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Reducing Pediatric Sternal Wound Infections: A Quality Improvement Project

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Abstract

Objectives—To evaluate whether a quality improvement intervention reduces sternal wound infection (SWI) rates in children after cardiac surgery.

Design—This is a pre- and post-intervention quality improvement study.

Setting—A 16-bed cardiac intensive care unit in a university-affiliated pediatric tertiary care children's hospital.

Patients—All patients undergoing cardiac surgery via median sternotomy from January 2010 to December 2014 are included. The SWI rates for primary closure (PC) and delayed sternal closure (DSC) are reported per 100 sternotomies. The hospital acquired infection (HAI) records were used to identify pre- intervention cases, while post-intervention cases were collected prospectively.

Intervention—Implementation of a sternal wound prevention bundle (SWPB) during the preoperative, intraoperative and postoperative periods for cardiac surgical cases.

Measurements and Main Results—During the pre-intervention period, 32 (3.8%) patients developed SWI while only 19 (2.1%) developed SWI during the post-intervention period ($p=0.04$). The rates of SWI following PC were not significantly different pre- and post-intervention (2.4%

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vs. 1.6%; $p=0.35$). However, patients with DSC had significantly lower post-intervention infection rates (10.6% vs. 3.9%; $p=0.02$).

Conclusions—Implementation of a SWPB during the perioperative period was associated with lower SWI rates in surgeries with DSC.

Keywords

Pediatric cardiac surgery; quality improvement; surgical site infections; sternal wound infections; delayed sternal closure; infection prevention bundle

Introduction

Surgical site infections (SSI) are a common postoperative complication in children undergoing cardiac surgery (1, 2). Risk factors for SSI include: younger age at time of surgery, presence of genetic abnormalities, pre-operative hospitalization, ventilator support, extracorporeal membrane oxygenation (ECMO) use and delayed sternal closure (DSC) (3–9). According to the National Nosocomial Infection Surveillance System (NNIS), the Center for Disease Control (CDC) and prevention, SSI rates vary from 0.5–6% following pediatric cardiac surgery (6–9).

Prior to 2012, our institution did not have a standardized process for identifying or preventing sternal wound infections (SWI). An observational analysis revealed inconsistency among surgeons regarding skin antisepsis prior to and during surgery, timing of dressing change post-surgery, and lack of standardized surveillance to identify SWI. We initiated a quality improvement (QI) effort to reduce SWI in all patients undergoing cardiac surgery. A sternal wound prevention bundle (SWPB) was instituted in July 2012. These interventions were multi-faceted and recommended for patients of all ages undergoing surgery (10–13). The interventions were instituted in three periods of acute surgical care: pre-operatively, intraoperatively and post-operatively (Figure 1).

The purpose of the project was to reduce SWI. We describe the QI, SWPB elements, timing of bundle elements implementation, and comparison of SWI rates before and after QI implementation. We also describe the effects of the SWPB on outcomes including mortality and resource utilization in patients with SWI.

Methods

Setting and Context

All patients undergoing cardiac surgery at a tertiary care center in the Intermountain West between January 1, 2010 and December 31, 2014 were included. We performed an observational analysis of SWI rates for primary closure (PC) and delayed sternal closure (DSC) procedures, before and after implementation of a multi-disciplinary QI project.

The pre-intervention period was from January 2010 to June 2012. SWI cases were collected retrospectively. The post-intervention period was from July 2012 to December 2014. Data of cases identified post-intervention were collected prospectively.

Pre-intervention

Prior to July 2012, pre-operative patients had a regular bath but no other preparation. The first dose of antibiotic was routinely administered during peripheral IV placement with a potential delay between antibiotic administration and time to surgical incision. Subsequent antibiotic doses were administered every 4 hours. Skin antisepsis in the operating room (OR) was surgeon dependent and varied between Hibiclens and Prevail solutions. Hair removal was done using razors. Post-operatively, patients with open sternums had dressing changes at least once per day; however, there were no dressing change protocols and timing was variable. For PC, an occlusive dressing was placed over the incision in the OR; however, time to removal post-operatively was also variable. Post-operatively, chest tubes were immediately placed to wall suction. For patients with open sternums, 10 Fr suction catheters were occasionally placed inside Argyle chest tubes according to surgeon preference and removed once the immediate post-operative bleeding was well controlled. Our institution does not utilize routine nasal screening practices to determine *Staphylococcus aureus* carrier status.

