.060
ECMO	.232	.450	26.953
RACHS-1 (surgical risk score)	**.05**	.995	4.012
Aortic cross clamp time	.536	.972	1.015
CPB time	.165	.995	1.030
Number of chest explorations	.347	.526	6.210

Table 5: Multivariable logistic regression analysis for risk factors of 30-day mortality among neonates undergoing DSC post cardiac surgery. CI= confidence interval. The bold values show statistical significance (p <0.05).

Variables	p-value	95% C.I.	
Age at operation (days)	.359	.666	1.159
Sex	.336	.180	150.776
Operative weight	.629	.023	9.672
ICU days	.116	.680	1.043
DSC days	.824	.648	1.412
ECMO	**.002**	.000	.122
RACHS-1 (surgical risk score)	.126	.029	1.550
Aortic cross clamp time	.159	.987	1.086
CPB time	.604	.966	1.020
Number of chest explorations	.915	.068	20.174