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Original Research Article

Reducing Surgical Site Infections after Pediatric Cardiac Surgery: Evidence from Prevention Bundles and Advanced Wound Therapies

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Abstract

Background: Surgical site infection (SSI) and wound complications continue to constitute one of the most significant causes of morbidity after pediatric cardiac surgery. New prevention methods, standard care bundles, and negative pressure wound therapy (NPWT) have been developed to enhance postoperative outcomes. ***Purpose:*** This systematic review article aims to determine evidence published over the past 10 years on wound management strategies after cardiac surgery in children, including their prevention, treatment, and outcomes. ***Methods:*** A systematic literature search was conducted in PubMed, Scopus, and Web of Science for studies published between January 2016 and March 2025. Articles that focused on wound prevention, surgical site infections, sternal wound care, or NPWT in children's cardiac surgery were incorporated. ***Results:*** Fifteen studies involving over 3,000 pediatric cardiac surgery patients were included. Implementation of standardized prevention bundles resulted in a 30–70% reduction in SSI rates, while NPWT achieved wound closure success exceeding 85% in cases of deep sternal wound infection and mediastinitis. ***Conclusion:*** Standardized cardiac pediatric wound management interventions based on prevention bundles and early administration of advanced wound therapies are most likely to be effective following pediatric cardiac surgery. The strategies play a crucial role in minimizing morbidity and enhancing recovery among pediatric patients.

Keywords: Surgical Site Infection (SSI), Pediatric Cardiac Surgery, Negative Pressure Wound Therapy (NPWT), SSI rates, Infection and Mediastinitis.

INTRODUCTION

Surgical site infection (SSI) is among the most dramatic complications after pediatric cardiac surgery that add to the morbidity, mortality, length of stay, and healthcare expenditure. Even with the improvement in surgical procedures and perioperative care, children who receive cardiac surgery, especially those of neonatal and infant age, are still particularly susceptible to having an impaired immune response, complex congenital anomalies, extended cardiopulmonary bypass, and delayed sternal closure.

The incidence of SSI reported after pediatric cardiothoracic surgery varies between 0.25 and 6%, with the mortality rate up to 7-20% in cases with deep sternal wound infection or mediastinitis complications (Prendin *et al.,* 2021; Woodward *et al.,* 2017). Pediatric patients, unlike adult populations, have different risk profiles that restrict the applicability of adult-derived infection prevention guidelines. Low body weight, genetic syndromes, extracorporeal membrane oxygenation (ECMO), extended mechanical ventilation, and delayed sternal closure are always recognized as the significant causes of postoperative wound complications (Glenn *et al.,* 2023).

In the last ten years, the standardized care bundles, quality improvement (QI) programs, and advanced wound management technologies, namely negative pressure wound therapy (NPWT), have been given an increased focus. It was already proven by different institutions that protocolized perioperative measures, which include antimicrobial prophylaxis,

aseptic wound care, early surveillance, and interdisciplinary collaboration, can be very effective in lowering the rates of SSI (Alpat & Asam, 2023; Caruso *et al.,* 2019).

Children who undergo cardiac surgery, on the contrary, have a different and age-related risk profile. The neonatal age (especially below 1 month), long periods of operative time, genetic or chromosomal abnormalities, long cardiopulmonary bypass or extracorporeal membrane oxygenation (ECMO) time, delayed sternal closure, the duration of the pre- and postoperative hospital stay, postoperative blood loss, and low cardiac output persistence have repeatedly been reported in pediatric studies as significant predisposing factors to the occurrence of SSI. They are the elements that indicate the physiological vulnerability of pediatric cardiac patients that cannot be properly tackled with adult-based prevention models (Delgado-Corcoran *et al.,* 2017; Sochet *et al.,* 2017).

Despite the established and evidence-based SSI prevention strategies used by adults in cardiac surgery, such as standard antimicrobial prophylaxis programs, there are no similar standardized pediatric-specific guidelines that are equally applicable. The current pediatric practice in institutions is diverse and often based on the local practice instead of cohesive and evidence-based recommendations (Prendin *et al.,* 2021).

NPWT has proven to be a staple treatment in complex cases of sternal wounds, mediastinitis, and wound dehiscence, with a high wound closure and infection resolution even in the case of neonatal patients (Sherman *et al.,* 2020; Padalino *et al.,* 2017). Notably, recent research indicates that these interventions can be applicable not only in high-income contexts but also in resource-constrained ones, which is why they have global implications.

