Early outcome of primary delayed sternal closure after cardiac surgery in neonates and infants

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ABSTRACT:

Background: Delayed sternal closure (DSC) commonly is used after pediatric cardiac surgery in many centers for many reasons including support of the failing myocardium and control of intractable non -surgical bleeding. There is many benefits of this technique as avoiding cardiac compression especially with the presence of myocardial edema, stabilizing postoperative critically ill patients providing easy access for exploration of patients with intractable bleeding.

Methods: After open heart surgery on children, the researchers at Mansoura University in Egypt conducted this prospective study in which they analysed the medical records of 45 patients who experienced delayed sternal closure. We reviewed the data including the Indications of DSC, perioperative hemodynamic status, postoperative infection, and mortality.

Results: Transposition of great arteries (TGA) with intact interventricular septum was the most common preoperative diagnosis (26.7%). We intended to leave the sternum opened routinely for any neonate after complex cardiac surgery, which represented the most common indication for DSC (42.2%), followed by intractable non-surgical bleeding (28.9%). The mean duration of open chest was 1.98 ± 0.87 days (1 – 5). The mean duration of ICU stay was 9.33 ± 7.01 days (4 - 43 days). The mean duration of hospital stay was 14.78 ± 9.02 days (6 - 51 days). Nine patients had deep sternal wound infection (20%). Sepsis was found in 2 patients (4.4%), and it was the cause of mortality for this two patients (33.3%) of all mortality. Duration of open chest didn't significantly influence deep sternal wound infection. Bypass time and cross clamp time was not significant risk factors for prolongation of the duration of open chest. Duration of open chest was a significant risk factor for prolonged ventilation time $p < 0.001$, prolonged ICU stay $p < 0.001$, and prolonged hospital stay $p = 0.011$. There was no statistically significant relation between sepsis and any of the following, duration of ICU stay $P = 0.559$, duration of ventilation $P = 0.865$, duration of open chest $P = 0.288$, and duration of postoperative hospital stay $P = 0.912$. The mortality rate was 13.3% (N = 6).

Conclusion: A delayed sternal closure is a strategy that is thought to be useful in the management of neonates and babies who are at risk for hemodynamic instability, respiratory instability, or persistent bleeding early on in the recovery process after open heart surgery.

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Introduction:

The therapy of newborns and babies at risk for hemodynamic instability, respiratory instability, or uncontrollable bleeding soon after open heart surgery is thought to benefit from delaying sternal closure. The implantation of extracorporeal support systems, hemodynamic instability, myocardial edoema, respiratory compromise, intractable bleeding, and persistent arrhythmias are only a few indications for this method (**Riahi et al., 1975**)-**(Gielchinsky et al., 1981**). This method has been approved for the early postoperative management of paediatric patients who are thought to be at risk of such complications due to its safety and effectiveness. After surgery, the sternum is closed, which has a compressive impact on the heart. This results in decreased ventricular compliance and filling, which lowers cardiac output and raises pulmonary venous pressure (**Shore et al., 1982**)-**(Jogi and Warner, 1985)- (Kay et al., 1989)**. Open sternotomies are thought to provide fast access to the sources of intractable bleeding in patients who are at risk. Due to the need of managing the physiological transitions from open

sternotomy to delayed sternal closure, In this study, we analysed data from a series of 45 newborns and neonates who underwent heart surgery with an open sternum and a delayed sternal closure.

MATERIALS AND METHODS:

This is a prospective study in which we reviewed the records of 45 patients, in whom we left the sternum open (DSC), after open heart surgery for congenital heart diseases at congenital cardiac surgery unit Mansoura University, Egypt from April 2021 to December 2022. Cardiac pathology of the reviewed patients is shown in **table 1**.

We found that keeping track of this information will help us evaluate delayed sternal closure in our centre. This includes the reason for DSC, the time of sternal closure, and the hemodynamic status before and after sternal closure. Other data, including mechanical ventilation duration, mean intensive care unit (ICU) and hospital stay times, mortality, wound infections.

We did primary delayed sternal closure on 45 patients younger than 1 year old from April 2021 to December 2022. Routine median sternotomy, aortic and bicaval cannulation, and then setting up cardiopulmonary bypass. Antegrade cold crystalloid cardioplegia (Custediol), with epicardial ice slush was used for myocardial protection. Drafting of the Systemic temperature was done to 28°-30°C. Hypothermic circulatory arrest was not done for any patients. Antegrade cerebral perfusion (ACP) was done for 12 patients (26.7%). Ultrafiltration was done routinely for all patients, during CPB.

Our protocol includes Leaving the sternum open for all neonates routinely after complex cardiac surgery, for infants we leave the sternum open if there is hemodynamic instability, of myocardial edema, intractable non-surgical bleeding and bulging conduits. At the end of the operation irrigation of the chest cavity was done with antibiotic solution (eg, Gentamycin and Vancomycin) and mediastinal and pleural drains were placed, peritoneal catheter was placed routinely to avoid occurrence of ascites if there is right ventricular failure, ascites can compress the renal arteries when it is sever causing renal ischemia and oliguria.

