

R E V I E W

Management of pediatric cardiac surgery wound: a literature review

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Background: Sternal wound infection is a severe complication of cardiac surgery in the pediatric population (0-18 years old) that can lead to increased morbidity, mortality, and prolonged hospitalization. Health professionals have the ability to perform some interventions during the pre, intra and post-surgery to correctly manage sternal wounds, with the goal of preventing infections. *Objectives:* To identify and discuss current best practice in the prevention, incidence, and treatment of infections of the cardiac surgery site in the pediatric population. *Methods:* Between February 20th 2021 and February 28th 2021 we consulted the PubMed database adopting full text, 20 years, Humans, English, Child aged 0 to 18 years as criteria. Twenty articles out of sixty-six were considered relevant to this study. These were divided into four themes. *Results:* All studies highlight the lack of standard guidelines for managing pediatric patients undergoing cardiac surgery. Some centers developed protocols for managing antibiotic prophylaxis supported by measurable interventions; others implemented infection surveillance systems involving families taking care of patients after hospital discharge. *Discussions:* the identification of healthcare-associated infections in the pediatric population after cardiac surgery is useful in all peri-operative phases. The limited and restricted literature connected to single centers, with relatively small sample sizes, the use of a single database. *Conclusion:* There is a lack of standard guidelines. The prevention of site infection ought to be the goal of reducing surgical site infections. Building a network between the multidisciplinary staff and the pediatric patient's family improves the infection surveillance system, reducing the incidence of infections. (www.actabiomedica.it)

Key words: Surgical Wound Infection, Cardiac Surgical Procedures, Pediatrics/Children, Review.

Background

The surgical site infection (SSI) after cardiac surgery is a serious concern for both the adult and the pediatric populations. Numerous studies confirm that SSIs are a complication with significant sequelae, such as longer hospitalization, increased morbidity and mortality, and higher health care costs (1, 2, 3, 4, 5, 6, 7, 8, 9, 10). The incidence of SSIs after pediatric cardiothoracic surgery in the United States is reported between 0.25% and 6%, and it has an associated mortality range between 7% and 20% (11). Pediatric

recommendations for SSI management are based on expert's opinions and data extrapolated from adult guidelines (12). Adult guidelines are based on risk factors such as obesity, diabetes, and smoking. These items, however, are not the same risk factors identified for SSIs in children (13). Potential pre-operative, intra-operative, and post-operative risk factors for children include: age lower than one month, duration of surgery, presence of genetic abnormalities, prolonged extracorporeal circulation (ECMO) time, delayed sternal closure, pre-operative hospitalization and prolonged post-operative hospitalization,

post-operative hemorrhage, and persistent low cardiac output (10, 14). While for the adult population there are predefined measures that aim at reducing the rate of the infections connected to cardiac surgery wounds, such as the ones presented by Bratzler et al. (2013) for the use of antimicrobial agents for the prevention of SSIs, there are no standardized protocols and guidelines for the management of cardiac surgery wounds in the pediatric population (15). This led us to ask ourselves what are the possible consequences of this lack of guidelines, and whether the introduction of protocols/guidelines would improve the management of sternal wounds in the pediatric population.

Objective

To identify and analyze current best practices in the prevention, incidence, impact and treatment of cardiac site infections after cardiac surgery, focusing on sternal wounds, in neonatal/pediatric users in the pre, intra, and post-operative phases.

Materials and Methods

The structured literature systematic review was guided by Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) (16). We consulted the PubMed database between February 20th 2021 and February 28th 2021, using the following Mesh terms: “Surgical Wound Infection” and “Cardiac Surgical Procedures”. We selected the studies considered in this review according to the following criteria. We selected the categories: full text articles (other categories such as abstract only were considered not enough detailed for the purpose of this study), published within the last 20 years, referring to human species only, written in English, and related to a neonatal and/or pediatric population (Infant: birth to 23 months, Child: birth to 18 years). We included both qualitative and quantitative studies, randomized controlled trials (RCTs), prospective and retrospective comparative cohort studies, regression analysis, case-control studies, quality improvement (QI) and survey studies. We excluded articles on patients over 18 years

of age, in foreign languages other than English. Out of one hundred-sixteen articles, twenty-two articles were determined by us to be relevant and connected to our research (Image 1, Table 1). From an initial analysis of the twenty-two articles identified according to the criteria introduced above, we extrapolated four main recurring topics: 1) *risk factors for developing SSIs*; 2) *strategies to reduce SSIs*; 3) *relationship between colonization and clinical infection (SSIs rate)*; 4) *impact of SSIs in terms of costs for the healthcare system*. We thus decided to structure our study and show the results around these topics, for a more accurate examination and comparison.