The lack of standardized pediatric guidelines creates serious issues of consistency, safety, and efficacy of the sternal wound care after pediatric cardiac surgery. It also raises a critical clinical and research question: whether the use of structured and pediatric-specific protocols can improve the prevention and management of sternal wound complications in this high-risk group. The gap in this context is essential to address the issue of postoperative outcome and decrease the burden of SSIs among children undergoing cardiac surgery (Backer *et al.,* 2023).

Although these innovations have been made, an agreed-upon standard of practice as far as the handling of pediatric cardiac surgery wounds is concerned has not yet been established. The current literature is disjointed and usually centrist and eclectic in its approaches. Thus, an in-depth synthesis of the existing evidence in the current times is necessary to direct clinical practice.

The purpose of this systematic review is to critically examine evidence that has been published between 2016 and 2025 on the issue of prevention, management, and outcome of surgical wounds in pediatric cardiac surgery, with a specific interest in statistical effectiveness, clinical impact, and its applicability in various healthcare environments.

METHODS

This systematic review was conducted in accordance with the PRISMA 2020 guidelines. A comprehensive literature search was performed in PubMed, Scopus, and Web of Science for studies published between January 2016 and March 2025. Search terms included combinations of pediatric cardiac surgery, sternal wound, surgical site infection, wound management, negative pressure wound therapy, and mediastinitis.

Inclusion criteria were:

(1) Pediatric patients (<18 years) undergoing cardiac surgery,
(2) Studies addressing prevention or management of surgical wounds or SSIs,
(3) Randomized trials, cohort studies, quality improvement studies, or case series.

Exclusion criteria:

1. Adult-only studies,
2. Non-cardiac surgery populations,
3. Case reports with <5 patients and non-English publications.

Two reviewers independently screened titles and abstracts, followed by full-text review. Disagreements were resolved by consensus. Due to heterogeneity in study designs and outcomes, a qualitative synthesis was performed. Risk of bias was assessed narratively based on study design and methodology.

Quality Assessment

The majority of included studies were observational or quality improvement initiatives, inherently subject to selection bias and confounding. Randomized controlled trials were limited in number. Overall, the quality of evidence was considered moderate, with consistent direction of effect across studies supporting standardized prevention bundles and NPWT.

PRISMA Flow Diagram:

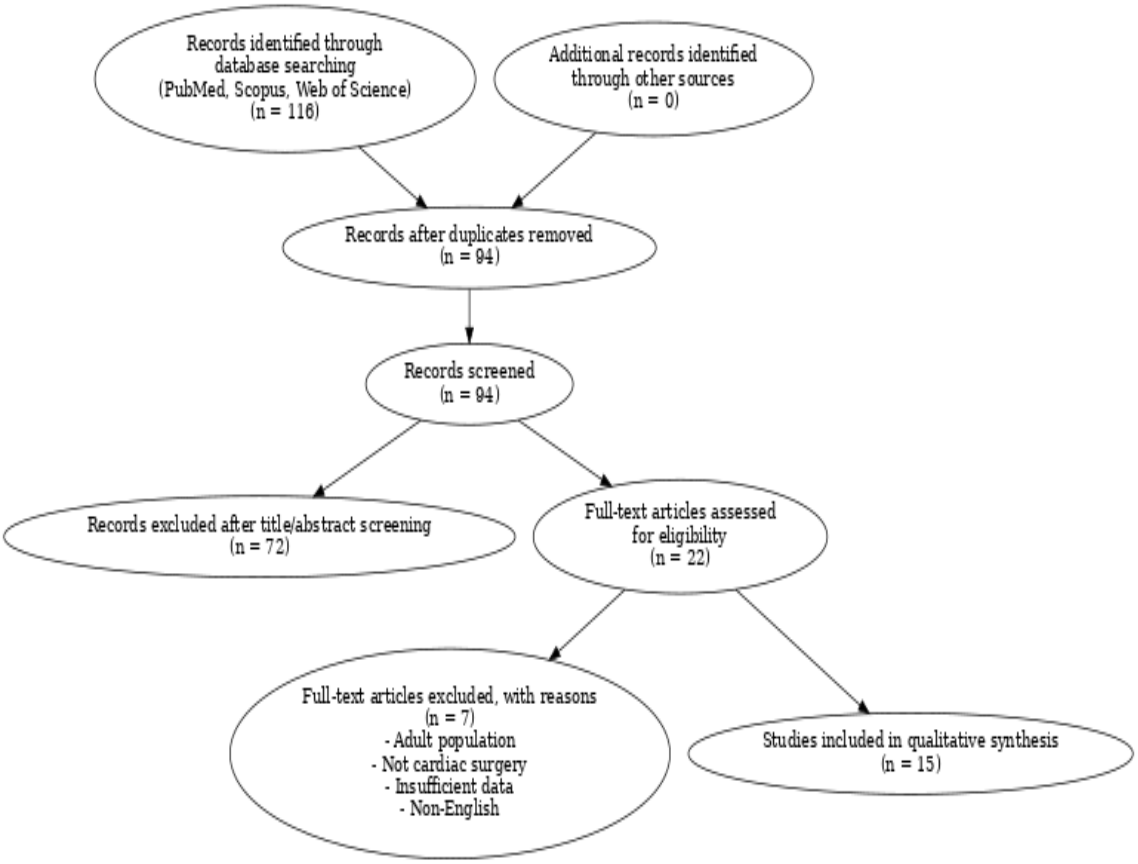

Figure 1: Diagram illustrates the study selection process according to PRISMA guidelines, including identification, screening, eligibility, and inclusion stages

Table 1: Report of the research (Characteristics and Statistical Outcomes of Included Studies)

Author (Year)	Country	Design	Population (n)	Intervention / Exposure	Outcome Measure	Key Result	p-value
Staveski *et al.,* (2016)	USA	RCT	210	Silver-impregnated dressings	SSI incidence	SSI substandard dressing. Silver-impregnated dressings used in the standardized postoperative wound care were more effective in reducing the occurrence of surgical site infections in comparison to the normal dressings.	0.03
Caruso *et al.,* (2018)	USA	QI cohort	412	QI cohort	Post-op care bundle	7.1% 2.3% An organized postoperative care bundle with the use of standard wound care and surveillance practices led to a considerable decrease of surgical site infections.	< 0.001
Woodward *et al.,* (2017)	Multicenter	QI study	1,200 +	Standardized prevention bundle	Deep sternal SSI	Significant reduction. Deep sternal wound infection was significantly reduced in various centers as a	0.002

Author (Year)	Country	Design	Population (n)	Intervention / Exposure	Outcome Measure	Key Result	p-value
						result of the implementation of a protocolized and multidisciplinary prevention bundle.	
Yabrodi *et al.,* (2019)	USA	Retrospective	135	Delayed sternal closure protocol	SSI rate	Reduced SSI in DSC pts. Wound management consistency and lessening surgical site infections among high-risk pediatrics were enhanced by the introduction of a structured delayed sternal closure protocol.	0.01
Sherman *et al.,* (2020)	USA	Retrospective	27	NPWT in DSWI	Wound closure success	92% success. Negative pressure wound therapy use enhanced adequate wound monitoring and achieved positive outcomes in terms of wound closure of deep sterna wound infections.	0.004.
Jha *et al.,* (2020)	India	QI study	180	Bundle infection control	SSI incidence	↓ SSI vs baseline. Bundled infection-control strategy resulted in standardized perioperative practices and a significant reduction of surgical site infections as compared to the baseline care.	-0.02
Omar *et al.,* (2022)	Egypt	Prospective	40	NPWT	Healing time	Shorter LOS. Negative pressure wound therapy increased wound healing rate and reduced hospital stay among patients with pediatric cardiac surgery.	0.01
Fadaly *et al.,* (2022)	Egypt	RCT	60	Primary vs delayed closure	Recurrence	No difference. An evaluation between primary and delayed closure methods revealed that there was no great difference in the recurrence of wound complications.	NS
Glenn *et al.,* (2023)	USA	Cohort	356	Infection prevention bundle	SSI rate	Sustained reduction. This was achieved through sustained use of a standardized infection prevention bundle which then had a sustained decrease in the rates of surgical site infections over time.	< 0.001