We leave the sternum open and the skin was not closed. Sterile packs was used in case of intractable non-surgical bleeding. The skin was dripped by betadine then dried, the head of the patient was extended to expose enough skin above the incision then, we covered the sternotomy incision by sterile transparent film (opsite), but before applying the opsite we used to stretch the skin to avoid wrinkling which may allow air to enter and blood to leak from the mediastinum. Also we used to do air tight application of the opsite for effective mediastinal drainage and to prevent contamination of the mediastinum. In case of patients with marked disproportion between cardiac size and mediastinal cavity due to myocardial edema or the presence of bulging conduit, we fixed a piece of bypass circuit tube or plastic syringe (strut) between the two edges of sternum to keep distance between them and avoid compressing the heart **(Fig 1)**.

Daily dressing for the open chest was done in the ICU with completely sterile precautions. Reexploration of the mediastinum was performed in the ICU for some cases due to intractable non-surgical bleeding under complete sterile condition, the opsite was reapplied in the same way as in the OR. We used Meronem and Vancomysin as antibiotic prophylaxis, then according to culture. Postoperatively, we used Fentanyl and Midazolam for sedation and Pancuronium as a muscle relaxant for decreasing tissue oxygen requirements, preventing pulmonary artery vasospasm, avoiding endotracheal tube displacement, and avoiding erosion of the heart by the sternum. Inotropic support was used to adjust the hemodynamic state of the patients (adrenaline, dopamine, dobutamine, milrinone). Diuretic therapy in the form of furosemide infusion was used to accomplish negative fluid balance and decrease the myocardial edema.

Attempting atrial of chest closure was done when hemodynamic status and respiratory parameters improved, negative fluid balance settled, accepted blood gases, good cardiac function by echocardiography, and if the generalized or flank edema resolved.

Before closure of the chest routine swab was taken from the mediastinum then, the sternal edges were approximated for at least 10 minutes, if there was no marked hemodynamic drop, the sternum was closed. Closure of the sternum was done under complete aseptic condition by interrupted simple stainless steel wires (size 1-2, according to the weight). Muscle layer was closed by 3/0 Vicryl sutures, subcutaneous tissue and skin were closed as one layer by interrupted mattress 3/0-4/0 polyprolene sutures.

Table (1): Pre-operative diagnosis in the patients

Diagnosis	Study cases N = 45	
	N	%
CCTGA, LVOTO	1	2.2
HAA	5	11.1
HLHS	6	13.3
IAA	4	8.9
LVOTO	2	4.4
PA	2	4.4
TGA	12	26.7
TGA-VSD	5	11.1
Truncus arteriosus	8	17.8

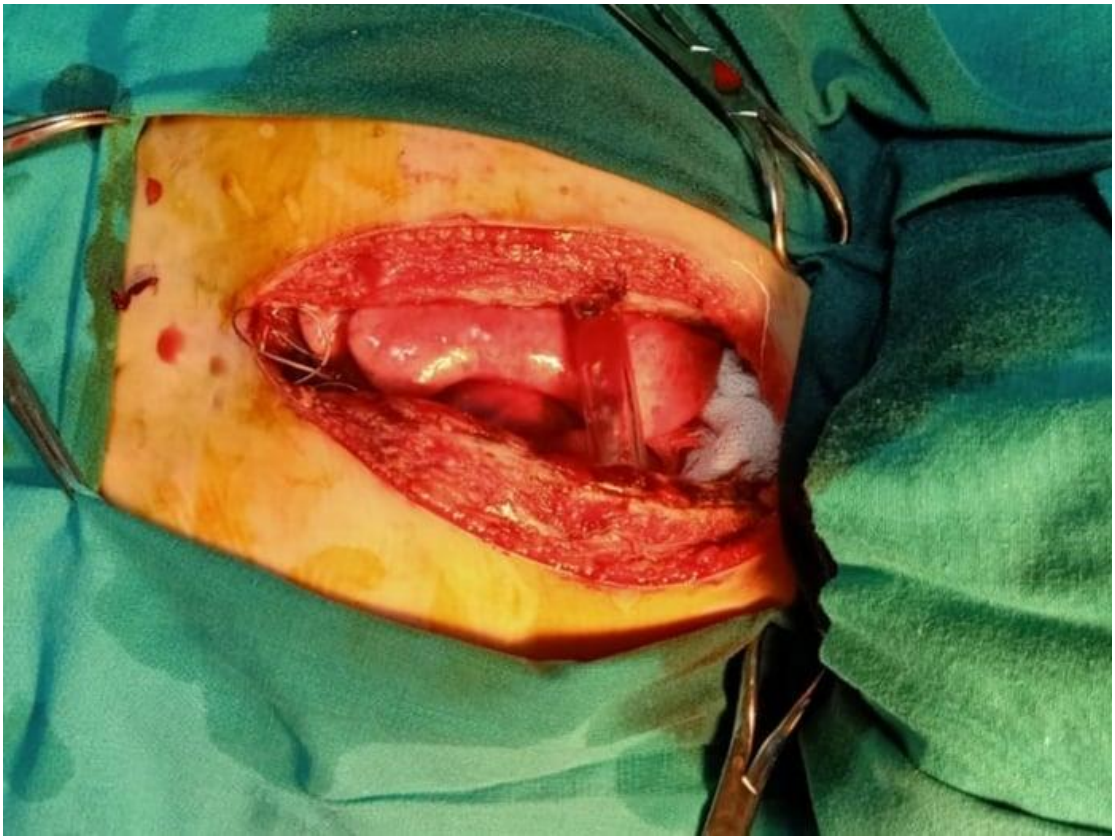

Figure 1: intra operative picture for the strut separating the two sternal edges to avoid compression on the heart.