Results

Of the twenty-two analyzed studies, nine are retrospective (1, 2, 3, 5, 6, 9, 11, 17, 18); three are prospective studies (8, 19, 20); three are quasi-experimental studies (21, 22, 23); five are quality improvement studies (7, 10, 24, 25, 26); one article is a survey (13); and one is a regression analysis (4). Common to all the articles considered in our study is the research of defined criteria that can help the multidisciplinary staff to recognize and prevent possible sternal wound infections. In what follows, we are illustrating our findings proceeding according to the four themes introduced above (i.e., Risk Factors, Strategies to reduce SSIs, SSI rate, and impact of SSIs in terms of costs for the healthcare system).

Risk factors. Nine articles (1, 2, 3, 4, 5, 6, 7, 8, 9) argue about the possible risk factors of developing SSIs. These studies confirm that SSIs after congenital heart surgery are a complication with significant sequelae. Hence it is important to understand the risks associated with this procedure, and what treatments can positively or negatively affect the risk factors. A number of variables are associated with major infections (Table 2).

Strategies to reduce SSIs. Five studies (10, 22, 23, 25, 26) introduced the idea of a written protocol. They sustained the bundle approach, i.e., a set of evidence-based practices adopted collectively by the multidisciplinary team as a valid instrument to pursue the reduction of the SSIs. The use of a sternal



