Indian Journal of Thoracic and Cardiovascular Surgery (October–December 2019) 35(4):530–538
https://doi.org/10.1007/s12055-019-00830-1

ORIGINAL ARTICLE

Elective delayed sternal closure portends better outcomes in congenital heart surgery: a retrospective observational study

Simran Kundan[1] · Kamlesh Tailor[2] · Hari Bipin Radhakrishnan[1] · Smruti Ranjan Mohanty[1] · Keyur Bhavsar[2] · Shankar Kadam[2] · Preetha Joshi[3] · Vinay Joshi[3] · Tanuja Karande[4] · Prashant Bobhate[4] · Snehal Kulkarni[4] · Suresh Gururaja Rao[1]

Received: 21 October 2018 / Revised: 7 March 2019 / Accepted: 2 May 2019 / Published online: 19 July 2019

Abstract

Introduction Delayed sternal closure is used in paediatric cardiac surgery as a management strategy for patients with unstable hemodynamics or postoperative bleeding routinely. We hypothesise that planned postponement of sternal closure leads to better outcomes than emergent reopening in the intensive care unit (ICU) in patients exhibiting some hemodynamic indication for the same.

Methods We retrospectively analysed the outcomes of delayed sternal closure 220/2111 (10.42%) out of which 14 sternums were opened in the ICU after shifting the patients.

Results A total of 220/2111 (10.42%) sternums were left open postoperatively, out of which 14 were opened after shifting to the ICU. Total mortality of the delayed sternal closure was 33/220, i.e. 15%. The patients whose sternums were left open from the theatre had a mortality of 23/206, i.e. 11.16%, whereas those patients whose sternums were opened in the ICU had a mortality of 10/14, i.e. 71.42%.

Conclusion In doubtful postoperatively hemodynamic, the choice of leaving the sternum open electively has better outcomes, rather than opening the sternum as a terminal bail out procedure.

Keywords Delayed sternal closure · Cardiac surgery · Hemodynamics

Introduction

The concept of leaving the sternum open was introduced by Riahi et al. [1]. Though first described for adult patients, the practice of leaving the sternum open electively is more common in paediatric and neonatal patients. The indications for leaving the sternum open vary among centres and among individual surgeons as well. Some leave the sternum open routinely for complex cases, others leave it open for lesion specific indications, and yet others will leave the sternum open empirically for all neonates [2, 3]. Here, we report our institute's experience of leaving the sternum open in the paediatric population undergoing complex cardiac surgery.

Aim and objective

There is universal consensus on the efficacy of leaving the sternum open in paediatric population as a management strategy after complex procedures. There is enough data on the pros and cons of leaving the sternum open in sick babies; hitherto, there have been no studies or reports on outcomes of patients in the subgroup of patients among those who have the sternum left open as a choice, compared to those in whom the sternum had to be reopened after hemodynamic compromise.

Methods

We retrospectively analysed our database from January 2010 to December 2014; all paediatric cardiac surgical patients

✉ Simran Kundan
simrankundan@yahoo.com

[1] Pediatric and Congenital Heart Surgery, Kokilaben Dhirubai Ambani Hospital, Mumbai, India

[2] Pediatric Cardiac Anesthesiologist and Intensivist, Kokilaben Dhirubai Ambani Hospital, Mumbai, India

[3] Pediatric and Neonatal Intensivist, Kokilaben Dhirubai Ambani Hospital, Mumbai, India

[4] Pediatric Cardiologist, Kokilaben Dhirubai Ambani Hospital, Mumbai, India

Table 1 Distribution according to heart defect and associated mortality

Index surgery	Total cases	Total number whose sternum remained closed (A2-1)	Mortality of closed sternum	Total number whose sternum was left open from theatre (B)	Mortality of open sternum cases	Sternum opened in the ICU (A2-2)	Mortality of the patients whose sternum was opened in the ICU
ASO	225	171	8	53	2	1	1
TAPVC	120	69	6	48	8	3	1
Aortic arch repair	86	59	2	25	3	2	2
TOF-ICR	432	404	12	23	6	5	3
Norwood's stage I	11	NA	NA	11	5	0	0
ALCAPA	24	18	1	6	0	0	0
Shunt surgery	34	28	9	4	2	2	2
VSD closure	660	654	2	6	0	0	0
Fontan completion	46	44	1	2	1	0	0
AP window	14	9	0	5	1	0	0
Truncus arteriosus repair	6	2	1	4	0	0	0
Double switch	8	5	1	3	1	0	0
RPA implantation	6	4	0	2	0	0	0
DKS	4	3	1	1	1	0	0
PDA with pneumonectomy	1	0	NA	1	1	0	0
BDGS	76	74	1	2	0	0	0
AV canal repair	31	30	0	1	0	0	0
Bentall procedure	4	3	0	1	0	0	0
PA BANDING single ventricle	12	5	1	6	2	1	1
PA BANDING for biventricular repair	5	3	0	2	0	0	0
Others	306	306 (A1)	NA	NA	NA	NA	NA
Total	2111	1891	46	206	33	14	10