Results:

This study includes Forty five patients less than one year of age, operated on for complex cardiac anomalies transferred to the ICU with open chest and planned for primary delayed sternal closure. The mean age for the patients was 97.2 ± 119.09 (6 - 357 days). The mean weight was 4.61 ± 2.51 (2.2 – 11.5 kg). Our study included 19 (42.2%) female and 26 (57.8%) male patients. Nineteen patients (42.2%) were neonates. History of prematurity was positive in three patients (6.7%). The most common preoperative diagnosis was TGA with intact septum (26.7%) followed by truncus arteriousus (17.8 %). The mean bypass time was 202.51 ± 67.76 minutes (63 - 381 minutes) and the mean clamp time was 144.58 ± 49.30 minutes (38 - 242 minutes). We did not use total circulatory arrest for any patient in our study. ACP was done for 12 patients (26.7). Indications for open chest in OR are summarized in **table 2**. We had to put a strut between the sternal edges for six patients (13.3%) to avoid compressing the edematous heart by the sternal edges. We did peritoneal dialysis was for 1 patient (2.2%) for managing postoperative renal failure. There were two patients (4.4%) acquired chest infection in the ICU, but after broad spectrum antibiotics and chest physiotherapy improvement of the chest condition happened. Inotropic drug infusion such as (adrenaline, dopamine, dobutamine, milrinone) was used for all patients to improve the hemodynamic state. Furosemide infusion was used for 32 patients (71.1%) to accomplish negative fluid balance and decrease generalized and myocardial edema before closure of the chest. Re-exploration of the mediastinum for intractable bleeding was done for 8 patients (17.8%). The mean duration of open chest was 1.98 ± 0.87 days (1 - 5 days). Failure of chest closure did not happen for any patient. The mean period of mechanical ventilation was 4.84 ± 4.52 days (2 - 28 days). The mean duration of ICU stay was 9.33 ± 7.01 (4 - 43 days) and mean duration of hospital stay was 14.78 ± 9.02 (6 - 51 days). Sepsis was found in 2 patients (4.4%) one patient was positive blood culture for klebsiella pneumonia and the other was methicillin resistant staph aureus (MRSA).

Nine patients required prolonged antibiotic use due to deep sternal wound infection (20%), but after surgical debridement and wound care wound healing occur. Mediastinitis did not occur in any patient after closure of the chest. We had 6 cases (13.3%) of mortality, with variable causes of death illustrated in **Table 3**.

According to the statistical analysis, there was significant drop of the mean arterial blood pressure (mean BP) of the patients after closure of the sternum as in our study we measured the mean BP and the central venous pressure (CVP) for all patients immediately before and after closure of the sternum, the mean of BP before closure was 64.04 ± 6.23 mmHg and after closure was 59.67 ± 6.04 mmHg ($P < 0.001$). Also there was a significant rise in the CVP immediately after closure of the sternum, mean CVP immediately before closure was 10.91 ± 2.02 cm H2 and immediately after closure was 13.33 ± 1.85 cm H2O ($P < 0.001$).

In our study we found that cardiopulmonary bypass time and cross clamp time didn't affect the duration of open chest significantly, $p= 0.331$ and $p= 0.092$ respectivley. Duration of open chest was a significant risk factor for prolonged ventilation time $p < 0.001$, prolonged ICU stay $p < 0.001$, and prolonged hospital stay $p = 0.011$ **(figure 2)**.

We found that re-exploration of the mediastinum in the ICU for intractable bleeding didn't significantly affect the duration of open chest ($P = 0.445$). Duration of open chest didn't significantly affect deep sternal wound infection ($P = 0.867$).

There was no statistically significant relation between sepsis and any of the following, duration of ICU stay $P = 0.559$, duration of ventilation $P = 0.865$, duration of open chest $P = 0.288$, and duration of postoperative hospital stay $P = 0.912$.