Planning and Implementing the Study Intervention

In early 2012, a QI team was assembled to evaluate perioperative patient care practices. The team met, reviewed SWPB research, and created a process map to assess current practices utilized for prevention of SWI in children. We identified deficiencies in processes and delineated primary drivers as: 1.) Implementation of a SWPB and 2.) Need to accurately and promptly diagnose SWI (Figure 2).

The QI team assessed previously reported efforts to reduce rates of sternal wound infections in children. The adoption of a SWPB in our hospital is mostly adapted from best adult practices and includes the use of chlorhexidine (CHG) baths for skin antisepsis both pre and operatively (12). In addition, SWPB adopted use of nasal mupirocin ointment to de-colonize nasal carriers of Methicillin resistant *Staphylococcus Aureus* (MRSA) during the preoperative period, as this can be associated with a 2- to 14-fold increased risk of SSI (14–16).

Implementation of the SWPB required broad based provider education as well as support from hospital leadership, cardiothoracic surgery, and providers at all levels and disciplines.

A surveillance system for SWI was implemented in collaboration with the information technology (IT) department. The IT department provided automatic surveillance and distribution of patients with a suspected SWI to the QI team on a weekly basis. The criteria used to identify potential SWI included: hospital readmission within 90 days of surgery, patients treated with antibiotics for more than 72 hours after chest closure, as well as SWI infections identified in the cardiothoracic surgery database. All patients with suspected SWI were reviewed by a multidisciplinary team including a member from infection control team and a cardiac intensive care unit (CICU) nurse practitioner, applied standardized CDC criteria to confirm a case of SWI. All SWIs were presented in scheduled morbidity conferences held by the cardiothoracic surgery, critical care, and cardiology divisions.

The initiative for SWPB was implemented in July 2012 for inpatients undergoing planned cardiac surgery. The outpatient implementation for patients admitted from home started in March 2013.

The inpatient preoperative SWPB intervention—The inpatient preoperative SWPB intervention consisted of nightly CHG baths and mupirocin nasal ointment twice daily for 2–5 days prior to surgery. The outpatient SWPB intervention included mupirocin and CHG bath provided to patients during their preoperative outpatient visit with detailed instructions to begin application within 1–3 days of surgery.

The intraoperative SWPB interventions—The intraoperative SWPB interventions included skin antisepsis with CHG (Chloraprep) solution and hair removal with clippers for all cardiac surgical patients undergoing sternotomy or thoracotomy. Standardized intravenous antibiotic doses by weight were administered at the following time points: within 5–60 minutes of the initial surgical incision, with initiation of cardiopulmonary bypass, and every 3 hours intra-operatively for the duration of the case.

Post-operative SWPB—Post-operative SWPB antibiotic duration was standardized to 48 hours after PC or 48 hours after DSC. The occlusive sternal dressing applied at time of chest closure was removed 48 hours post-operatively. A standardized checklist used during CICU rounds prompts team members to inspect the sternal wound 48 hours post-operatively and daily thereafter. Additionally, a standardized process for bedside care of an open sternum, including timing of dressing changes, sternal closure procedure, and chest tube removal were implemented.

Cohort Identification

All patients with SWI were identified from the hospital acquired infection (HAI) control database using the CDC criteria of the corresponding year and rate reported per 100 sternotomies. All sternotomies from the corresponding years were reviewed and followed the CDC recommendations for inclusion in the denominator. The SWI cases were divided between PC and DSC. SWI related to DSC followed the same CDC definitions for PC once the sternum was closed. If the sternum was not closed, they were categorized as non-surgical DSC-other. The SWI were categorized using the National Healthcare Safety Network (NHSN) definitions from the CDC as superficial, organ space or non-surgical site- other/ abscess if the infection occurs after open sternotomy and prior to delayed closure. None of the infections were classified as deep because of the lack of deep soft tissue between the skin and the sternum in infants and young children.