ASO arterial switch operation, *TAPVC* total anomalous pulmonary venous connection, *TOF-ICR* tetralogy of Fallot-intra cardiac repair, *ALCAPA* anomalous left coronary artery origin from pulmonary artery, *VSD* ventricular septal defect, *AP* aorto pulmonary window, *RPA* right pulmonary artery, *DKS* Damus Kaye Stansel, *PDA* patent ductus arteriosus, *BDGS* bidirectional Glenn shunt, *AV* atrio-ventricular canal, *PA* pulmonary artery

whose sternums were kept open at some point in time after an open-heart procedure were included (Tables 1 and 2). All the patients were operated and managed by the same team of surgeons, anaesthesiologist and intensivists.

For the purpose of classification (Chart 1), we have classified the cases into group A, i.e. total number of case received in the ICU with the sternum closed. Group A was further divided into A1, i.e. cohort of simpler cases, e.g. patent ductus arteriosus' (PDAs), atrial septal defect's (ASDs), partial anomalous pulmonary venous connection's (PAPVCs) and valve repairs, in whom the sternum was never left open in any case; and A2, i.e. cohort of index cases, who came to the ICU with their sternums closed. Group A2 was further subdivided into group A2-1, i.e. index cases who came to the ICU with their sternums closed and remained closed, and group A2-2, i.e. cohort of index cases who came to the ICU with the sternum closed and were later reopened when the hemodynamics deteriorated, and group B, i.e. patients who had their sternums left open from the theatre.

Table 2 Distribution according to age

< 1 month	123	55.9%
1 month–3 month	31	14.1%
3 month–1 year	39	17.7%
1 year	27	12.3%

Consent

The study was put up to the Institutes Ethics Committee and they waived the need for consent.

Patient selection

Our unit's surgical database was queried for all patients who underwent an open-heart procedure and were shifted to the ICU with their sternums open or reopened during some point in time after the primary closure. Any patient who underwent a thoracotomy procedure was excluded.

Chart review

All the patients included in the study had the data extracted from the Medical Records Department. The primary end point was mortality from all causes. Secondary end points included mediastinitis, blood stream infection, ventilatory-associated pneumonia, ICU and hospital stay. Analysis included reason for leaving or reopening the sternum.

Statistical methods

The numeric data were summarised by descriptive statistics like *N*, mean, standard deviation, median, minimum and maximum. For statistical significance of numeric data, *t* tests were

