Int. J. New. Chem., 2022, Vol. 9, Issue 3, pp. 480-492.

International Journal of New Chemistry

Published online in http://www.ijnc.ir/

Open Access

Print ISSN: 2645-7237

Online ISSN: 2383-188x

Original Research Article

Delayed Sternal Closure after Cardiac Surgery: A Review Study

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Received: 2021-11-01 *Accepted: 2022-01-29* *Published: 2022-02-01*

ABSTRACT

Delayed sternal closure [DSC] has been shown to be a common strategy, when sternal closure resulted in a negative effect on cardiac and respiratory function. This strategy can contribute to improving cardiovascular and pulmonary adaptation with a positive effect on cardiac mechanics and breathing in order to hemodynamic stability. Due to the importance of the subject in the current study we reviewed published literature related to delayed sternal closure after cardiac surgery in children and adults, definition and history of the subject, prevalence, its relationship with the circulatory and respiratory system, sternal closure time, indications and risk factors, complications and mortality rate. Literature review showed that DSC is an effective method in patients with severe reduction in cardiac output, respiratory failure, uncontrolled bleeding, arrhythmia and myocardial edema after on-pump cardiac surgery. DSC is more common in infant and pediatric cardiac surgery than in adults. However, surgeons need to consider the correct use of this strategy, physiological changes, and patient management when the sternum is left open, as well as the consequences of DSC, including infection at the surgical site. In general, the literature shows an acceptable rate of complications and mortality if this technique is used properly, however, due to the conflicting results of various studies in this field, the multi- institutional researches is recommended in order to accurately identify of the related postoperative processes.

Keywords: Delayed sternal closure [DSC], Cardiac surgery, Sternal wound infection [SWI]

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Introduction

Delayed sternal closure [DSC] is a management strategy for hemodynamic instability, significant myocardial edema, respiratory hazards, persistent bleeding, and arrhythmias, which is described as a way to prevent cardiac compression after heart surgery. DSC has been proposed as a way to prevent compression of the heart after cardiac surgery and as a management strategy for hemodynamic instability and severe blood coagulation disorders after heart surgery [Figure 1]. It has been shown to contribute to hemodynamic stability by improving cardiovascular and pulmonary adaptation with a positive effect on cardiac and respiratory mechanics [1]. Despite its wide-ranging advantages for hemodynamic benefits, DSC may be associated with higher rates of postoperative infections, resulting in increased hospital stays, higher health care costs, and increased early mortality.

Figure 1. Cardiac Surgery

Delayed sternal closure has been described as a useful treatment for severe heart failure, uncontrollable bleeding, and arrhythmias. Sternal closure can be performed after stabilizing the patient's hemodynamic status. Usually, the sternum is closed 24-72 hours after surgery, when the physiological recovery stage was reached [2]. Delayed sternal closure is often required in the care of pediatric patients undergoing heart surgery to minimize postoperative respiratory and hemodynamic instability [3]. Delayed sternal closure was first described in 1975 as a way to

prevent cardiac compression following heart surgery in adults. This method has since been widely used in congenital heart surgery, and DSC is especially common in infants after complex operations [2]. Due to the higher ratio of heart size to thoracic cavity as well as longer cardiopulmonary bypass times in young patients, DSC is more common in pediatric heart surgery than in adult heart surgery and children are more likely to benefit from DSC [4]. However, despite its widespread validation for hemodynamic benefits, DSC has been associated with a higher rate of postoperative complications and infections in single- and multi-institutional studies compared to initial sternal closure [5]. These infections are costly both in terms of resources and patient outcomes, as postoperative infections are associated with longer hospital stays, higher health care costs, and increased mortality. Surgeons should be aware of its proper use as well as physiological changes and patient management when the sternum is open. Several previous studies have shown wide variation in DSC methods by institutions. Apparent differences in the postoperative care of patients with DSC highlight the need for prospective surveys with available control groups that could lead to the implementation of standard monitoring protocols across institutions [Figure 2]. The aim of this review study was to evaluate the various aspects of DSC in pediatric and adult heart surgery, including its prevalence, its relationship with the circulatory and respiratory systems, sternal closure time, symptoms and risk factors, complications and mortality rate due to this strategy, based on available literature.

