Outcomes of delayed chest closure after congenital heart surgery in neonates

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Abstract

We present the outcomes of delayed chest closure in neonates who underwent congenital heart surgery under cardiopulmonary bypass. Eighty-one consecutive neonatal patients (age ≤ 28 days) with congenital heart diseases who underwent heart operations and after surgery, chest remained open in the intensive care unit until DCC. Correction of transposition of the great arteries pathology was the most common surgical procedure (48.1% of patients). Median sternal closure time from surgery was 3 (2-4) days. Median age of neonates was 9 (5-12) days. In addition, in 4 cases (4.9%) there was secretion from the surgical site after DCC and after taking cultures, in 2 (2.4%) of the cases a pathogen was identified. Multivariable linear regression analysis (adjusted to gender and CPB) showed that only the age-predicted the sternum closure time (β=-0.09, 95%CI: -0.16 to -0.02, p=0.02). In-hospital mortality was 6 (7.4%) patients. Although the DCC in neonates who underwent CHD surgical correction was related to a high mortality rate, only the age of neonates predicted the sternum closure time in the ICU.

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Introduction

Delayed chest closure (DCC) is an important and well-described technique in neonatal and infant heart surgery, especially in the management of postoperative excessive hemorrhage and hemodynamic and respiratory instability.[1-4] DCC can also be used electively to help in hemodynamic and respiratory stability in the initial postoperative period.[2,5] Some of the adverse causes that consist indications for DCC are uncontrolled or excessive hemorrhage; reperfusion-related myocardial edema and diastolic dysfunction, more prominent in neonatal especially after cardiopulmonary bypass (CPB) and administration of cardioplegia and decreased pulmonary compliance.[1-3] In addition, long duration of CPB, small chest cavity, and complex surgical procedures can also lead to DCC.[2,3]

Although the benefits of this strategy are well described prior studies have shown conflicting results regarding infection risks, hospital length of stay (LOS), and mortality of patients after DCC. Some of them have reported an increased risk of both sternal wound and bloodstream infections and also increased hospital LOS others have not.[2,5-9,10]

However, it is clear that the more complex and prolonged the cardiac surgery is the more likely the need to keep the chest open after the procedure. Subsequent postoperative tissue edema (fluid overload), and potential high ventilatory peaks due to thoracic constriction upon chest closure could be considered as parameters discriminating the outcome of the procedure in terms of hemodynamic instability and potential sternal wound dehiscence.[1-10]

Obtaining routine mediastinal cultures during DCC seems to be of help in keeping the incidence of sternal wound infection (SWI) low, and is strongly advocated to remain in practice.[9] Moreover, from the literature review on the subject, there seems to be an association between prolonged sternal closure time and increased postoperative infection rate, so DCC should take place as soon as hemodynamic and clinical stability is reached.[9-12]

In this study, we present the outcomes in neonates who underwent DCC after congenital heart surgery.

Materials and Methods

Study population

Study period from 2015 to 2020. Eighty-one consecutive full-term neonates (age ≤ 28 days) underwent an operation for congenital heart disease using CPB with or without hypothermic circulatory arrest (transposition of the great arteries, interrupted aortic arch, truncus arteriosus, total anomaly pulmonary vein connection, single ventricle, and interrupted aortic arch with or without aortopulmonary window) and they were transferred from operating theater to ICU with an open chest.

The study was performed in with accordance the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki Declaration, as revised in 2013. This retrospective study was approved by our Institutional Review Board (705/15.01.2021).

Indications and management of delayed chest closure

The DCC was used as a rescue treatment in patients unable to wean from CPB due to low cardiac output syndrome with/or excessive hemorrhage. The operations were performed by three surgeons. Indications criteria for leaving the chest open postoperatively were the following for all surgeons: hemodynamic instability, respiratory distress, and non-surgical intraoperative bleeding. All patients received antibiotics during the period of open chest and for one day after DCC, according to the ICU protocol (teicoplanin and piperacillin/tazobactam).