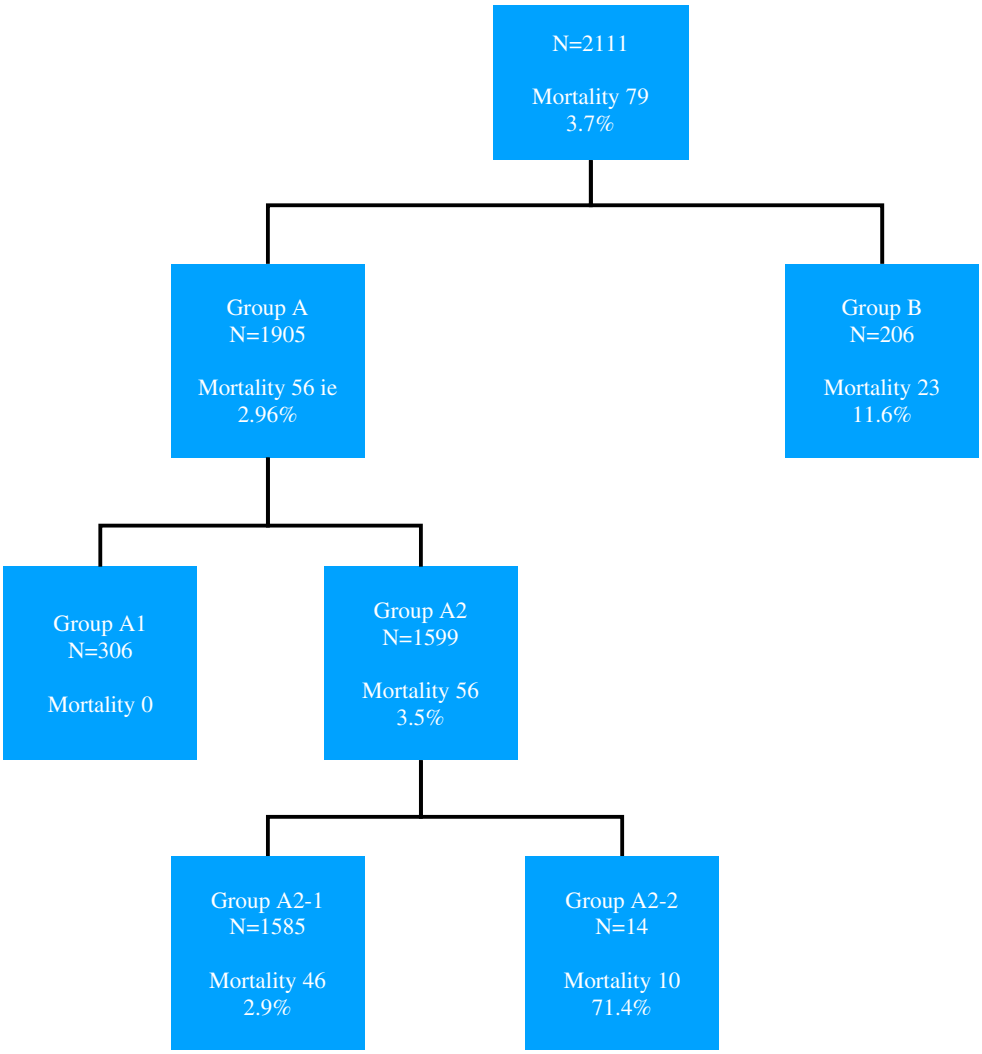

Chart 1 Classification of groups. Group A, total number of patients received in the ICU with closed sternum. Group A1, cohort of simple cases, in whom no sternums were left open. Group A2, cohort of total index cases, who came to the ICU with the sternum closed. Group A2-1, cohort of index cases, who came to the ICU with sternum closed and remained closed. Group A2-2, cohort of index cases, who came to the ICU with the sternums closed and were later opened. Group B, cohort of index cases, who had their sternums left open from the theatre

used. The categorical data were summarised by frequency count and significance was analysed using chi-square/fisher exact test. A value of $p < 0.05$ was considered significant.

Indications for leaving the sternum open

In certain patients, the diagnosis itself entails leaving the sternum open and the parents are counselled likewise, e.g. obstructed infra-cardiac total anomalous pulmonary venous connection's (TAPVCs), neonatal arterial switch operation (ASO), interrupted aortic arches. In neonates with poor pre-operative status, we tend to leave the sternum open in majority of such patients. Other indications may include situations in which the pump time and clamp time have been prolonged, leading to tissue oedema involving the heart and lungs, ventricular dysfunction, medical bleed and palliative surgeries which might have a hemodynamically unstable postoperative course requiring high inotropic support, situations in which there was a space constraint, e.g. conduit placement or in patients with central extra corporeal membrane oxygenation (ECMO) (Table 3).

Indications of opening the sternum in the ICU included cardiac arrest; low cardiac output syndrome (LCOS) not responding to medical manoeuvres, especially those involving right ventricle (RV) diastolic dysfunction; bleeding; and arrhythmias.

Technique of leaving the sternum open

If it is decided to keep the sternum open and close the skin, we close it in a continuous fashion using non-absorbable monofilament suture. If it is decided to stent the sternum, we use a soft plastic covering of an umbilical catheter as a stent so that it does not erode into the fragile neonatal sternum; and in an older child, we use a 1/4-in. tubing cut to size. Both are easily available in the theatre. The size and position of the stent is determined as per the case involved, to keep as much of the sternum off the myocardium. This construct is covered with a lenticular shaped patch, cut from the collapsible intravenous infusion bag, sutured to the skin edge using 5-0 polypropylene. The plastic patch is sutured in

Table 3 Reason for leaving the sternum open

Indication for leaving the sternum open	*N*	Percentage (%)	Mortality
Hemodynamic instability	100	45.5	21
Bleeding	110	50	10
Central ECMO	10	4.5	2

ECMO extracorporeal membrane oxygenation

such a way so that it overrides the skin edge by about 2–3 mm. The suturing is tensionless so that the chance of ischemia to the skin edge is minimum. The principles to patch follow the fundamentals of patching with wide-spaced bites on the skin and closer bites on the patch to fit the patch without tension and prevent dog earring, which happens often and results in a portal for exit of tissue fluid and influx of microorganisms. Once the patch is complete, the skin plastic interface is covered with iodine impregnated membrane or Tegaderm® with minimal extent onto the skin but yet to get a water tight seal. The rationale to keep the occlusive dressing patch to the minimum is that later when the child is taken for sternal closure, a smaller membrane minimises the denudation of delicate epithelium which reduces gross scarring. In cases when the indication is for hemodynamic instability and haemostasis is not a concern, we simply cover the incision and the skin with a patch of Tegaderm® and maintain a water-tight seal around the incision.

For the patients whose sternums were left open from the theatre, we leave the purse strings cinched in hemoclips for those patients in whom we anticipate hemodynamic instability. This technique helps to expedite institution of bypass or ECMO if needed.