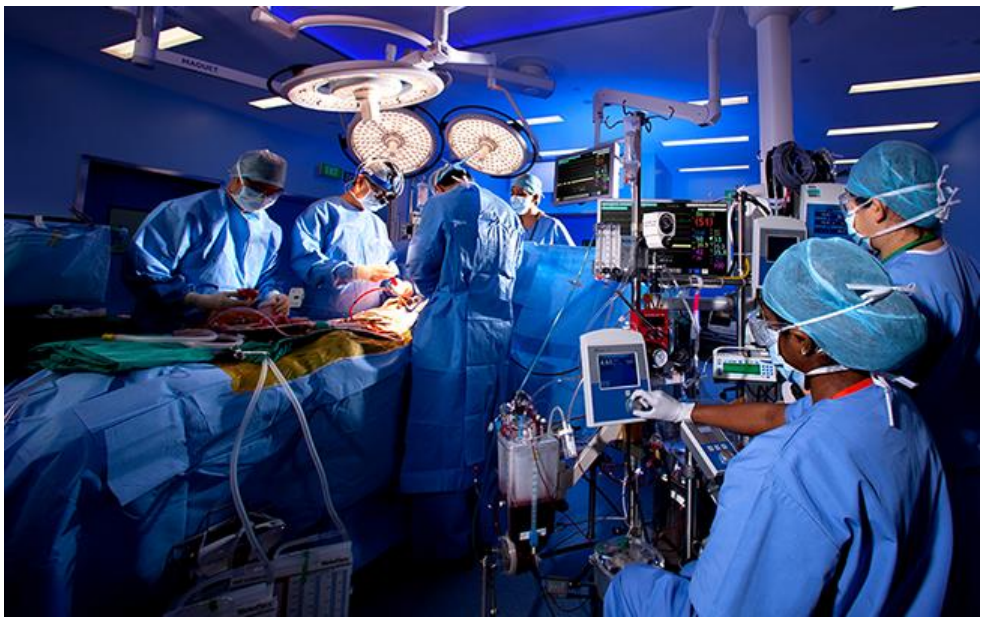

Figure 2. Heart Surgeons, Department of Cardiothoracic Surgery

Search Strategy

Google Scholar, MEDLINE / PubMed and Scopus databases were used to search for relevant studies. The search was performed using keywords including delayed sternal closure [DSC] in children and adults, heart surgery and sternal wound infections [SWI]. No language or template restrictions were enforced on the search. Related articles from the time of the DSC description [1975] to 2020 were reviewed and a total of 215 studies were identified. The references of the found papers were also examined to identify other relevant publications. In general, a total of 54 studies were considered and summarized related to this study. Issues related to DSC and its consequences in pediatric and adult heart surgeries were investigated in this study. We first review the history of DSC and then the prevalence, risk factors, indications and complications, and mortality rates associated with this technique.

History of DSC

Delayed sternal closure [DSC] after cardiac surgery was first reported in the mid-1970s by Riahi et al. [6]. He described DSC as a life-saving option in patients with uncontrolled bleeding, myocardial edema, low cardiac output or postoperative arrhythmias, stating that initial sternal closure leads to hemodynamic instability. Then, Ott et al. [7] reported that primary DSC is essential to prevent postoperative bleeding or cardiac compression. Gielchinsky et al. [8] reported the first series of 29 adult patients with DSC in 1981. Subsequent studies [9] have reported an incidence of 1% to 2% DSC in adult patients undergoing cardiac surgery. These early studies have identified causes of DSC in adults including myocardial edema, bleeding, persistent arrhythmias, and placement of ventricular assist devices [10]. DSC after pediatric heart surgery has been described in several studies [1]. Since the first report by Riahi et al. [6] several small and large-scale studies have been performed at various cardiac surgery centers around the world, leading to valuable but still controversial findings.

Prevalence and causes of DSC

It has been shown that the physiology of the heart is different in open and closed sternal positions, and sternal closure in cases with systolic dysfunction can be life-threatening by causing unbearable changes in blood pressure and cardiac output. It should be noted that the cardiac response to