Table (2): Indications of DSC for the patients of the study

Indications of Open chest primary	Study cases N = 45	
	N	%
Bleeding	13	28.9
Bulging conduit	2	4.4
Myocardial edema	11	24.4
Neonate	19	42.2

Table (3): Number and causes of mortality

Mortality	**Study cases N = 45**	
Mortality	**N**	**%**
No	39	86.7
Yes	6	13.3
Cause of death (N= 6)	**N**	**%**
Heart Failure	1	**16.7**
Lung injury	1	**16.7**
Aspiration	1	**16.7**
Sepsis and multiorgan failure	2	**33.3**
Shunt thrombosis	1	**16.7**

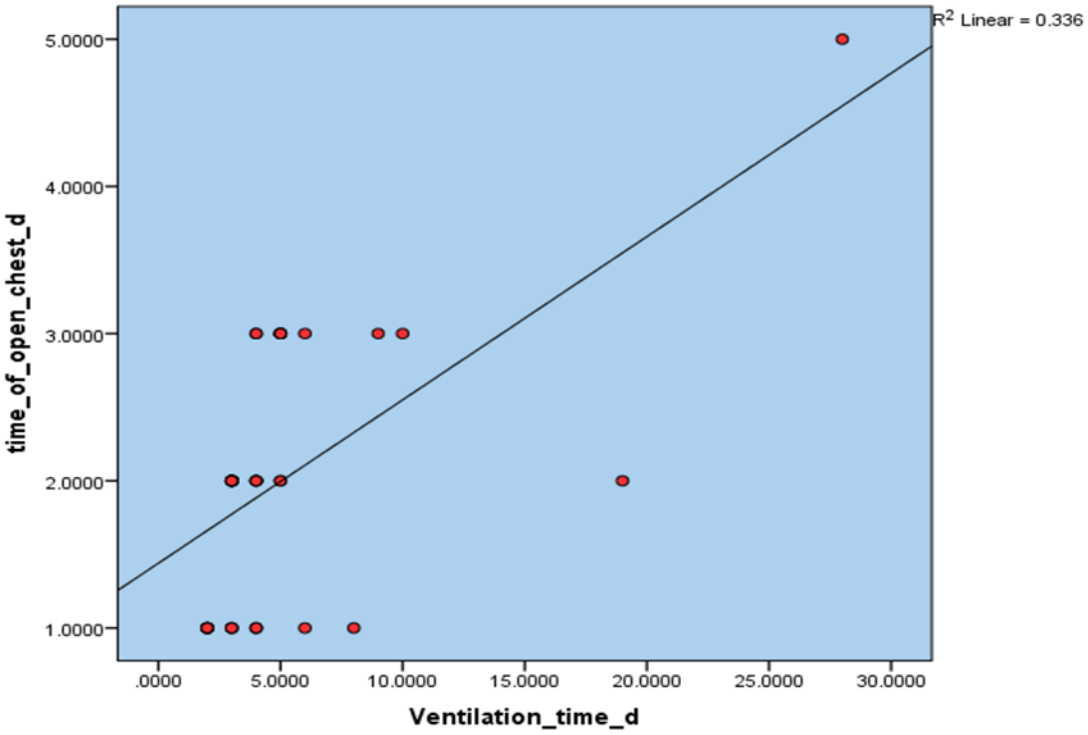

Figure (2a): Correlation between duration of open chest and ventilation time

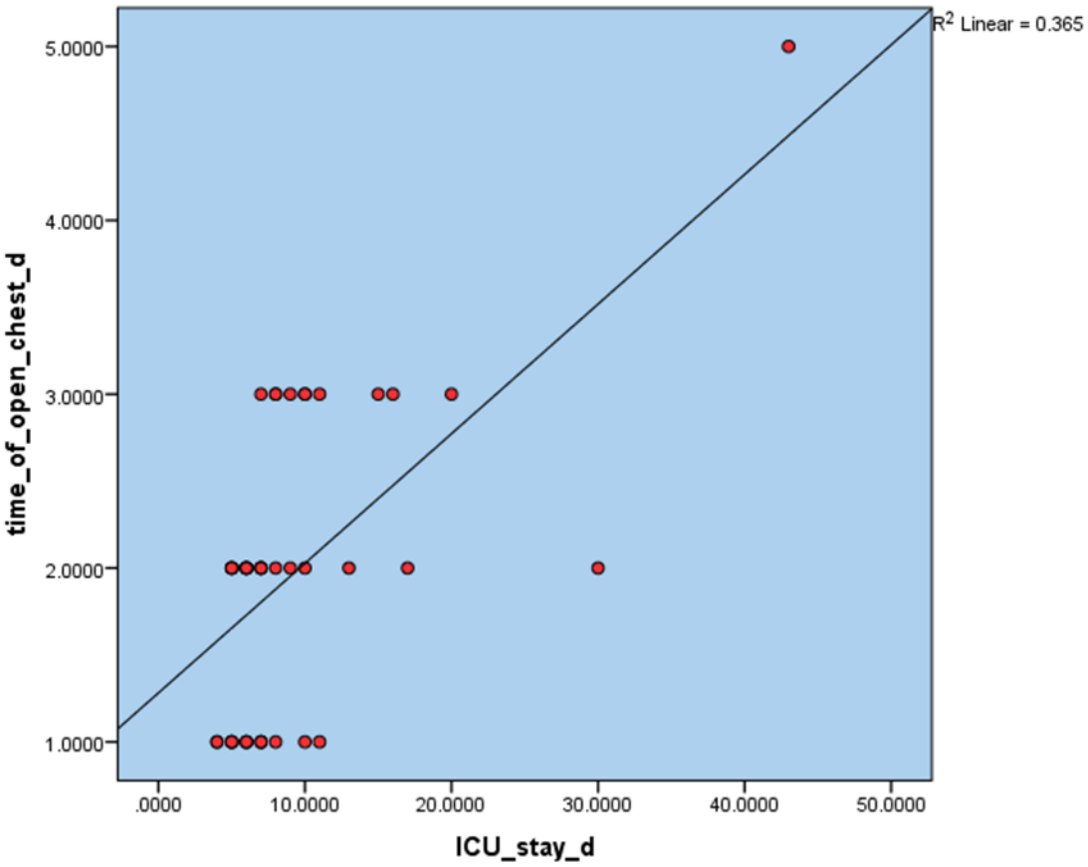

Figure (2b): Correlation between duration of open chest and ICU stay

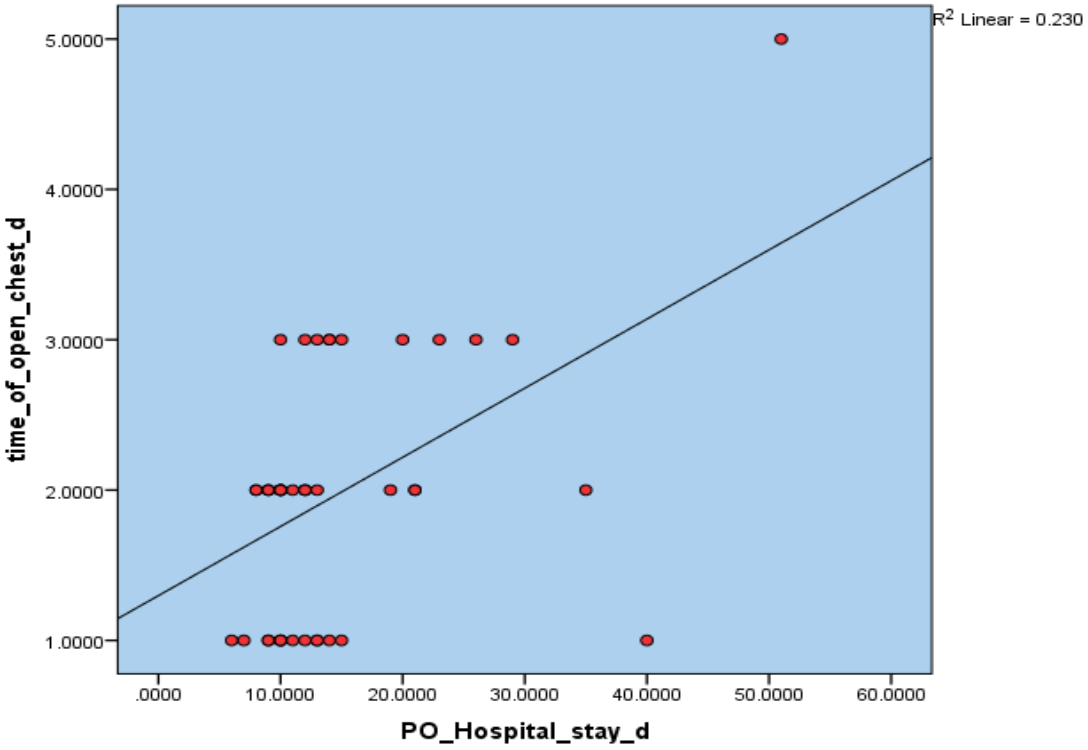

Figure (2c): Correlation between duration of open chest and PO hospital stay

DISCUSSION:

Disproportion between the cardiac size and the mediastinal cavity after cardiac surgery was first described by Riahi and colleagues in 1975 **[Riahi et al., 1975]**. Capillary leak syndrome is the transudation of the plasma content to the third space including the myocardium causing myocardial edema. After open heart surgery in infants capillary leak increases by increasing the duration of cardiopulmonary bypass and poor myocardial protection. Bleeding, arrhythmias, ventricular dysfunction and myocardial edema increase the cardiomediastinal disproportion **(Schaper et al., 1982)**.

When the sternum closes, the central vein pressure goes up, but the mean arterial pressure and cardiac output go down. After the sternum is closed, there is less blood in the heart. Because of the higher pressure outside the heart, which lowers ventricular filling, echocardiography shows that the left ventricular end-diastolic dimensions are smaller after sternal closure, which lowers cardiac output **(Jögi and Werner., 1985)**.

Using pericardial catheters to assess the rise in pericardial pressure directly following congenital heart procedures, Kay and associates investigated the impact of sternal closure on postoperative hemodynamics. They discovered that during difficult surgeries like truncus arteriosus repair or transventricular repair of tetralogy of Fallot, the pericardial pressure increased noticeably after sternal closure **(Kay et al., 1989)**.

Nowadays many centers commonly use DSC in their protocol for its beneficial effect on the hemodynamic state of the patients, Furnary and associates proved that, reopening of the sternotomy incision has been shown to improve Low cardiac output, the cardiac index increased by 59% and the systemic blood pressure increased by 18% when the sternal incision was closed, they also proved that, children will have more benefits from DSC than adults due to larger cardiac size relative to the small thoracic cavity **(Furnary et al., 1992)**.