Closing the sternum

As a policy, we close all the sternums in the theatre. Once the patient has settled down from a hemodynamic point of view, a decision to close the sternum is taken, assessing tissue perfusion and adequate urine output, blood gas, space in the mediastinum, appearance and compliance of the lungs, airway pressures and absence of any significant arrhythmias. A stringent checklist is adhered to while taking these patients for closures. Monitoring includes heart rate, blood pressure, arteriogram trace, right- and-left sided filling pressures, airway pressures, saturations, blood gases, urine output and a pre- and postclosure 2D ECHO.

Table 4 ICU and hospital stay

	PSC	Open sternum	*p*
Average ventilation	33.4	96.3	< 0.0001
ICU stay	4.8 days	8.9 days	< 0.0007
Hospital stay	12.6 days	18.8 days	NS

After closure, the patient is monitored closely for the same flag signs. In case of any deviation from normal convalescence and the achieved hemodynamic stability, serious thought is given to reopening the sternum if the reason for such deviation cannot be delineated and cannot be corrected.

Usually, after closure, it is observed that mean arterial pressure reduces and after a short period of time the peripheral perfusion improves as the child gradually adjusts to the new circulation. The airway pressure increases marginally and so do the central venous and left atrial pressures [4], which settle down over time.

Results

The patients whose sternums were left open were ventilated for an average of 96.3 h as compared to 33.4 h for patients whose sternums were closed primarily ($p < 0.0001$). The patients who underwent a delayed sternal closure stayed in the ICU for 8.9 days on an average compared to 4.8 days for the patient whose sternum was primarily closed ($p < 0.0007$). The average hospital stay was 12.6 days for children whose sternums were closed primarily compared to 18.8 days for children whose sternums were kept open (*p* value not significant) (Table 4). The incidence of respiratory sepsis was not significantly different (delayed sternal closure (DSC) 6.36% vs primary sternal closure (PSC) 2.4%, $p = 0.0264$); blood-borne sepsis was higher in patients whose sternums were left open (DSC 15% vs PSC 2.1%, $p < 0.0001$). The incidence of swab-positive mediastinitis however was not significant (DSC 3.18% vs PSC 3.18%, $p = 0.9203$) (Table 5).

The 14 children who required secondary sternum opening in the ICU were actually stable at the termination of their operative procedure and hence underwent sternal closure in the operating room. The reasons for opening the chest in the ICU (Table 6) were hemodynamic instability in 6 patients, post arrest in 6 patients and arrhythmias in 2 patients. The patients whose sternums were reopened for hemodynamic instability 3/6 expired (one ASO, one intracardiac repair for tetralogy of Fallot (TOF) and one central shunt). The patients whose chests were reopened post arrest all expired (one TAPVC rerouting, two arch repairs, two intra cardiac repair (ICR) for TOF, one right modified Blalock–Taussig shunt (RMBTS)). Out of the 6 arrests, ECMO cardio pulmonary resuscitation (ECPR) was instituted in 3 patients. The patient whose sternum was reopened for arrhythmia, post pulmonary artery (PA) band for single ventricle developed intractable ventricular tachycardia (VT), expired.

The patients who survived after having the chest opened in the ICU included 2 TAPVCs both of whom had pulmonary hypertensive crisis and 2 ICR for TOF, 1 had restrictive physiology and the other child developed SVT and low cardiac output.

Table 5 Sepsis

Criteria	Primary sternal closure	*N*: PSC	Percentage	delayed Sternal closure	*N*: DSC	Percentage (%)	*p* value
BSI	38	1821	2.1%	33	220	15	0.0001
Respiratory sepsis	44	1821	2.4%	14	220	6.36	0.264
Mediastinitis	58	1821	3.18%	7	220	3.18	0.9203

BSI blood stream infection, *PSC* primary sternal closure, *DSC* delayed sternal closure

The total mortality during the study period was 79/2111, i.e. 3.7% (Chart 1 and Table 7). Mortality of group A was 56/1905, i.e. 2.96% (p, 0.0526 compared to total mortality, i.e. not significant). Mortality of group B was 33/220, i.e. 11.6% ($p < 0.001$ compared to total mortality, $p < 0.001$ compared to group A). Mortality of group A2 was not significantly different from that of group A or the total mortality. Mortality in group A2-2 was significant compared to the total mortality ($p < 0.0001$), significant as compared to group A ($p < 0.0001$) and group A2 ($p < 0.0001$) and statistically significant as compared to group B ($p < 0.0001$).

The optimal time to close the sternum varies among centres and depends on the diagnosis and reason to keep the sternum open. In our series, if the sternum was left open for bleeding and coagulation derangement, it was tended to be closed earlier with a median closure time of 18 h (range 12–32 h) and if the sternum was left open for hemodynamic instability, it was closed on an average within 42 h (14–164 h) ($p < 0.0001$).