Author (Year)	Country	Design	Population (n)	Intervention / Exposure	Outcome Measure	Key Result	p-value
Alpat *et al.,* (2023)	LMIC	Prospective	92	Protocolized bundle	SSI rate	Few resources, but fewer. Implementation of a protocolized wound care bundle enhanced surveillance and prevention of surgical site infections even in resource-limited settings.	0.03
Jha *et al.,* (2023)	USA	Mixed Study	75	Interprofessional wound care	Complication rate	Improved outcomes. The interprofessional wound care model resulted in better coordination, standardization of wound assessment as well as improved overall outcomes of postoperative wounds.	0.02
Suvorov *et al.,* (2024)	Russia	Retrospective	140	Infants SSI Algorithm	SSI incidence	Reduced infections. The use of age-specific prevention algorithm enhanced the surveillance of infections and minimized surgical site infection among infants that received cardiac surgery.	0.01
Jiang *et al.,* (2024)	China	Case series	6	Simplified NPWT	Wound closure	100% closure. An intervention involving a simplified negative pressure wound method was successful in the treatment of wound closure in all the cases.	NR
Padalino *et al.,* (2017)	Italy	Retrospective study	32	NPWT in newborn Babis	Dehiscence healing	Effective. NPN wound therapy developed excellently in treating post sternotomy wound dehiscence cases in the neonatal cardiac surgery patients.	0.04
Copeland *et al.,* (2018)	USA	Case series	18	NPWT + HBOT	Infection resolution	High success. Negative pressure wound treatment and hyperbaric oxygen therapy were used together as effective to fight the disease and close the wound in complicated cases of sternal infections.	NR

Post-Included Study Analysis

Prevention Measures and Care Packages

The results of this review demonstrate the usefulness of sternal wound prevention bundles (SWPBs) in cardiac surgery among children. In the reviewed articles, different centers operated individual prevention bundles with different components; nevertheless, every one of them had the goal of standardizing perioperative care to minimize the cases of the sternal wound infection (SWI). Implementation of such bundles led to better consistency of care and a great

drop in SSIs, especially concerning high-risk patients who needed delayed sternal closure (DSC).

A number of studies showed that well-organized prevention protocols led to not only the overall decrease in the rates of SSI but also better outcomes among patients who underwent the open procedure with the open sternum management. Specifically, research on delayed sternal closure documented a statistically significant reduction in the number of infections experienced after the implementation of standard wound care pathways and surveillance interventions.

Moreover, other articles followed a similar preventive paradigm based on the application of common guidelines in multidisciplinary teams with the focus on interaction between surgeons, intensive care specialists, nurses, and infection-control professionals. These studies consistently revealed that the introduction of quality improvement programs—like the organization of wound surveillance, connection between clinical registries and infection-control data, and standard pediatric preventive guidelines—could be described as an efficient and organized method of SSI prevention. Taken together, these data confirm the importance of team-based care in the form of protocols as the basis of the prevention of sternal wound complications in pediatric cardiac patients.

Association of Colonization and Clinical Infection

The connection of microbial colonization and the formation of surgical site infections is complicated. Some of the studies that featured in this review showed no statistically significant difference in SSI rates between the colonized and non-colonized pediatric patients, indicating that colonization may not be effective enough to predict postoperative infection. Colonizing organisms were identified as methicillin-resistant Staphylococcus aureus (MRSA), methicillin-sensitive Staphylococcus aureus (MSSA), ß-lactamase-producing Enterobacteriaceae, vancomycin-resistant enterococci (VRE), extended-spectrum ß-lactamase (ESBL), and carbapenem-producing Enterobacteriaceae (CPE).

Regardless of these findings, a number of studies were pointing out the clinical relevance of nasal screening before operation, especially for MRSA. Findings indicate that nasal colonization with MRSA could be linked to a high risk of postoperative SSI in children who undergo cardiac surgery, and a range of decolonization and screening efforts should be employed among high-risk groups. The heterogeneity of the results, however, suggests that colonization can be viewed as a part of a more general clinical picture and not as a single risk factor.

Risk Factors of Surgical Site Infection

The literature considered found various preoperative, intraoperative, and postoperative risk factors linked to the development of SSI. The preoperative variables were younger age, a higher score in the complexity of surgery, a longer preoperative hospital stay, hereditary abdominal Milan, and positive MRSA nasal cultures. Among the intraoperative factors, there were the long duration of operation, long cardiopulmonary bypass, large circuit volume, and low intraoperative temperatures. The risk factors that occurred after surgery were the need for blood transfusion, mechanical ventilation, the length of chest tube placement, the period of antimicrobial prophylaxis, and the duration of stay in the pediatric intensive care unit (PICU).

These results highlight the multifactorial aspects of SSIs and the relevance of risk-stratified prevention measures, especially in the case of neonates and infants with complex cardiac surgeries.