The majority of the open chest re-explorations and the DSC were performed in the pediatric intensive care unit (PICU). We did not close the skin but we used the membrane (silicone placed by sutures through the dermis of the wound) closure technique to minimize the contamination risk and risk of hypothermia. Perioperative data were recorded. In addition, the mediastinal cultures were taken in any re-exploration of the sternum and at DCC. Indications for closing the chest were hemodynamic stability, a negative total fluid balance, optimization of the respiratory profile and arterial blood gasses, the coagulation parameters, and improvement of the myocardial and pulmonary edema for at least 24 hours.

Statistical analysis

The data were presented with median (Q1-Q3) (interquartile range, IQR) or number=n (%). Variables normality distribution was tested by the Shapiro-Wilk test, histogram, and Q-Q plot. Parametric (Student t-test), non-parametric test (Mann-Whitney test and Kruskal-Wallis test), and Chi-square test or Fisher's exact test were implemented for the data analysis. Correlation between variables was examined with Spearman (r_s) or Pearson (r) correlation coefficient. Univariable and multivariable linear regression model was used to identify the association of demographics and other factors with sternum closure time. The effect size was expressed by linear regression coefficient "β". The confidence interval was set at 95% (95% confidence interval) in all tests. The statistically significant difference was considered p<0.05. IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) was used to record the data analysis.

Results

Eighty-one neonates, 47 of them males, and 34 females, with congenital heart disease were included in this study. Correction of transposition of the great arteries was the most common surgical procedure (48.1% of patients). Preoperative data are listed in Table 1. The age of patients by type of CHD is presented in Figure 1. As shown in Figure 1, the patients who underwent truncus arteriosus correction were older than patients with other CHD pathology.

In-hospital mortality was 6 (7.4%) patients. None of the 75 neonates developed a deep sternal wound infection (DSWI). Median sternal closure time from surgery was 3 (2-4) days. Four patients experienced wound discharge (4.9%) but only two of them, after culture of the discharge, showed evidence of infection (2.4%). One case was *Enterococcus faecalis* and the other one was *Staphylococcus aureus*, whereas there was no incident of positive sternal culture taken at the time of DCC. No in-hospital death was observed in patients with wound discharge and positive sternal culture. The perioperative data are presented in Table 2.

The weight of neonates, cardiopulmonary bypass, and circulatory arrest time were not correlated with the time of sternum closure, r_s=-0.07, p=0.52, r_s=-0.06, p=0.59 and r_s=-0.18, p=0.10, respectively, while the age of the patients were correlated with the sternum closure time (r_s=-0.28, p=0.01) (Figure 2). In addition, no difference was observed in sternum closure time between the types of CHD correction (p=0.10). Multivariable linear regression analysis (adjusted to gender and CPB) showed that only the age-predicted the sternum closure time (β=-0.09, 95%CI: -0.16 to -0.02, p=0.02) (Table 3). When the study population was divided into two groups (mortality *versus* no-mortality), no differences were observed between perioperative parameters such as the age: 9.5(7-15) *versus* 9 (5-12) days (p=0.44), weight: 2.7 (2.4-2.8) *versus* 2.8 (2.4-2.9) kilogram (p=0.54), surgical procedure (p=0.68), CPB time: 244 (220-250)

Table 1. Preoperative data.

Variables	Total number of patients (n=81)
Age, median (IQR), days	9 (5-12)
Weight, median (IQR), kilogram	2.8 (2.4-2.9)
Gender, female, n (%)	33 (40.7)
Congenital heart disease, n (%)	
Transposition great artery	39 (48.1)
Interrupted aortic arch	9 (11.1)
Truncus arteriosous	7 (8.6)
Total anomaly pulmonary vein connection	13 (16)
Single ventricule	12 (14.8)
Interrupted aortic arch and aorto-pulmonary window	1 (1.2)

IQR, interquartile range; n, number.

versus 245 (180-280)minutes (p=0.95), and CA time: 40 (0-42) *versus* 40 (0-45) minutes (p=0.86) (Table 4).