PRISMA 2009 Flow Diagram

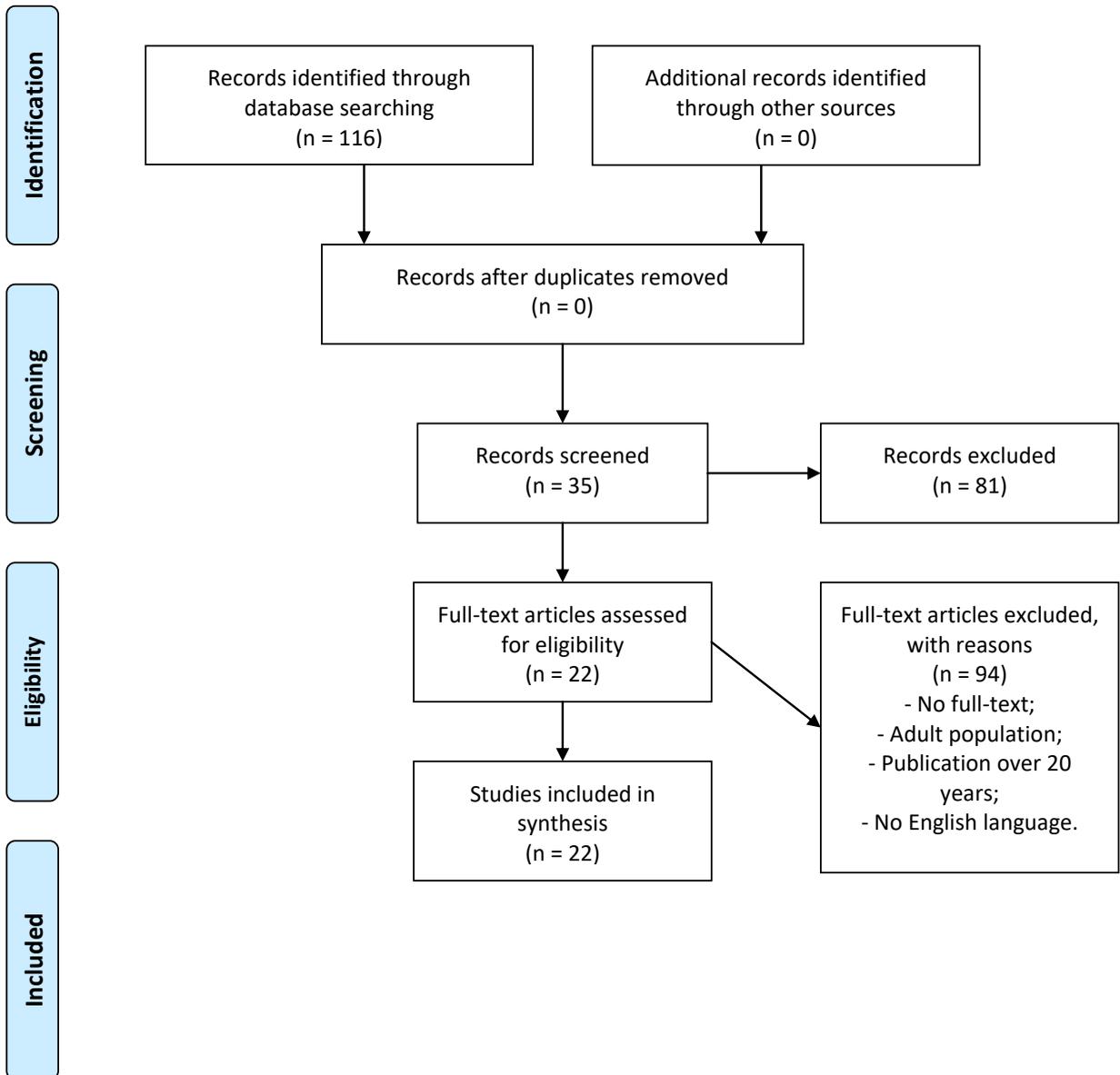


Figure 1. Prisma Flow Diagram

Table 1. Report of research

Author/s (year), title	Study design	Purpose	Sample size and sites	Key findings/ comments
Bath et al. (2016), Impact of standardization of antimicrobial prophylaxis duration in pediatric cardiac surgery	Almost experimental study	To evaluate the clinical impact after implementation of a protocol that limited postoperative prophylaxis to 48 hours following sternal closure in pediatric cardiac surgery.	Patients 18 years and younger who underwent cardiac surgery from April 2011 to November 2014 at a single institution	The implementation of a protocol limiting antimicrobial prophylaxis to 48 hours following sternal closure.
Cannon et al. (2016), Improving surveillance and prevention of surgical site infection in pediatric cardiac surgery.	Almost experimental study	To implement the surgical surveillance of wounds and reduce the incidence of surgical site infections in patients undergoing cardiac surgery.	Infants and children underwent cardiac surgery within 30 days by the operation.	The surveillance of the cardiac surgery wound and the introduction of process and surveillance measures based on NHS guidelines for the prevention of SSIs.
Caruso et al. (2018), A Postoperative Care Bundle Reduces Surgical Site Infections in Pediatric Patients Undergoing Cardiac Surgeries.	Quality improvement (QI)	To study a postoperative SSI reduction care bundle for pediatric patients after cardiac surgery.	Pediatric patient after cardiac surgery from January 1, 2013, through May 31, 2015, and an intervention/sustainment period from June 1, 2015, through March 30, 2017.	Describes five key drivers and 11 elements that were dedicated to reducing the risk of SSI during prolonged CVICU recoveries from pediatric cardiac surgery.
Costello et al. (2010), Risk factors for surgical site infection after cardiac surgery in children	Matched case-control study (Retrospective)	To identify risk factors for any type of surgical site infections (SSI) in children undergoing cardiac surgery in a large congenital heart program.	All patients experiencing any type of SSI after undergoing cardiac surgery at Children's Hospital Boston from January 2004 through December 2006.	Prevention of SSI.
Delgado-Corcoran et al. (2017), Reducing pediatric sternal wound infections: a quality improvement project. Pediatric Critical Care Medicine	Qualitative study	The implementation of a bundle for the prevention of surgical site infections.	Pediatric patients undergoing cardiac surgery by median sternotomy, from January 2010 to December 2014.	To reduce the incidence of cardiac site infections in users undergoing delayed sternal closure.
Harder et al. (2013), Risk factors for surgical site infection in pediatric cardiac surgery patients undergoing delayed sternal closure.	Case-control study	To determine the incidence and risk factors for SSI in users undergoing cardiac surgery with delayed sternal closure.	375 pediatric patients (aged <18 years) undergoing delayed sternal closure, between January 1, 2005, and December 31, 2009.	To find new treatment strategies for the prevention and prophylaxis of SSI in pediatric intensive care.