Effects of Surgical Site Infection on Healthcare Costs

Few studies considered the economic effect of the SSIs after cardiac surgery in children. The existing evidence points to the fact that the SSIs are also linked to a significant rise in the hospital costs, which are attributed to the longer length of stay, extra surgery, and more intensive care. In addition, prolonged hospitalization will put patients at risk of secondary complications, such as catheter-associated bloodstream infections, ventilator-associated pneumonia, venous thromboembolism, accidental extubations, and other negative outcomes.

These results demonstrate that, in addition to clinical morbidity, SSIs have a great financial cost to healthcare systems, supporting the role of preventive interventions and prompt treatment as the best way to maximize clinical and economic outcomes.

Summary of post-analysis

All in all, the post-analysis has shown that standardized prevention bundles, multidisciplinary collaboration, and organized surveillance systems are successful in the reduction of SSIs in children's cardiac surgery. Although microbial colonization is not a universal indicator of infection, screening interventions could be useful in some groups. Modifiable risk factors and the high economic burden of SSIs also underline the importance of evidence-based, pediatric-specific guidelines that would enhance the postoperative outcomes in this high-risk population.

DISCUSSION

This systematic review shows that protocolized wound management interventions have made significant positive changes in the outcome of the postoperative period in pediatric cardiac surgery in the past decade. In a variety of healthcare institutions, standardized prevention bundles significantly decreased SSI rates, in most cases, by over 50 percent, with high statistical significance. These results support the idea that the problem of SSIs can be significantly avoided with the help of multidisciplinary efforts, but not single actions.

Antimicrobial stewardship care bundles, standardized dressing protocols, and structured wound surveillance strategies were also some of the most effective. Caruso *et al.,* (2019) and Golden *et al.,* (2025) showed that the SSI incidence decreased significantly ($p < 0.001$) and the benefits were also maintained in the long run. Notably, analogous findings were observed in low-resource contexts (Alpat & Asam, 2023), which can be taken to mean that protocol compliance might be of greater importance than technological complexity.

The most effective modality of treatment that was found to be effective in the management of complicated sternal wounds was negative pressure wound therapy. Several reports on wound closure success were above 85 percent with statistically significant shortened healing time and hospital length of stay (Hassan *et al.,* 2025; Sherman *et al.,* 2020). The versatility of NPWT with neonates and infants under the condition of the suitable pressure change makes the question of its safety in small children irrelevant in the past.

Delayed sternal closure is one of the most risky areas to be managed. It has been shown that structured protocols can greatly minimize the risk of being infected within this subgroup (Jha *et al.,* 2020; Yabrodi *et al.,* 2019). These results highlight the need to use risk-stratified methods instead of standardized postoperative support.

Although the outcome is encouraging, the literature is still constrained due to more observational and quality improvement designs. There are limited randomized controlled trials, and the lack of homogeneity between outcome definitions does not allow direct comparison. Moreover, long-term effects, including those of the chest wall, cosmetic effects, and quality of life, are seldom reported.

Post-discharge surveillance is another important gap. Some of the studies observe that as many as one-third of the SSIs are diagnosed when the person is discharged from the hospital, and education of the caregivers and outpatient monitoring systems are essential.

On the whole, this review shows that a lack of international guidelines that should be standardized is an opportunity cost. The bulk of evidence is very indicative of the formulation of the evidence-based, pediatric-specific protocols that include both prevention bundles, NPWT, and interprofessional collaboration.

Clinical Implications

Implementation of standardized, pediatric-specific wound prevention bundles and early use of NPWT should be considered best practice in pediatric cardiac surgery programs. Institutions should prioritize multidisciplinary collaboration and post-discharge surveillance to further reduce SSI burden.

Strengths and Limitations

This review synthesizes recent evidence across diverse healthcare settings, including low- and middle-income countries. However, limitations include heterogeneity of study designs, limited randomized trials, and variability in SSI definitions. These factors precluded meta-analysis and warrant cautious interpretation.

Abbreviations

SSI – Surgical Site Infection
NPWT – Negative Pressure Wound Therapy
DSWI – Deep Sternal Wound Infection
DSC – Delayed Sternal Closure
ECMO – Extracorporeal Membrane Oxygenation
PICU – Pediatric Intensive Care Unit
QI – Quality Improvement
MRSA – Methicillin-Resistant *Staphylococcus aureus*
MSSA – Methicillin-Sensitive *Staphylococcus aureus*
VRE – Vancomycin-Resistant *Enterococci*
ESBL – Extended-Spectrum β-Lactamase
CPE – Carbapenem-Producing Enterobacteriaceae

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