Discussion

Myocardial edema and CPB-related capillary leak that continue into the postoperative period and the decrease in cardiac output and diastolic filling, after sternal closure, even in patients with preserved cardiac performance can compromise myocardial function and cause postoperative hemodynamic and respiratory instability.[2,13] The use of DSC is an important technique for postoperative management of LOCS and excessive hemorrhage in neonates who underwent congenital heart disease (CHD) surgery. In some centers, DCC can be used electively to optimize hemodynamic stability in the initial postoperative period.

Sternal wound infection (SWI) remains a serious risk factor for worse postoperative outcomes in terms of morbidity, intensive care unit stay, hospital LOS, and mortality.[7,11,14,15] Obtaining routine mediastinal cultures during DCC seems to be of help in keeping the

Table 2. Intra- and post-operative data.

Variables	Total number of patients (n=81)
Cardiopulmonary by-pass time, median (IQR), minute	245 (180-280)
Circulatory arrest time, median (IQR), minute	40 (0-45)
Closure of sternum after operation, median (IQR), days	3 (2-4)
In-hospital mortality, n (%)	6 (7.4)
Sternal wound infection, n (%)	2 (2.4)
Enterococcus faecalis	1 (1.2)
Staphylococcus aureus	1 (1.2)

IQR, interquartile range; n, number.

Table 3. Multivariable linear regression analysis. Association of age with sternal closure time (adjusted to gender and cardiopulmonary bypass time).

Variable	p	β	95%CI
Age	**0.02***	-0.09	-0.17 to -0.02
Gender	0.31	0.45	0.43 to 1.35
Cardiopulmonary bypass time	0.47	-0.003	-0.01 to 0.005

CI, confidence interval; β, linear regression coefficient.*Statistical significant if p <0.05.