Author/s (year), title	Study design	Purpose	Sample size and sites	Key findings/ comments
Hatachi et al. (2019), Antibiotic Prophylaxis for Open Chest Management After Pediatric Cardiac Surgery.	Retrospective, single-center, observational study	To compare the occurrence rates of bloodstream infection and surgical site infection between the different prophylactic antibiotic regimens for open-chest management after pediatric cardiac surgery.	Patients younger than or equal to 18 years old with open chest management after cardiac surgery followed by delayed sternal closure, between January 2012 and June 2018 in a PICU at a tertiary children's hospital.	To reduce SSIs and BSIs for open-chest pediatric patients after cardiac surgery
Kansy et al. (2012), Major infection after pediatric cardiac surgery: external validation of risk estimation model	Retrospective analysis	To validate externally the Society of Thoracic Surgeons (STS) risk estimation model and verify its specific risk factors using a single institution's complete and verified database.	Patients 18 years or younger at their institution who between 1995 and 2010 underwent major congenital heart surgery procedures classified using both ABC and RACHS-1.	The clinical impact of the model developed using STS Congenital heart Surgery data as a tool for predicting serious postoperative infections and providing information that can and should be used for prevention and neutralization of the risk of this major complication.
Katayanagi et al. (2015), Nasal methicillin-resistant <i>S. aureus</i> is a major risk for mediastinitis in pediatric cardiac surgery.	Retrospective study	To investigate the preoperative, intraoperative, and postoperative factors that are associated with the occurrence of mediastinitis.	Patients aged < or = 15 years who underwent pediatric open-heart surgery between October 2002 and October 2010.	The success of the comprehensive SSI prevention measures implemented in their hospital.
Lex et al. (2013), Postoperative differences between colonization and infection after pediatric cardiac surgery—a propensity matched analysis	Prospective single-center study	To identify the postoperative risk factors associated with the conversion of colonization to postoperative infection in pediatric patients undergoing cardiac surgery.	Pediatric (<18 years) patients between January 1, 2004, and December 31, 2008.	The comparison between bacterial colonization and the clinical infection in the pediatric cardiac population.
Macher et al. (2016), Preoperative Staphylococcus aureus Carriage and Risk of Surgical Site Infection After Cardiac Surgery in Children Younger than 1 year: A Pilot Cohort Study	Monocentric prospective pilot cohort study	To describe the prevalence of Staphylococcus Aureus (SA) colonization in children under 1 year old before cardiac surgery.	Children <1 year old, undergoing cardiac surgery under cardiopulmonary bypass from May 2012 to November 2013.	The association between SA colonization and surgical site infections (SSI) incidence.

Table.1 (continued)