Discussion

Delayed sternal closure has been around since 1975 when Riahi et al. [1] used open sternum to prevent cardiac compression in the adult population. Over time, leaving the sternum open electively has evolved as a therapeutic manoeuvre in congenital heart surgery, especially in neonates [5, 6]. The reported incidence of DSC is around 1–2% in adults [7], whereas in paediatric age group it varies from 7 to 48% and 76% when only neonates are considered [4, 8].

Leaving the sternum open helps the child to settle down hemodynamically, by allowing room for a dilated, dysfunctional ventricle or poorly compliant lungs to expand; it prevents what is called atypical tamponade. Post surgery, there is significant oedema, especially in neonates who might have been on prostaglandin, due to the lesion itself, the bleeding tendency etc. All these factors set the milieu for a low cardiac output state. The diastolic restriction leads to a tamponade-like situation of the right ventricle [9] which in turn leads to systolic dysfunction of the left ventricular due to septal shift and ventricular interdependence. These are the patients whose sternums are stented and the skin closed with a plastic membrane. Leaving the sternum open allows the right ventricle to decompress anteriorly and offsets the tamponade on it. Studies have confirmed the rise in pericardial and transventricular pressure post complex cardiac surgeries on closing the sternum [10] and leaving the sternum open improved the cardiac output by as much as 59% and systemic pressures by 18% [11].

On the outward, it may seem that leaving the sternum open, compared to primary sternal closure, suggests a high risk for mortality [12, 13] (even in our study PSC, i.e. group A vs open sternum, i.e. group B $p < 0.001$, Table 7), but this cohort of patients is the one with multiple risk factors. Leaving the sternum open electively in this sick cohort of babies may bring down the morbidity and mortality rate in this group of patients vis a vis primarily closing the sternum.

Out of the 220 open sternum cases, 14 patients (group A2-2) were shifted to the ICU with a closed sternum but were reopened in the ICU in the immediate postoperative period (Table 6). Total mortality of the open sternum cohort was 33/220, i.e. 14.5%. Of the patients who were shifted to the ICU with their sternums open, the mortality was 23/206, i.e. 11.16%, and mortality of patients whose sternums were reopened in the ICU in the immediate postoperative period

Table 6 Indications of opening the sternum in ICU

Case	*N*	Hemodynamic instability	Arrest	Arrhythmia	Mortality
ASO	1	1	0	0	1
TAPVC	3	2	1	0	1
Arch	2	0	2	0	2
ICR for TOF	5	2	2	1	3
Shunt surgery	2	1	1	0	2
PA band for single ventricle	1	0	0	1	1
Total	14	6	6	2	10

Table 7 Mortality

Cases	*N*	Mortality	Percentage	*p* value
Total	2111	79	3.7	
Group A	1905	56	2.96	$p = 0.6$ (NS vs total)
Group A1	306	0	NA	NA
Group A2	1599	56	3.5	NS (vs total)
				NS (vs group A)
				NS (vs OS)
				NS (vs group B)
				NS (vs group A2-2)
Open sternum (OS)	220	33	14.5	< 0.001 (vs total)
				< 0.001 (vs group A)
Group B	206	23	11.6	< 0.001 (vs total)
				< 0.001 (vs group A)
				= 0.05 (NS vs OS)
Group A2-1	1585	46	2.9	NS (vs total)
				NS (vs groups A and A2)
Group A2-2	14	10	71.4	< 0.0001 (vs group A)
				< 0.0001 (vs group B)
				< 0.0001 (vs OS)
				< 0.0001 (vs total)

Group A: total number of patients received in the ICU with closed sternum

Group A1: cohort of simple cases, in whom no sternums were left open

Group A2: cohort of total index cases, who came to the ICU with the sternum closed

Group A2-1: cohort of index cases, who came to the ICU with sternum closed and remained closed

Group A2-2: cohort of index cases, who came to the ICU with the sternums closed and were later opened

Group B: cohort of index cases, who had their sternums left open from the theatre

was 10/14, i.e. 71.42% (Table 7). The fact that the mortality of the patients whose sternums were reopened in the ICU for reasons of hemodynamic instability, post arrest or arrhythmias, is 71.42% as compared to the mortality of the patients whose sternums were left open from the theatre which was 11.16% ($p < 0.0001$) portends the possibility of better salvage had the sternum never been closed. This fact cannot be highlighted more, as a randomised trial would not be ethical and the clinical judgement is paramount in the decision to leave the sternum open.

Limitations

There are several limitation to this study. This is a single-centre study which reflects a particular referral pattern, which might have impacted the outcomes. Being a retrospective observational study, the true outcomes may have been reflected by a randomised control trial for a matched patient population, but that would not have been ethical.

In cases where there was an iota of doubt regarding closing the sternum or leaving it open, we have tried to standardise these variables by having a concerted discussion and decision in the theatre at the end of the procedure.