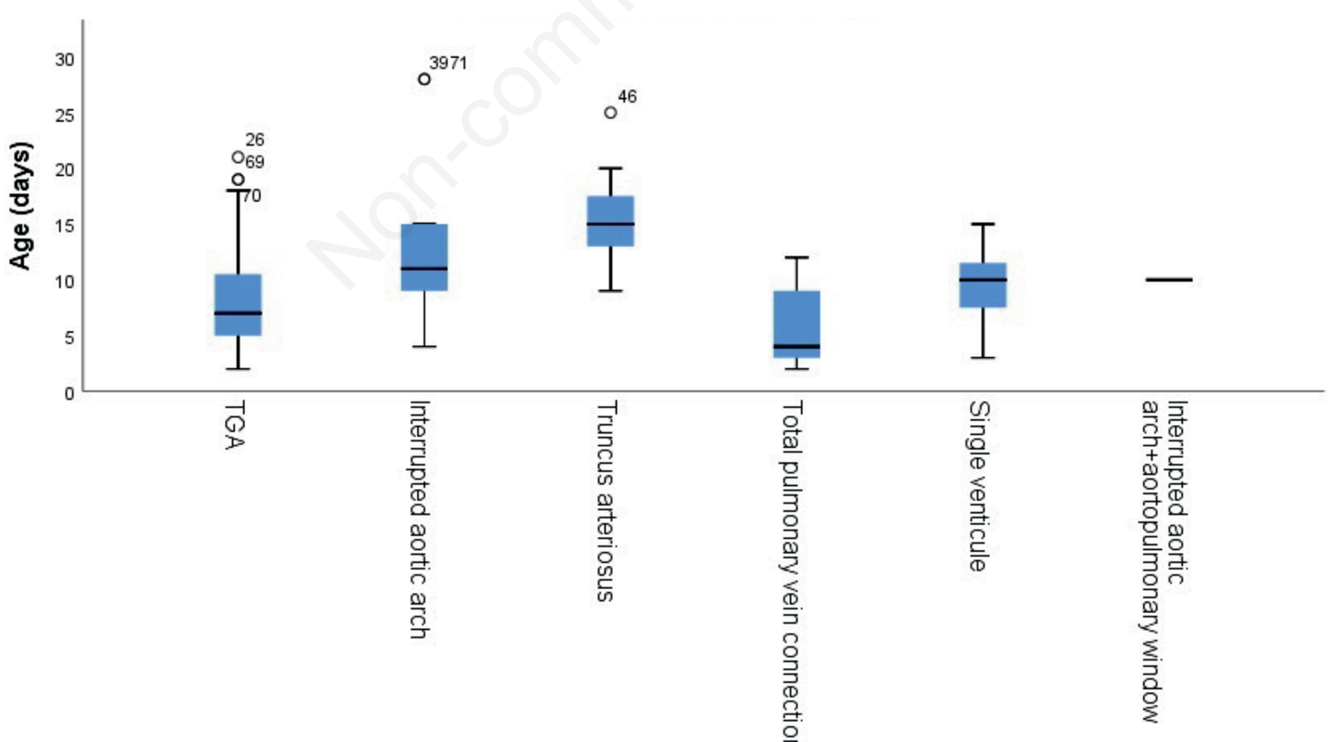

Figure 1. Boxplot of age of patients (days) by type of congenital heart disease (CHD).

incidence of SWI low and is strongly advocated to remain in practice.[9] In our study, no in-hospital death was observed in patients with SWI and positive sternal culture. Only 2.4% of the total number of our patients had a positive culture result. At this point, it should be noted that the prophylactic administration (according to our protocol) of antibiotics may potentially distort the results of cultures sampled during DCC. In a study by Adler *et al.* in 2014, out of 155 patients, 26 of them (17%) had positive mediastinal cultures that were obtained during DCC.[9] 6 of them (23.1%) developed a SWI, statistically significant, contrary to the 5 patients of 129 with negative cultures (3.9%). In their analysis, the positive culture result was the only variable associated with the onset of SWI. Several demographic and postoperative data of the patients with positive and the patients with negative cultures during DCC differed significantly.

Table 4. Comparison between patients groups (mortality versus no mortality).

Variables	In-hospital mortality				P-value
	No (75 patients)		Yes (6 patients)		
	Median	N	Median	N	
Age, median, (IQR), days	9 (5-12)		9.5 (7-15)		0.44
Weight, median, (IQR), kilogram	2,8 (2.4-2.9)		2,7 (2.4-2.8)		0.54
Gender					
Male		44		4	0.52
Female		31		2	
CHD					
Transpostion great artery		37		2	0.68
Interrupted aortic arch		9		0	
Truncus arteriosus		6		1	
Total anomaly pulmonary vein connection		12		1	
Single venticule		10		2	
Interrupted aortic arch+aortopulmonary window		1		0	
Cardiopulmonary by-pass time, median (IQR), minute	245 (180-280)		244 (220-250)		0.95
Circulatory arrest time, median (IQR), minute	40 (0-45)		40 (0-42)		0.86

Total number of patients, 81; IQR, interquartile range; N, number; CHD, congenital heart disease. Statistical significance was set at p<0.05.