Currently some pediatric cardiac surgery programs electively leave the sternum open in the operating room when the patient had marginal hemodynamic state. Other pediatric institutions routinely leave the sternum open prophylactically after long cardiopulmonary bypass time and after specific operations as stage 1 Norwood operation for hypo plastic left heart syndrome **(Long et al., 2005)**. Our protocol is to leave the sternum open routinely for all neonates after complex cardiac surgery as a prophylaxis against hemodynamic compromise, for infants above 1 month of age, we decide to leave the sternum open electively in the OR if the surgeon noticed massive myocardial edema, hemodynamic instability, bulging conduit, and intractable non-surgical bleeding.

The most common pre-operative diagnosis reported in the study of **(Riphagen et al., 2005)**, was TGA and hypo plastic left heat syndrome, and in the study of **(Elassal et al., 2019)** was TGA. In our study the most common preoperative diagnosis was TGA with intact septum (26.7%) of all cases followed by truncus arteriousus (17.8%). Some studies limit their research about DSC for certain pathologies as the study of **(Das et al., 2011)**, which is concerned about DSC only for hypo plastic left heart syndrome patients.

The indications for DSC are variable, including myocardial edema, hemodynamic instability, bulging conduits, extra corporeal support devices, and intractable non-surgical bleeding. Bleeding and hemodynamic instability are the most common indications for DSC in the study of **(Elassal et al., 2019)**, representing 38.8% and 34.7% respectively. In our study, we routinely leave the sternum open for all neonates after complex cardiac surgery as a prophylaxis against cardiac compression even if myocardial edema was not noticed by the surgeon, as we found better results in neonates by doing that especially with the absence of ECMO in our center, it represent the most common indication (42.2%), followed by intractable non-surgical bleeding (28.9%).

We tried to be accurate and precised while doing surgery for the patients of the study, with meticulous handling of the myocardial tissue to decrease myocardial edema and avoid prolonged bypass and cross clamp time, mean bypass time was 202.51 ± 67.76 minutes (63 - 381 minutes) and the mean clamp time was 144.58 ± 49.30 minutes (38 - 242 minutes). Also we considered the use of antiinflammatory drugs (steroids) before bypass, and using ultrafiltration routinely during bypass due to their cardioprotective and antiinflammatory effect decreasing myocardial edema post bypass. Riphagen and associates stated that using steroids before bypass, modified ultrafiltration during bypass, and administration of phosphodiesterase inhibitors early post-operative, helped a lot in decreasing the incidence and attenuating the severity of low cardiac output syndrome in the post-operative period, and made early sternal closure easy **(Riphagen et al., 2005)**.

We decided to place a peritoneal drainage catheter in the abdomen routinely for all patients of the study, we thought the catheter will be useful to

drain peritoneal fluid if it was excessive due to right sided heart failure, also peritoneal dialysis could be done through it if needed. We needed peritoneal dialysis for only one patient with renal failure (2.2%). Iyer and his colleagues reasoned that a peritoneal catheter would be helpful for lowering right atrial filling pressures and, in turn, blood pressure **(Iyer et al., 1997)**.

Sometimes even with leaving the sternum open, the two sternal edges were close to each other especially in the presence of severe myocardial edema, in this case we decided to fix a stent (strut) between the two sternal edges separating them from each other and decreasing the friction and shearing force between the heart and sternal edges. We made the strut by cutting part from the bypass circuit and fixed it to the sternal edges by sutures. We needed to make struts for six patients (13.3%) in our study. Struts had been used in in multiple studies **(Matsumoto et al., 1980**) and **(Iyer et al., 1997)**. Polyvinyl chloride tube stents, like those employed by Iyer and colleagues, are easily sourced from the bypass circuit's standard 14-inch and 38-inch tubes.

Variable techniques used to cover the sternotomy incision during the period of open sternum, these techniques differ between pediatric cardiac surgery centers. Direct closure of the skin leaving the sternum open, sewing a latex membrane (Esmark Bandage) to the edges of the skin, or using VAC treatment was reported in the study of **(Fleck et al., 2008)**, in the study of **(Ozker et al., 2012)**, they used transparent nylon serum bag for covering the incision. In our center we used transparent sterile film (opsite), it was easy to use, gave us the opportunity to monitor the mediastinum for bleeding or clot formation as it is transparent, and made it easy during re-exploration in the ICU. Finally the wound was isolated from the atmosphere preventing mediastinal contamination. We kept chest drain suction minimal to avoid sucking the opsite on to the heart causing compression and tamponade like effect.

Maintenance of open sternum in the ICU is very important to achieve best hemodynamics and lower the incidence of mediastinitis and surgical site infection. The optimal time for sternal closure is debatable between different centers, because the decision to close the sternum usually made by personally based criteria, so it is markedly subjective decision. Some surgeons leave the sternum open for at least 3 days, and then the decision to close the sternum was taken any time from 2 to 14 days post-operative **(Long et al., 2005)**. Other surgeons applied aggressive approach for DSC, they aimed to close the sternum within 24 hours **(Estrera et al., 2008)**, claiming that the earlier the chest closure, the less incidence of mediastinitis and surgical site infection. Nelson and associates stated that DSC should be used judiciously aiming to achieve sternal closure in the first few days after surgery, as soon as the hemodynamic state of the patients permits, they also noticed that, there was a considerable risk of infection associated with keeping the sternum open for few days, they proved that there was small day to day increments in the risk of infection **(Nelson-McMillan et al., 2016)**.