Author/s (year), title	Study design	Purpose	Sample size and sites	Key findings/ comments
Murray et al. (2014a), Surgical site infections and bloodstream infections in infants after cardiac surgery.	Retrospective cohort study	To determine the incidence of surgical site infections (SSIs) and bloodstream infections (BSIs) in infants after cardiac surgery.	470 infants (aged <1-year-old) undergoing cardiac surgery from January 2010 to December 2011.	To identify the risk factors, the responsible pathogens and their susceptibility to antimicrobial agents.
Murray et al. (2014b), Implementing a standardized perioperative antibiotic prophylaxis protocol for neonates undergoing cardiac surgery.	Almost experimental study	To develop a standardized perioperative antibiotic prophylaxis protocol for neonates undergoing cardiac surgery.	Infants who underwent cardiac surgery from 1 July 2009 to 30 June 2012.	To assess compliance with selected process measures for perioperative antibiotic prophylaxis.
Nayar et al. (2016), Improving Cardiac Surgical Site Infection Reporting and Prevention By Using Registry Data for Case Ascertainment	Quality improvement (QI)	Linking clinical registry and infection surveillance data to the electronic health record data to improve identification of at-risk cases, adjudicating and resolving differences across the various data sources, visualizing surgical site infections (SSI) rates according to the different data sourced and criteria, and implementing QI interventions to decrease the incidence of SSI.	Children's Hospital of Philadelphia SSI data from January 2013 to December 2014	Integrating clinical registry data with administrative and infection surveillance data for more accurate SSI rates.
Nelson-McMillan et al. (2016), Delayed Sternal Closure in Infant Heart Surgery-The Importance of Where and When: An Analysis of the STS Congenital Heart Surgery Database	Regression analysis	The evaluation of the rate of infectious complications associated with maintenance of an open sternum in the infant cardiac surgery population.	Infants (age 0 to 365 days) undergoing open-heart surgery at center participating in the Society of Thoracic Surgeons Congenital Heart Surgery database from January 1, 2007, through December 31, 2013.	Maintaining an open sternum for a few days is associated with a considerable risk of infection.
Sen et al. (2017), Postoperative Infection in Developing World Congenital Heart Surgery Programs: Data From the International Quality Improvement Collaborative	Quality improvement (QI)	To identify risk factors for postoperative infection and the impact on outcomes after congenital heart surgery.	Congenital heart surgery in patients < 18 years of age between January 2010 and Decembre 2012.	To provide a platform for a robust data collection, data reports for self-evaluation, and an educational program for quality improvement.
Silveti et al. (2017), Preoperative colonization in pediatric cardiac surgery and its impact on postoperative infections	Retrospective cohort study	To verify the association between colonization and clinical infection.	Patients aged < or = 18 years who underwent pediatric open-heart surgery in the years 2015.	Patient colonization and antimicrobial prophylaxis.

Author/s (year), title	Study design	Purpose	Sample size and sites	Key findings/ comments
Sochet et al. (2017), Surgical Site Infection After Pediatric Cardiothoracic Surgery.	Matched cohort study (Retrospective)	To assess the health-care cost and resource utilization associated with surgical site infections (SSI) in children.	Children (aged 0 to 18 years) with deep and organ/space SSI after cardiothoracic surgery (CTS), from January 2010 to December 2013.	The attributable hospital cost associated with SSI following pediatric CTS.
Staveski et al. (2016), Silver-Impregnated dressings for sternotomy incision to prevent surgical site infections in children.	Clinical prospective randomized controlled trial	The identification and drafting of a multidisciplinary protocol to evaluate the effectiveness of silver impregnated dressing, Silver with the aim of reducing SSI in children undergoing cardiac surgery.	Patients aged under 18 years old with congenital heart disease undergoing by median sternotomy.	The prevention of the SSI.
Turcotte et al. (2014), Health care-associated infections in children after cardiac surgery	Retrospective cohort study	To assess the epidemiology of several types of health care-associated infections (HAIs).	Children 18 years of age or younger undergoing cardiac surgery from July 2010 to June 2012.	To find potentially modifiable pre-, intra-, and postoperative risk factors.
Woodward et al. (2011), Sternal wound infections in pediatric congenital cardiac surgery: a survey of incidence and preventative practice	Survey study	To determine the incidence of and preventative practice regarding pediatric sternal wound infections with a long-term aim to develop best practice guidelines.	Children less than 18 years of age.	Pre, intra and postoperative measures to prevent sternal wound infections.
Woodward et al. (2017), Multicenter Quality Improvement Project to Prevent Sternal Wound Infections in Pediatric Cardiac Surgery Patients	Quality Improvement (QI)	To improve the health care of children by evaluating the efficacy of a protocolized approach to reduce Sternal wound infection.	Patients up to 18 years of age, who underwent sternotomy for cardiac surgery from July 1, 2013, to June 30, 2015.	The importance of adhering to a standardized protocol.

wound prevention bundle (SWPB), where each single center in the four analyzed studies adopted different items, in pediatric cardiac patients results in both a standardizations of the peri-operative care to prevent sternal wound infection (SWI) (25) and a significant reduction in patients with delayed sternal closure (DSC) (10, 22, 23). Other four articles (13, 19, 21, 24) adopted a similar approach, that is, the use of common guidelines across the multidisciplinary team, to reduce SSIs. The authors showed how the implementation of quality improvement measures, such as linkage of registry and infection control surveillance, pediatric preventive guidelines and practice bundles, are considered an effective and systematic way to deliver preventive measures for reducing the SSIs (13, 19, 21, 24).