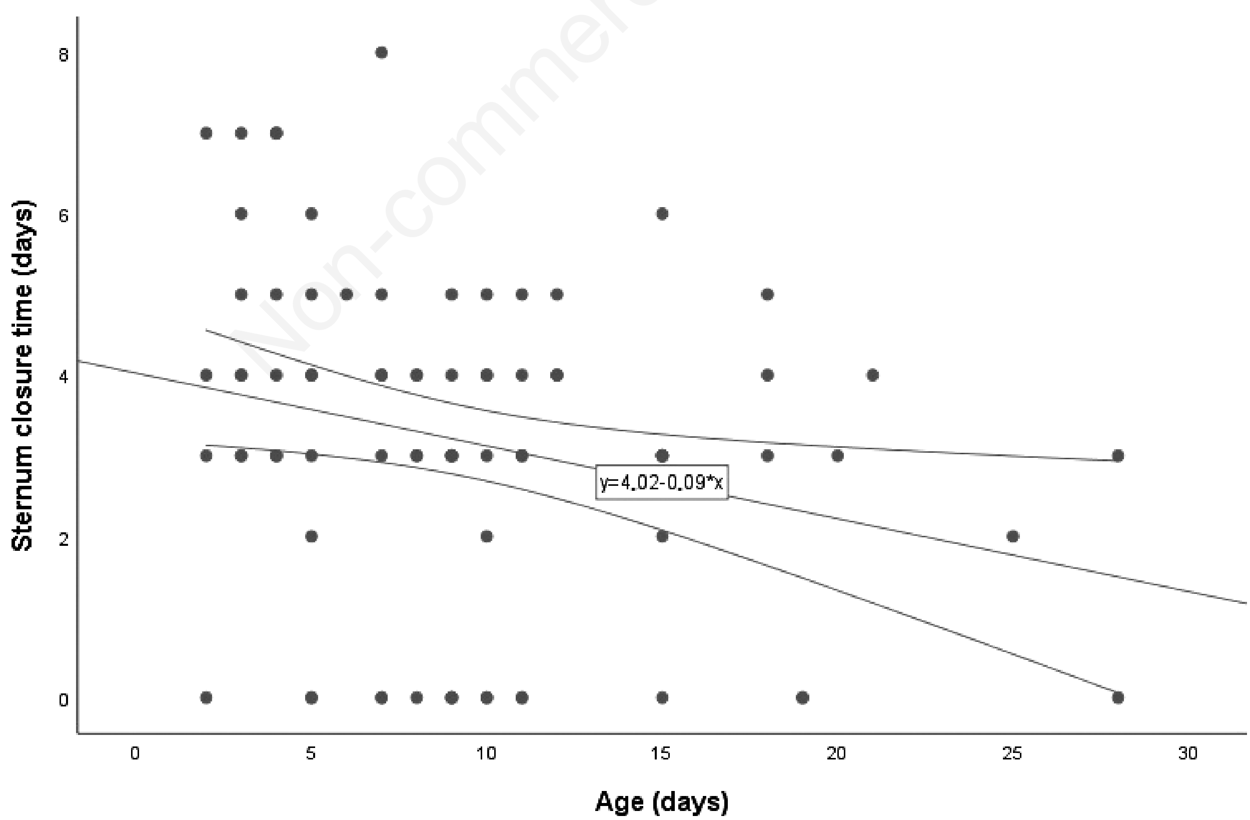

Figure 2. Association of sternum closure time after operation with age (β=-0.09, 95%CI: -0.16 to -0.02, p=0.02). CI, confidence interval; β, linear regression coefficient.

Adler *et al.* concluded that patients with positive sternal cultures are most probable premature neonates, of older age or to have undergone multiple surgical interventions while open sternum. In comparison with the current study, positive culture results were present in only one patient (1.2%) who never developed a SWI. In 4 cases where there was sternal wound discharge after the DCC and new fluid cultures were obtained, only 2 of them (2.2%) had positive results. None of the variables of the study had a statistically significant association with a SWI. There is no recommendation for obtaining and evaluating routine mediastinal cultures during DCC as a preventive measure of SWI. In a study of 38 centers, half of them routinely obtained cultures during DCC, and although the mechanism is not clear, these centers showed a lower rate of SWI.[12]