In our study we didn't have strict criteria for closure of the chest, we considered closure of the sternum when the patient had better hemodynamic state, decreased myocardial edema, negative fluid balance, fair arterial blood gases, good cardiac function by echocardiography, and improvement of coagulopathy and intractable bleeding. The mean duration of open chest was 1.98 ± 0.87 days (1 - 5 days). Our protocol for the sternal closure time goes with the study of Schaper and associates, which stated that, the toleration for closing the sternum was associated with steady diuresis and negative fluid balance, reduced cardiac size and chest wall and flank edema, and return near the preoperative weight **(Schaper et al., 1982)**. The majority of studies proved that negative fluid balance was a major prerequisite for determination of sternal closure time **(Alexi et al., 1995) (Tabbutt et al., 1997)**. Riphagen and associates tried to avoid excessive edema formation by avoiding prolonged neuromuscular blocking, fluid restriction, and judicious volume replacement **(Riphagen et al., 2005)**.

In the study of Ozker et al, they proved that, the longer the duration of bypass time and cross clamp time, the longer the sternal closure time **(Ozker et al., 2012)**. This didn't go with our study, as we didn't find a statistically significant relation between the bypass time and cross clamp time and the sternal closure time p= 0.331 and p= 0.092 respectivley.

All patients of the study underwent sternal closure in the ICU under strict sterile circumstances with all the surgical team present, using portable lights resembling a mini-OR. At first approximation of the two sternal edges was done for ten minutes watching the blood pressure and oxygen saturation, if there was no significant drop of both, continuation of the process of sternal closure was done. For sternum closure, we employed interrupted simple stainless steel wires (size 1-2, depending on weight), muscle layer 3/0 Vicryl sutures, subcutaneous tissue and skin as one layer by interrupted mattress 3/0-4/0 polyprolene sutures.

Alexi and his colleagues used absorbable sutures (Vicryl) to close the sternum for all patients, and also used Gore-Tex surgical membrane in 70% of patients to cover the heart before closure of the sternum, they found that it didn't increase the risk of deep wound infection **(Alexi et al., 1995)**.

Careful monitoring of the hemodynamic state of the patient during and after sternal closure is very important as changes in the hemodynamic state are very common at the time of sternal closure. In the study of McElhinney and his colleagues, they stated that, after closure of the sternum there was significant increase in the central venous pressure, but the mean blood pressure didn't decrease significantly, according to them the explanation for that was this, the heart had recovered from bypass for few days and myocardial edema was decreased so, it was able to withstand and compensate sternal compression without drop in the systemic blood pressure, After 2-3 days of bypass recovery, the hearts have regained some coronary reserve, thus the drop in coronary blood supply after sternal closure is less likely to produce myocardial ischemia **(McElhinney et al., 2000)**. McElhinney and his colleagues tried also to keep fair hemodynamic state during sternal closure by increasing the inotropic support just before sternal closure and administration of albumin or packed red blood cells to augment cardiac output.

In our study we believed that sternal closure will inevitably affect the systemic blood pressure and central venous pressure, so we thought that by DSC we can decrease the impact of sternal closure on the hemodynamic state as the myocardial and chest wall edema will be decreased by time before closure of the chest. After statistical analysis we found that, there was significant drop of the mean arterial blood pressure (mean BP) of the patients after closure of the sternum as in our study we measured the mean BP and the central venous pressure (CVP) for all patients immediately before and after closure of the sternum, the mean of BP before closure was 64.04 ± 6.23 mmHg and after closure was 59.67 ± 6.04 mmHg ($P < 0.001$). Also there was a significant rise in the CVP immediately after closure of the sternum, mean CVP immediately before closure was 10.91 ± 2.02 cm H2 and immediately after closure was 13.33 ± 1.85 cm H2O ($P < 0.001$).

We thought that if the sternum closed early in the OR and this drop in blood pressure would be far more than that due to the presence of marked myocardial edema or hemodynamic instability early post-operative. In our study no reported cases with failure of sternal closure, we thought that, close monitoring of the patients and accurate timing of sternal closure is very important.

Before we close the sternum in the ICU, routine mediastinal swap was taken for all patients. We tried to make sure that, the rate of mediastinitis will not increase in patients of DSC and if mediastinitis occurred, a culture from the mediastinal fluid would be very helpful in determination of the antibiotic therapy. The surveillance culture was positive in only 5 patients (11.1%), the most common organism was coagulase negative Staphylococcus in 4 patients (80%), followed by Staphylococcus Aureus in 1 patient (20%). Surprisingly no mediastinitis reported in our study, we thought early administration of culture based antibiotics and good sterilization during sternal closure helped a lot in decreasing the rate of mediastinitis and septicemia. Among a multicenter analysis of 8,774 patients, Woodward and colleagues found 1.53% mediastinitis rates in DSC patients **(Woodward et al., 2011)**.