Relationship between colonization and clinical infection (SSIs rate). Three articles (17, 18, 20) show that there is no significant difference between colonized and non-colonized children regarding the SSIs rate (17, 18, 20). Colonization can be caused by MRSA and Methicillin-Sensitive Staphylococcus Aureus (MSSA), β -Lactamase-Producing Enterobacteria (ESBL), Vancomycin-Resistant Enterococci (VRE), ESBL, or Carbapenems-producing Enterobacteriaceae (CPE). Another important point specified in some studies is the use of the pre-operative nasal culture. Some studies show an association between nasal colonization by Methicillin-Resistant Staphylococcus Aureus (MRSA) and surgical site infection following heart surgery in pediatric patients (8).

Table 2. Univariate risk factors for SSI

Variable
Pre-operative factors
ABC score
BSA (m ²)
Male
Age (year)
RACHS-1 category
Pre-operative-Ventilatory support or tracheostomy
Pre-operative Hospitalization (day)
Acidosis (EGA)
Shock
Genetic abnormalities
Pre-operative-Hb (g/dl)
Positive nasal culture of MRSA
Intra-operative factors
Complexity of surgical procedure
Operation time (hour)
CPB time (hour)
CPB-circuit volume (dl/m ²)
Lowest rectal temperature (°C)
DUF±MUF (dl/m ²)
Post-operative factors
Blood transfusion
Mechanical ventilation (hour)
Chest drainage tube duration (day)
Antimicrobial Prophylaxis (day)
PICU stay (day)

ABC: Aristotle Basic Complexity; BSA: Body Surface Area; CI: Confidence interval; CPB: Cardiopulmonary Bypass; DUF: Dilutional Ultrafiltration; Hb: Hemoglobin; PICU: Pediatric Intensive Care Unit; MUF: Modified Ultrafiltration; MRSA: Methicillin-resistant *Staphylococcus aureus*; RACHS-1: Risk Adjustment for Congenital Heart Surgery.

(Harder et al., 2013, Murray et al., 2014a, Katayanagi 2015, Nelson-McMillan et al., 2016, Kansy et al., 2012, Costello et al., 2010, Sen et al., 2017, Lex et al., 2013, Turcotte et al., 2014).

The impact of SSIs in terms of costs for the health-care system. One article (11) deals with this topic. The study of Sochet et al. (2017) is the first to value the hospital cost associated with SSIs following pediatric congenital heart surgery, showing an increased operational and departmental cost. The SSIs increase the

length of stay (LOS) in the hospital, and this exposes children to a greater risk of catheter-associated blood infections, venous thromboembolism, accidental extubations, catheter-associated urinary tract infections, ventilator-associated pneumonia, and adverse events (11).

Discussion

The infection of the sternal wound after cardiac surgery is a serious concern. According to Woodward et al. (2011) the incidence of major infection remains a source of morbidity and mortality in post-operative pediatric cardiac patients. The identification of healthcare-associated infections (HAIs) in the pediatric population after cardiac surgery is useful in all peri-operative phases (9). The literature shows that adult standardized guidelines for cardiac surgery wound management should not be used with paediatric populations since there are substantial differences between adults and children. One important point investigated in many studies is the impact of standardized peri-operative antibiotic prophylaxis protocols for pediatric cardiac surgery. Bath et al. (2016) demonstrated that limiting antimicrobial prophylaxis to 48 hours post-operative pediatric cardiac surgery did not increase the incidence of SSIs or alter other clinical outcomes in this population (23). Murray et al. (2014) demonstrated that limiting peri-operative antibiotic prophylaxis after neonatal cardiac surgery to 48 hours in neonates with a closed sternum and to 24 hours after sternal closure is safe and does not increase the rate of SSIs. (22). Delgado-Corcoran and colleagues reported lower SWI rates caused by *Staphylococcal*; however, MRSA contributed to 10% of those infections. MRSA is associated with higher mortality rates, longer hospital length of stay, and higher hospital costs if compared with other infections (10). The duration of pre-operative hospitalization is important in the prevention of SSIs (17). The study of Katayanagi suggests that treatment with Mupirocin is an effective tool (3). Mupirocin should be given intranasally to all patients with documented *Staphylococcus Aureus* (SA) colonization (17). The pre-operative eradication of SA was proven effective in the prevention of SSIs