Conclusion

Delayed sternal closure has evolved along with congenital heart surgery, especially in neonatal surgery. It has gone through an era when chests were kept open for prolonged periods of time, to its current standing of being left open for a few hours [14–18]. It is better to err on the side of electively leaving the sternum open from theatre, if bleeding, hemodynamic instability and arrhythmias are anticipated, even though delayed sternal closure does increase ICU and hospital stay with a higher incidence of blood-borne sepsis. Incidence of mediastinitis associated with leaving the sternum open however is no different from primary sternum closures. Leaving the sternum open electively in the hemodynamically unstable patients improves outcomes and in turn brings down the morbidity and mortality vis a vis reopening the sternum in the ICU in the immediate postoperative period.

Compliance with ethical standards No animals were involved in the study.

Funding None.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Riahi M, Tomatis LA, Schlosser RJ, Bertolozzi E, Johnston DW. Cardiac compression due to closure of the median sternotomy in open heart surgery. Chest. 1975;67:113–4.
2. Ziemer G, Karck M, Müller H, Luhmer I. Staged chest closure in pediatric cardiac surgery preventing typical and atypical cardiac tamponade. Eur J Cardiothorac Surg. 1992;6:91–5.
3. Misawa Y. Liberal use of delayed sternal closure: sternal infection does not increase. Ann Thorac Surg. 2003;75:638.
4. Tabbutt S, Duncan BW, McLaughlin D, Wessel DL, Jonas RA, Laussen PC. Delayed sternal closure after cardiac operations in a pediatric population. J Thorac Cardiovasc Surg. 1997;113:886–93.
5. Shore DF, Capuani A, Lincoln C. Atypical tamponade after cardiac operation in infants and children. J Thorac Cardiovasc Surg. 1982;83:449–52.
6. Riphagen S, McDougall M, Tibby SM, et al. "Early" delayed sternal closure following pediatric cardiac surgery. Ann Thorac Surg. 2005;80:678–84.
7. Yasa H, Lafci B, Yilik L, et al. Delayed sternal closure: an effective procedure for life-saving in open heart surgery. Anadolu Kardiyol Derg. 2010;10:163–7.
8. Erek E, Yalcinbas YK, Turkekul Y, et al. Indications and risks of delayed sternal closure after open heart surgery in neonates and early infants. World J Pediatr Congenit Heart Surg. 2012;3:229–35.
9. Matsumoto M, Oka Y, Strom J, et al. Application of transesophageal echocardiography to continuous intraoperative monitoring of left ventricular performance. Am J Cardiol. 1980;46:95–105.
10. Kay PH, Brass T, Lincoln C. The pathophysiology of atypical tamponade in infants undergoing cardiac surgery. Eur J Cardiothorac Surg. 1989;3:255–60.
11. Furnary AP, Magovern JA, Simpson KA, Magovern GJ. Prolonged open sternotomy and delayed sternal closure after cardiac operations. Ann Thorac Surg. 1992;54:233–9.
12. Hurtado-Sierra D, Calderón-Colmenero J, Curi-Curi P, et al. Outcomes of delayed sternal closure in pediatric heart surgery: single-center experience. Biomed Res Int. 2018. https://doi.org/10.1155/2018/3742362.
13. Samir K, Riberi A, Ghez O, Ali M, Metras D, Kreitmann B. Delayed sternal closure: a life-saving measure in neonatal open heart surgery; could it be predictable? Eur J Cardiothorac Surg. 2002;21:787–93.
14. Riphagen S, McDougall M, Tibby SM, et al. "Early" delayed sternal closure following pediatric cardiac surgery. Ann Thorac Surg. 2005;80:678–84.
15. McElhinney DB, Reddy VM, Parry AJ, Johnson L, Fineman JR, Hanley FL. Management and outcomes of delayed sterna closure after cardiac surgery in neonates and infants. Crit Care Med. 2000;28:1180–4.
16. Özker E, Saritaş B, Vuran C, Yörüker U, Ulugöl H, Türköz R. Delayed sternal closure after pediatric cardiac operations; single center experience: a retrospective study. J Cardiothorac Surg. 2012;7:102.
17. Nelson-McMillan K, Hornik CP, He X, et al. Delayed sternal closure in infant heart surgery— The importance of where and when: an analysis of the STS congenital heart surgery database. Ann Thorac Surg. 2016;102:1565–72.
18. Alexi-Meskishvili V, Weng Y, Uhlemann F, Lange PE, Hetzer R. Prolonged open sternotomy after pediatric open heart operation: experience with 113 patients. Ann Thorac Surg. 1995;59:379–83.