In our study 9 patients had surgical site infection (20%), only 3 (33.3%) of them had positive surveillance mediastinal cultures, and it was the same organism in the mediastinal and wound culture: coagulase negative Staphylococcus. Other studies for DSC showed lower incidences for deep sternal wound infection, 6.7 % in the study of Tabbutt and his colleagues **(Tabbutt et al., 1997)**, 11% in the study of Harder and associates **(Harder et al., 2013)**, and 2.7% in the study of Elassal and his colleagues **(Elassal, et al., 2019)**. We thought we had a higher incidence of surgical site infection 20%, but by surgical debridement of the wound and antibiotic management, healing occurred and all patients of the study with SSI had improved without sepsis or mediastinitis.

Re-exploration of the mediastinum for intractable bleeding was done for 8 patients (17.8%), we found that re-exploration of the mediastinum in the ICU didn't significantly influence the duration of open chest ($P = 0.445$). In our study we were concerned about the association between sternal closure time (SCT) and SSI. The mean duration of open chest was 1.98 ± 0.87 days (1 - 5 days), we found that, SCT didn't significantly influence the rate of SSI ($P = 0.867$). This confirms the results of multiple studies **(Woodward et al., 2011)**, **(Elassal, et al., 2019)**, **(Erek et al., 2012)**, and **(Tabbutt et al., 1997)**. Other studies reported increased risk of SSI with a longer duration of open chest as, **(Nelson - McMillan et al., 2016)**, **(Anderson et al., 2002)**, and **(Furnary et al., 1992)**.

Ozker and his colleagues observed that prolonged SCT was associated with elevated rates of SSI. They hypothesised that infants with DSC were

critically unwell for various causes, which may cause prolonged ICU stay, which was also a substantial risk factor for SSI in their study **(Ozker et al., 2012)**. Some studies compared SSI for patients with DSC and patients with primary sternal closure (PSC), Kagen et al **(Kagen et al., 2007)**, and Allpress et al **(Allpress et al., 2004)** found that DSC was not associated with increased risk of SSI. On the other hand, Abou Elella and his colleagues reported that, DSC was a significant risk factor for SSI **(Abou Elella et al., 2010)**.

We were convinced by the study of Harder et al which stated that, repeated DSC far more influenced the rate of SSI rather than prolonged duration of open chest **(Harder et al., 2013)**, which made us didn't rush for early closure of the sternum until we made sure that the hemodynamic state was good, and any reason for DSC had been resolved, but this came on the expense of ventilation time, ICU stay duration, and hospital stay duration as we found that, duration of open chest was a significant risk factor for prolonged ventilation time $p < 0.001$, prolonged ICU stay $p < 0.001$, and prolonged hospital stay $p = 0.011$.

Tabbutt and his colleagues stated that, potential risks of DSC are variable such as: mediastinitis, sepsis, bleeding, and sternal instability. For them the infectious complications are a well known contributors in the morbidity and mortality after pediatric cardiac surgery. They believed that, the patients with DSC had increased risk of infectious complications because they had precipitating factors such as: low cardiac output, the need for frequent mediastinal explorations, massive blood product transfusion, and prolonged bypass time **(Tabbutt et al., 1997)**. Nelson and associates analyzed the infection rate in 100 pediatric cardiac surgery centers and found that, infection rate was 18.7 % in DSC group compared with 6.6% in patients with closed chest in the same age and procedural group **(Nelson-McMillan et al., 2016)**. In our study, sepsis was found in 2 patients (4.4%) and the 2 patients died from sepsis one patient was positive blood culture for klebsiella pneumonia and the other was methicillin resistant staph aureus (MRSA). We tried to analyze the relation between sepsis and multiple variables we found that, the rate of sepsis didn't significantly influenced by the following: duration of ICU stay $P = 0.559$, duration of ventilation $P = 0.865$, duration of open chest $P = 0.288$, and duration of postoperative hospital stay $P = 0.912$. Elassal and his colleagues reported sepsis in 54.1% of the patients with DSC and the most common organism isolated from the blood cultures was Gram negative, for them the duration of ICU stay was a significant risk factor for sepsis **(Elassal et al., 2019)** , our results didn't go with this study. We also had different results than the study of Johnson et al which reviewed patients with hypoplastic left heart syndrome operated for stage 1 palliation in 45 centers, and underwent DSC, this study revealed that the longer the ICU stay, the higher the infection rate **(Johnson et al., 2010)**.

Mortality rate in our study was 13.3% (6 patients), causes of mortality is shown in table 3, this result is comparable to the study of Elassal et al, in their study mortality rate was 15.2% (ECMO used in 5 patients and not used in 6 patients) **(Elassal et al., 2019)**. Unfortunately we don't have ECMO in our center which is a major cause for us to encourage DSC protocol in neonates and infants till hemodynamic stability occur. Other studies reported slightly higher mortality rates, Özker et al reported 22% **(Özker et al., 2012)**, Hurtado et al reported 34.2% **(Hurtado et al., 2018)**.

Conclusion:

DSC remains a very important practice for management of neonates and infants with hemodynamic instability, myocardial edema, and coagulopathy after open heart surgery. It is proved to be useful for the patients of the study especially in the absence of ECMO

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