intravascular volume increase is the same in open and closed sternal positions, therefore, changes in pulse pressure and systolic blood pressure can be accurately applied to determine the cardiac response to intravascular volume increase [1]. A review of the literature showed that patients with heart disorders may have a significant reduction in cardiac index [CI] and blood pressure after sternal closure. The results of a study [2] showed that DSC is beneficial in patients with severe CI reduction after sternal closure. In this regard, another study reported that 59% increase in CI and 18% increase in blood pressure after re-opening of the sternum was observed in patients who experienced excessive CI collapse after sternal closure [1]. Although these events occur in all patients undergoing sternotomy, they are more common in patients with decreased cardiac output. In a study by McElhinney et al. [4], primary sternal closure in patients under 1 year of age resulted in a 5 mm Hg increase in pulmonary artery pressure. In another study, CI decreased from 2.9 to 2.3 after primary sternal closure in patients with normal preoperative cardiac output [1]. On the other hand, the effects of sternal closure are also significant on the respiratory system. Closure of the sternum in a normal patient without underlying pulmonary disorder results in an increase of 1.2 mm Hg mean airway pressure and a 2 mm Hg increase in maximal respiratory pressure [4]. Closure of the sternum in patients undergoing normal surgery also reduces CO2 removal by 29%, reduces pulmonary compliance by 19%, and increases endotracheal tube leakage [5]. The effect of sternal closure is significant on increasing pulmonary vascular resistance and can significantly reduce the arterial saturation in patients with shunt-dependent circulation [6]. The results of various studies are contradictory in relation to the prevalence rate of DSC. This wide diversity of outcomes is mainly due to differences in treatment strategies, experiences and tendencies of surgeons, and pathological diversity in the different study groups. Several previous studies have reported a DSC prevalence of 4.5% in children and 1.5% in adults [8]. However, the incidence of DSC in the adult heart surgery population has been reported in another study to be 4.2% [9]. Hashemzadeh et al. [2] reported that the DSC strategy was adopted for 3.3% of patients. In general, it has been reported that the incidence of DSC in different centers varies from 0.29% to 30% [1]. DSC is more common in pediatric and complex adult surgeries than closed heart surgery and coronary artery bypass grafting [CABG].

DSC indications and risk factors

DSC is a safe and simple method for the treatment of bleeding, arrhythmia and myocardial edema after on-pump heart surgery. Following the increase in the skill of heart surgeons in the DSC technique, its application rate may increase for cardiac pump surgery. Based on previous studies, DSC has generally been shown to have the following conditions: hemodynamic instability, myocardial edema, dilated heart, decreased myocardial function, persistent bleeding, dysrhythmia, respiratory distress, and placement of external cardiac support systems. The most common indications of DSC in corrective surgery for congenital heart defects are hemodynamic changes and inadequate homeostasis at the time of sternal closure undergoing heart surgery [4, 16]. Another sign of DSC in children and adults is uncontrolled bleeding. Alexi-Meskishvili et al. [5] reported that the indications of DSC in children are the same as those described in adults.

A clear understanding of outcomes and risk factors is essential because they may influence the clinical decisions of cardiac surgeons and intensifiers of care for these patients. Samir et al. [24] showed that weight, gender and mechanical ventilation did not affect the final decision, while age under 7 days and the type of heart disease were the main risk factors for DSC. Postoperative hyperglycemia, a potential risk factor for mediastinitis in infants and children after heart surgery, is another possible risk factor for DSC [6]. In general, accurate and independent predictors of DSC have not been shown in existing studies. Prospective research is essential in children and adults, which may explain the important risk factors for DSC.

Appropriate timing of sternal closure and considerations related to operational technique

Due to the presence of risk factors for long opening of the sternum, such as blood clotting and continuous bleeding, pulmonary edema and decreased pulmonary adaptation, the sternum should be closed at the appropriate time [7]. Sternal closure can be tested in the presence of stable hemodynamic conditions, improvement of respiratory status and acceptable arterial blood gases. On the other hand, observation of decreased heart rate, low arterial O_2 saturation, increased heart rate and acidosis indicate the necessary conditions for opening the sternum [4]. The most appropriate time range for DSC in intensive care units depends on the patient's condition, but is usually within the first 24 to 72 hours of recovery period [4]. However, in some clinical conditions,

the sternum should remain open for more than 72 hours. The optimal time for sternal closure is generally unknown, but sternal closure is often possible after 1-2 days in adults, while children may need more time [2]. However, different ranges of open chest management period, from 2 to 14 days after surgery, have been reported depending on the patient's condition and the surgeon's decisions [2, 14]. In one study [6], the mean sternal closure time was reported to be 3 days, whereas up to 5.5 days was reported by Moggio et al [2]. Other studies have reported a range of 2-5 days for sternal closure [8]. Samir et al. [4] suggest that sternal closure should not be performed in children before 3 days after surgery; however, a better decision can be made depending on the circumstances of each case. Patients after heart surgery often complain of sporadic and severe pain in the chest, shoulders, and spine, sternum, and neck. These pains are felt naturally after the surgery and will decrease in intensity over time. The mediastinum viscera should be covered while the sternum is open. Many surgeons prefer to repair the skin and leave the sternum open. However, this method does not seem to provide enough space in the chest [14]. Sternal closure can be performed in a completely sterile ICU and is not necessary to transfer the patient into operating room. However, some surgeons prefer to perform sternal surgery in operating rooms. It is important to note that not only the sternotomy closure technique but also the material and size of the sutures can affect the incidence of mediastinitis. The operational technique for sternal closure has been well studied in a review study [2]. The sternum becomes very sensitive and unstable after surgery; therefore, it is important to follow safety tips to prevent further injury and pain.