Commentary

Rajesh Sharma,
Consultant Paediatric Cardiac Surgeon,
Jaypee Hospital, NOIDA, UP, India

In their publication entitled 'Elective delayed sternal closure portends better survival after congenital heart surgery', Drs Simran Kundan et al. present a sizeable experience of a series of 2,111 consecutive congenital heart operations with an overall hospital mortality of 3.7%.The authors are to be complimented for a candid and thorough data retrieval and for tabulating their entire experience, divided into different categories.

Out of the 2,111 patients, there were 206 in whom the sternum was electively left open and in this group, they report a mortality of 11.6% (23 patients). There was an additional smaller group of 14 patients where the patients were shifted from OT with the sternum closed, but who required secondary opening of the chest in ICU for hemodynamic instability. In this group, they report a mortality of 71.4%, which was significantly higher than the elective chest-open group. The authors conclude that if problems can be predicted, it is safer postponing chest closure and shifting the patient to ICU with chest open at conclusion of surgery.

The conclusion reached in the paper makes intuitive sense in that any patient after intracardiac repair, where future hemodynamic compromise is likely, would be better off with the sternum unclosed. The paradigm they followed in deciding when to leave a sternum open in their own words is as follows: 'In neonates with poor preoperative status, we tend to leave the sternum open in majority of such patients. Empirically our indications include situations in which the pump time and clamp time are long, leading to tissue edema involving the heart and lungs, ventricular dysfunction, medical bleed, any palliated or residual lesions which predispose to a hemodynamically unstable postoperative course requiring high inotropes, situations in which there was a space constraint eg conduit placement or in patients with central ECMO. After closure, the patient is monitored closely for the same flag signs'. In their experience, 55.9% of the patients whose chest were left open were neonates. There were 4 major operations which constitute the bulk of their primarily open and also secondarily opened sternums: the arterial switch operation, repair of TAPVC, aortic arch repairs, and repair of tetralogy of Fallot.

Obviously, despite the above protocol, these 14 patients were missed or developed fresh problems in the ICU, which had not been predicted at the time of proceeding to close the sternum. Six of the 14 were opened for 'hemodynamic instability' and it is not clear if this was related to bleeding, cardiac tamponade or primary cardiac dysfunction with 3 survivors, while 6 others were reopened for a cardiac arrest. Of the latter group, 3 were put on ECMO, despite which there were no survivors among these 6. Two patients had sudden arrhythmia and one could be salvaged after reopening.

The authors postulate that presumably, the act of going ahead with sternal closure in these patients negatively impacted their potential chance of survival.
Quite possibly, in my opinion.

For the delay entailed in reaching the decision to reopen and the obvious reluctance to do so having once closed the chest, in an unpopulated hour of the night, after a busy day's work, can quite likely result in a progressively worsening situation, when one finally does reach the point of reopening a chest. Also, the valuable adjunct of leaving the chest open, i.e. having cannulation tourniquets already in place, is obviously missing in a closed chest, and placing fresh purse strings in a situation where the aorta is behind the anteriorly translocated pulmonary artery (post ASO) or in a diminutive aorta of a TAPVC, when the patient is spiraling out of control or has already had a cardiac arrest, single handedly, can be a daunting exercise to the best in the business.

What if they were to have left the sternum open in all the susceptible groups of patients, i.e. group A2?

The downside of leaving the sternum open, in their own experience, is higher blood stream infection, but no significant increase in local wound infection and an understandably higher time on ventilator, ICU stay and hospitalization. If the entire lot of their group A2 were to have been left open, or even if this was limited to the arterial switches, TAPVC repairs and arch repairs, it would entail a major increase in cumulative morbidity and hospital expenditure and would doubtless be an overkill.
The million dollar question is how do we identify the patient who looks okay, now in the OT, but is going to fall apart in the ICU?

Leaving the sternum open primarily is an option exercised by most units doing cardiac, and, especially, pediatric and, more so, neonatal cardiac surgery. 'Tight syndrome' is a well-recognized phenomenon in patients soon after having undergone neonatal cardiac surgery and results more often with prolonged cardiopulmonary bypass and ischemic times, especially after certain specific operations, e.g. arterial level repair of transposition of the great arteries, patients with obstructed total anomalous pulmonary venous drainage, or relief of aortic arch obstruction with or without concomitant intracardiac repair or stage I Norwood repair.

In general, significant oozing, borderline hemodynamics, bulging heart, hyperinflated lungs that would also take up space once the sternum is closed, higher than normal airway pressures and low central venous saturations in any patient are some of the prescribed indices to consider when deciding to close a sternum or not. In Dr. Kundan's group's experience, mixed venous saturation (MVO2) is not mentioned, as an index that was measured when taking this decision. In my opinion, this particular parameter, if one does not have access to near-infrared spectroscopy (NIRS) of the abdomen, needs to be looked at seriously, and may have a role in helping one take a call when all else suggests closeability.