Harder *et al.* described 375 patients under the age of 18, between 2005-2009, who underwent CHD and had to remain with open sternum in the ICU (11). They reported 43 cases (11%) that developed a SWI. The incidence of organ/space SWI in this study was 7.5%. The incidence of SWI was 1.4%, significantly lower than the DCC cohort (p<0.0001). In the current study, there were no cases that did not undergo DCC, and the percentage of 2.2% that developed a SWI, is lower than the one recorded at the Harder *et al.* study. One reason for this could be the different sample sizes that these two studies used, with the current study having a significantly lower sample size. Another differentiating factor is that Harder *et al.* included patients ≤18 years old, whereas in our study, only neonates (≤28 days old) were included. This can partially explain the difference in sample size. The authors concluded that patients who have to undergo DCC are at an increased risk for developing a SWI compared with the ones who undergo CHD repair but do not have a DSC.

A retrospective study by Özker *et al.* records 38 patients who had undergone CHD surgery, 21 males (55.3%) and 15 females (39.5%), and remained with open sternum postoperatively.[10] The mean age of these patients was 38.5±85 days old and this was their first heart surgery. 20 patients (52.6%) required prolonged antibiotic use due to postoperative infection. 6 out of the total patients (15.8%) had a sterile mediastinal discharge; however, there were 4 (10.5%) patients with postoperative mediastinitis with positive wound swabs, which required surgical re-exploration and antibiotic treatment. The authors concluded that prolonged open sternum is statistically significantly associated with increased rates of mediastinitis.

Erek *et al.* retrospectively studied 188 neonates and infants who required CHD surgery.[16] Patients were divided into three groups: Patients with primary sternal closure (PSC) at the end of the operation, n=97 (51.6%), patients with DCC skin closure technique (DCCs) n=45 (23.9%), and lastly, 46 (24.4%) patients with membrane patch closure technique (DCCm). The incidence of hospital infections was greater in the two groups with DCC 43.5% and 33.3% respectively, in comparison to the group with PSC (20.6%). Mortality in the DCCs group was 11.1% whereas in the DCCm patients, it was 28.2%. Nevertheless, there was no statistically significant difference between the groups as far as sternal wound complications, 4.1% PCS, 8.8 DCCs, and 4.4 DCCm. Their study showed that longer CPB times and clamping times for complex procedures, neonates, critical preoperative state, and diagnosis of TGA and IAA are factors leading to DCC. The researchers concluded that although the risk of sternal wound complication is not different, patients who need and undergo DCC, using either membrane or skin technique, have a more complicated post-CHS course than the ones with PSC. At this point, it would be useful to note that patients who necessitate DCC are by default more complex cases. In our study, the patients who underwent DCC had a more complex CHD in comparison to the patients who weren't candidates for DCC and therefore a greater rate of mortality and morbidity was expected.

Kumar *et al.* studied 1046 consecutive pediatric patients, 816 of whom were neonates (82%) who underwent CHD surgery and remained liberally with open sternum postoperatively.[5] There was a mortality rate of 4.6%. Of all obtained swabs, only 42 samples presented a pathogen. An interesting point is that of all the patients with positive culture results, only 19 (45%) developed a clinically significant SWI. 94 patients developed a postoperative infection. Clinical diagnosis of a SWI was made to 59 patients (5.9%), including 16 (1.6%) with mediastinitis and 22 with DSWI. The researchers did not find any correlation between the presence of a significant SWI and the incidence of a different type of infection. The number of days of open sternum was not associated with the development of a SWI and only demonstrated a trend toward association with any infection complication. The DCC was not correlated with adverse outcomes.

Conclusions

Although the DCC in neonates who underwent CHD surgical correction was related to a high mortality rate, only the age of neonates predicted the sternum closure time.

Study limitations

The inherent limitation of our study is that it is essentially a retrospective study with a great deal of missed data and with information and selection biases that reduce the size and power of the study. Also, the small number of patients in our study is not indicated to derive any safe conclusions and finally in the absence of a control group the ability to conclude is greatly weakened. These aforementioned factors have an impact on the study's generalizability and findings.

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