Primary DSC [PDSC], secondary DSC [SDSC] and DSC-related complications

As mentioned, DSC is still a common practice if sternal closure has a negative effect on heart and respiratory function. However, sternal closure at the end of surgery is sometimes associated with problems and complications. In addition, in some patients, reopening of the sternum and secondary delayed sternal closure [sDSC] may be necessary during the postoperative period in the intensive care unit [ICU] or operating room. There has always been a serious concern about increasing infection rates and postoperative mortality in these conditions. The findings of a recent study on the results of primary versus secondary delayed sternal closure in heart surgery of children using a study of patients under 18 years of age undergoing cardiac surgery showed that 3.8% of patients had primary DSC [PDSC, sternum left open after surgery] and 0.9% of patients had

secondary DSC [SDSC, sternum primarily closed and reopened after surgery] [9]. DSC may be dangerous for patients, despite the need to perform it to treat unstable patients. Risks of DSC include increased duration of ventilation, prolonged stay in the intensive care unit, and infection at the surgical site, which are often associated with increased complications and health care costs [3]. The exact effect of DSC on surgical outcomes, including survival to hospital discharge and diseases such as postoperative infection, is unclear [4]. This could be due to the small sample population as well as the lack of a relevant control group in studies that examined the association between DSC and side effects. Various studies have reported an infection risk of 0-20% [1]. The reasons for this diversity of results can be due to various strategies of different centers when the sternum is open, age variation and different DSC indications. In another study, it was reported that surgical centers with repeated use of DSC had a higher rate of postoperative infection [11]. Wound care methods, treatments and higher rates of nosocomial infections can be an effective factor in DSC outcome. Special care is highly recommended to prevent infection and mortality of open wounds after heart surgery that is prone to nosocomial infections. The mediastinal lining and the opening time of the sternum appear to affect the incidence of infection. Studies also show that infection may be more common in younger patients and patients undergoing DSC due to uncontrolled bleeding [2]. Although the main concern of surgeons in using DSC is increasing the rate of infection, however, other complications of DSC include respiratory failure, kidney failure, cerebrovascular accidents, heart attack, heart failure and gastrointestinal complications [liver failure, intestinal ischemia, etc.] should be considered [2]. However, the overall rate of complications is higher in patients undergoing DSC, and approximately 30-50% of these patients experience at least one major complication after surgery. The length of hospital stay and ICU stay in these patients is also significantly longer than other patients [7].

Sternal wound infections [SWI]

Sternal infection is a serious and high-risk complication after median sternotomy following heart surgery [2]. Although sternal wound infections are a major health issue in patients with delayed sternal closure after heart surgery, there is no specific guideline for DSC patients in order to prevent this costly complication. This complication leads to a significant burden in increasing health care with non-optimal results in terms of long-term hospitalization, increased readmission and increased morbidity and mortality. Some studies have suggested that changes in the

accompanying approach for DSC patients reduce the SWI rate [1]. Several recent studies from various institutions have reported an incidence of SWI about of 3 to 18% for cases of DSC [13]. In a study stating that low preoperative cardiac output is the most important cause of postoperative sternal infection, it was recommended that diabetic patients and patients with low cardiac output be identified to correct the high-risk areas before surgery in order to reduce the rate of wound infection [14]. Extensive studies in adult patients have reported a wound infection rate of 1.5% to 1.8% after cardiac surgery [15]. In the literature, the incidence of sternal wound infection in children after cardiac surgery has been reported from 0.1% to 7% and the incidence of 0% to 28% in patients with DSC [36]. According to the Center for Disease Control, sternal infection is divided into two categories. Superficial infection is when only the skin and subcutaneous tissue are involved and deep infection is when, in addition to the skin and subcutaneous tissue, the mediastinum and sternum are also involved in this infectious process [17]. According to global statistics, deep sternal infection has been reported between 0.4 and 5%, which requires multiple surgeries to control and treat the infection [18]. Superficial sternal infection is more common and its treatment is much easier than its deep type [19]. Children undergoing surgery for congenital heart disease [CHD] are at risk for sternal infection [4]. In one study, it was reported that surgical site infections accounted for 9.9% of more than 6,000 congenital heart surgery patients [1]. In another study, postoperative infections were identified as the leading cause of death in patients following DSC [2]. Identifying an appropriate antibiotic prevention regimen can have a significant impact on the outcomes of children in need of DSC. This issue has been well studied in two review studies [5, 2] whose results suggest that the standard management of antibiotics provided by the guidelines for adult heart surgery patients can be used as an acceptable strategy for the treatment of children with open chest after heart surgery. Early diagnosis and appropriate treatment are important principles for reducing mortality in patients. The most important point is to prevent this complication, which can be achieved by applying the principles of infection control continuously as well as checking the function and correcting the defects.