Similarly, having been received in the ICU with sternum closed, any patient whose abdominal NIRS or mixed venous saturation drifts low (MVO2 below 50%) would probably be better off with more space for lung expansion and cardiac filling, as the next step after optimizing inotropy and preload. This index, if followed serially in the ICU, may assist more timely intervention than other more conventional parameters mentioned earlier. If after this intervention, too, the situation still does not seem to improve, then arrangements for mechanical circulatory support as the final strategy for prevention of impending cardiac collapse can be readied.

Discussant:

Dr. Trushar Gajjar MB, MS DNB CTVS, FIACS
Senior Pediatric Cardiac Surgeon
U.N.Mehta Institute of Cardiology & Research Centre (UNMICRC)
Ahmedabad, India.

Q1. What are the indications of sternal closure with vertical traction according to you?

We have no experience in vertical traction. We are of the opinion that the patients who warrant an open sternum after the procedure should have a formal open sternum rather than closing the sternum and then lifting it off the heart. We believe that leaving the sternum open modulates the compliance of the cardiopulmonary compartment as a unit.

And there is always the issue of maintenance of sterility with the traction system.

Q2. What will be an ideal approach—sternal closure with traction or delayed sternal closure?

We have no experience with sternal traction; if the need arises, our patients get delayed sternal closure. Our choice of keeping the sternum open is between closing skin only, patch closure only or stented sternum with a patch on the skin.

In case the issue is only bleeding, we keep the sternum open and close the skin. In neonates, we keep the sternum open and close the skin with a patch. If the issue is space and unstable hemodynamics, we prefer to keep the sternum stented and close the skin with a patch.

Q3. What will be the antibiotic strategy during open sternum—whether to follow STS guideline or something else?

We routinely use cefuroxime for prophylaxis. When we leave the sternum open, we add vancomycin and it is continued till the sternum is open. In case we need to step up Gram-negative cover, we add piperacillin/tazobactam. Our third-line antibiotics depend on the culture positivity, if any.

In case of renal dysfunction, we adjust the dose according to creatine clearance.

Q4. Which were the parameters looked into for sternal closure in your both groups?

We monitor the patient for hemodynamic stability. We assess peripheral perfusion by monitoring temperature and urine output. Normalising ABG with a normal or a decreasing trend of lactates.

We are proponents of monitoring lines and more frequently than not, our patients come to the ICU with either an LA or a PA monitoring line, as the case warrants.

We assess for the parameters to normalise. Once the child's hemodynamics start to settle down, the normal course of things would be heralded by warm peripheries, good urine output, whether spontaneous or with the help of diuretics, normalising trend of LAp and Pap and improvement of cardiac function by screening transthoracic ECHO.

For TAPVCs, the lung compliance is assessed with airway pressures and assessing oxygenation and ventilation on ABG.

Q5. What would you suggest to be an ideal sternal closure time?

The ideal time to close the sternum would be as soon as possible. Once the child has settled down from point of view of why the sternum was left open, we actively work towards sternal closure.

In our experience, the sternum was closed earlier if it was left open for bleeding. In case the sternum was left open for hemodynamic point of view, the most important factor for sternal closure would be improvement in peripheral perfusion and the most important indicator of that would be improvement in urine output.

Q6. Is there any role of ideal place and its effect on outcome of delayed sternal closure?

As a policy, we close all our sternum in theatre. There have been situations when the child was closed in the ICU itself; the most important point, while closing the sternum in the ICU, is that even though it is logistically and economically attractive, the sterility has to be maintained at all cost. The ICU has to be geared up to bring the theatre sterility to the ICU. The entire team has to be comfortable with the idea of the sternum being closed in the ICU.

Q7. What will be the strategy in case of failed delayed sternal closure?

Once the child has failed delayed sternal closure and the sternum has been reopened, usually indicating that the child was not ready for sternal closure in the first place itself, the child and the team have to start from scratch. Any treatable cause has to be looked for aggressively and remedied.

The point is that, after delayed sternal closure, if the child is not settling down, no time should be wasted in decision-making for reopening the chest, so as not to jeopardise and deteriorate the hemodynamics further.

Q8. What would have been sternal morbidity rate? How you would like to manage?

In our experience, the sternal morbidity of leaving the sternum open is not significantly different from primary closure of the sternum. This is encouraging because if leaving the sternum open did increase the morbidity, it would beat the whole purpose helping the child.

We routinely swab all the mediastinum on closure. In case the child is positive, but clinically asymptomatic, we continue the susceptible antibiotic for 2 weeks and discharge the child on susceptible oral antibiotic for a further 1 week.

In case the swab is positive and the child is showing signs of sternal instability, the child is taken back to theatre and the sternum is reopened and a mediastinum washout is given and the sternum rewired. We have never faced reinfection after a sternal washout. The susceptible antibiotics are continued for 2 weeks and the child is discharged on oral antibiotics for a further 1 week.