and in the control of MRSA; however, the continuation of prophylactic antibiotic therapy in conjunction with delayed sternal closure may introduce antimicrobial resistance (8). In contrast to the reports above, the study by Macher and colleagues (2017) finds no association between SA carriage and the incidence of SSIs (20). Further studies are necessary in order to analyze this association. Previous studies (1, 2, 3, 4, 5, 6, 7, 8, 9) have evaluated risk factors for specific types of post-operative infections.

Standardized adult guidelines for cardiac surgery wound management may not be effective on the pediatric populations (13), as the first are based on different risk factors (e.g., obesity, diabetes and smoking) compared to the ones considered in the pediatric population (age lower than one month, duration of surgery, presence of genetic abnormalities, prolonged extracorporeal circulation time (ECMO), delayed sternal closure, pre-operative hospitalization and prolonged post-operative hospitalization, post-operative hemorrhage, and persistent low cardiac output) (10, 14).

According to the literature, the institution of a multidisciplinary team where coworkers follow a standardized protocol improves the patients' outcomes.

Galvin et al. (2009) assess that the adoption of a standardized procedure for how nurses perform skin preparation produces a positive effect on the practice over time (27).

Jha et al. (2020) demonstrate that a protocol-based bundled approach reduces the incidence of SWI (28). Blasco et al. (2015) underline the importance of implementing a multidisciplinary infection control program to reduce the incidence of SSIs in children and neonates undergoing cardiac surgery. Staveski et al. (2016) describe the Asepsis Tool as a valid tool for monitoring the assessment of cardiac surgery injury in the adult population. It consists of data sheet that allows the nurse to perform an initial wound assessment and to compare the subsequent evaluations throughout observable data calculated with numerical scores. The survey of 28 children's cardiac surgery programs of Woodward et al. (2020) presents an overview of the responders' efforts to reduce infection in their DSC patients. These programs showed very different approaches and, eventually, a few indicators were collected regarding what works to decrease infection in this population (29).

The standardization of the behavior of health workers, by the use of standardized protocol and guidelines, and the education for a correct use of these instruments, can strongly influence the patient's assistance and the consequent development of infections (25). Thirty-Six percent of the SSIs are identified after the patient's discharge from the hospital (21). The education of family members and a confident/strong collaboration with them are essential to reduce this incidence. The surveillance path of Cannon et al. (2016) revealed how family involvement and multidisciplinary work, both hospital and territorial, reduced SSIs. Therefore, the collaboration between the multidisciplinary team and the patient's family is fundamental during and after hospitalization since the risk of developing a sternal wound infection persists after the patient discharge.

Limits. The limited and restricted literature connected to single centers, with relatively small sample sizes, and the use of a single database.

Conclusion

From this literature review we can observe one-way indication for the management of the pediatric cardiac surgery wound. All the studies agree that the use of validated and shared tools, as well as the establishment of standardized protocols, consent to improve the SSI management. The common goal is the adoption of prevention techniques for contrast the insurgence of infections. The threat does not end with the discharge of the patient. For this reason, the post-operative follow-up is fundamental. Therefore, it is essential to create a strong network between the multidisciplinary hospital staff and the pediatric patient family.

Further research is necessary for the realization of standardized protocols or guidelines for the management of the pediatric cardiac surgery wound.

Conflicts of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Authors contribution: Angela Prendin is the Principal Project Leader. Benedicita Tabacco, Paola Claudia Fazio, Ilaria de Barbieri they helped to draft manuscript and approved the final manuscript.

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