Mortality rate

Reports of DSC mortality rates are inconsistent. According to previous studies, DSC mortality has been reported from 0% to 60%, but the average mortality in various studies has been 15-25%, which thirty-three to fifty percent of mortality occurred in the after sternal closure period [15]. In

another study, DSC mortality following complex aortic surgery was reported to be approximately 17% [6]. The mortality rate in cases of secondary DSC [sternal reopening after closure in the operating room or ICU] is more than twice as high as in primary DSC [14]. Length of hospital stay in SDSC was longer than PDSC, survival in PDSC was better than SDSC, and in general, PDSC showed better results than SDSC. However, reopening the sternum can save lives when properly anticipated. This finding emphasizes the importance of making the right decision when closing the sternum. Johnson et al. [1] concluded that in centers with high, moderate and low prevalence of DSC, the mortality rates were 15%, 26% and 23%, respectively [1]. In addition, the cause of DSC significantly affects mortality. Uncontrolled bleeding is associated with the highest mortality rate among DSC indications [2]. This finding emphasizes the role of coagulation disorders in mortality. The most common causes of death when the sternum is open are ventricular failure and after the sternal closure, these causes include renal failure, respiratory failure, and sepsis [5]. Estimation of mortality in various studies may not be accurate enough because some studies have reported overall mortality, while others have reported mortality while the sternum was open. On the other hand, in different studies, the age range of patients was from 1 day to 80 years and in studies of congenital heart diseases, it was even 1 day to 19 years. The overall mortality rate in pediatric patients with DSC varies from 11% to 36.2% [7]. Capillary leakage and edema associated with cardiopulmonary bypass continue into the postoperative period and can compromise cardiopulmonary function in infants and children. Since the pericardial and sternal closure after cardiac surgery has a limiting effect on cardiac function and may interfere with efficient mechanical ventilation, DSC is useful and sometimes necessary in the immediate postoperative period [8]. Some of the recent studies related to delayed sternal closure are summarized in Table 1.

Table 1- Selected recent studies related to delayed sternal closure

First Author [Ref.]	Title	Main point	year of publication
Elsisy [9]	Outcomes of Primary versus Secondary DSC …	Operative mortality was higher in SDSC [17.8%] compared to the PDSC [6.2%]	2021
Jha [1]	A Quality Improvement Initiative to Reduce Surgical Site Infections…	The SWI rate in DSC was 7.7%.	2020
Silvetti [13]	Antibiotic management for delayed sternal closure…	The SSI rate in patients with "non-standard" strategy was higher [8.8%] than in patients with "standard" strategy [6.8%].	2020
Kennedy [5]	A Systematic Review of Antibiotic Prophylaxis for DSC …	The overall incidence of bloodstream infection was 7.4%	2020
Woodward [4]	Efforts to reduce infections in DSC patients…	6.3% of the DSC patients developed a SWI.	2020
Yabrodi [3]	Minimization of SSI in patients with DSC after pediatric cardiac surgery	Median duration of open sternum was 3 days.	2019

Conclusion

DSC is an effective method in patients with severely reduced cardiac output, respiratory failure, uncontrolled bleeding, arrhythmia and myocardial edema after heart surgery, which, if used properly, can lead to acceptable mortality and complications rate. This strategy is more common in neonatal and pediatric heart surgery than in adults. Surgeons should be aware of its proper use,

physiological changes and patient management, as well as complications following DSC and infection when the sternum is left open. According to the literature review, it can be concluded that DSC is an important postoperative strategy for the care of congenital heart surgery patients with hemodynamic instability and postoperative hemorrhage. One of the important points in this regard is the incidence of surgical site infection [SSI] in patients undergoing DSC, which leads to increased treatment costs and high mortality rates. Given the conflicting results regarding the application of the DSC strategy in terms of success rates and complications, in general, multi-institutional researches is recommended in the population of high-risk patients.

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How to Cite This Article

Sohrab Negargar, "**Delayed Sternal Closure after Cardiac Surgery: A Review Study"** International Journal of New Chemistry., 2022; DOI: 10.22034/ijnc.2022.3.15.