For patients with SWI, demographic and clinical data were collected. These included underlying conditions, time from primary surgery to SWI diagnosis, antibiotic use 4 weeks, length of hospitalization to treat infection, microorganism cultured from the sternal wound, and whether bacteremia was present.

Evolution of the Interventions

Several Plan-Do-Study-Act (PDSA) cycles were instituted to facilitate and monitor compliance. A checklist was used during CICU rounds to prompt initiation of CHG baths and mupirocin nasal ointment administration 2–5 days prior to surgery. Later, pre-printed admission orders included mupirocin and CHG baths for all pre-operative cardiac patients. Biweekly safety rounds reminded providers to initiate preoperative SWPB. Date and time of mupirocin dispensing from the inpatient pharmacy were tracked. Due to the multi-dose nature of mupirocin, it was difficult to track daily nursing compliance with administration for inpatients in the CICU. Compliance to preoperative CHG baths was audited from bedside nursing documentation.

Intraoperative compliance to the SWPB during the post-intervention period was assessed using routine OR audits for both the use of CHG for skin antisepsis as well as the timing of IV antibiotic administration.

Post-operatively, reminders to inspect the sternal incision and to remove sternal dressings 48 hours following closure were placed on bedside computers and on the rounds checklist. A pre-printed post-operative admission order set provided standardization of antibiotic administration.

Surveillance for SWI was assessed by ICU staff members including physicians, nurse practitioners and nursing staff daily. Evaluation of patients with concerns for SWI included a sternal wound culture, blood culture and an infectious disease consultation whenever possible.

Measures

Primary outcome measures included: SWI rates per 100 sternotomies for patients undergoing either PC or DSC before and after implementation of the SWPB. Process measures included compliance with SWPB elements.

For balancing measures we used resource utilization of patients with SWI measured as the proportion of patients requiring at least one surgical debridement, wound vacuum assisted closure (VAC), use of peripherally inserted central catheter (PICC) for antibiotic administration, the proportion of patients treated with antibiotics for 4 weeks, and post-SWI hospital length of stay (HLOS). HLOS was defined as the length of inpatient hospitalization to treat a SWI. If a patient was an inpatient before SWI diagnosis, the HLOS was tabulated from date of primary surgery to home discharge. We included mortality to discharge and ECMO use comparing pre and post-intervention periods.

Statistical Analysis

Summary statistics are presented as means with standard deviation or median values with interquartile ranges (IQR). Continuous data were analyzed using Mann Whitney U test or an independent t test, while categorical data were evaluated using a chi-square test or Fisher's exact test. Statistical significance was defined as $p < 0.05$. All data were analyzed using SPSS 23.0 for Windows (SPSS, Chicago, IL) and Epi-info to compare features in the two patient groups.

Ethical Considerations

The study was approved and a waiver of informed consent granted by the University of Utah Institutional Review Board (IRB) and Primary Children's Hospital Private Board.

Results

Population Description of Entire Cohort

A total of 1,747 subjects, 847 pre-intervention (median age 234 days, IQR 89–1587 days) and 900 post-intervention (median age 191 days, IQR 25–1415 days) had sternotomies from January 1, 2010 to December 31, 2014. A total of 51 patients were identified with SWI during the study periods, 32 cases in the pre and 19 in the post-intervention group ($p=0.04$). The relative risk (RR) of a patient having a SWI before the SWPB implementation was 1.8 times greater than after implementation (95% CI 1.02–3.13). 60 patients need to be treated with SWPB for one SWI to be prevented.

Pre-intervention versus Post-intervention Groups

Demographic and clinical characteristics for the pre- and post-intervention groups are summarized in Table 1. Baseline characteristics including weight, proportion of patients with single ventricle physiology, and complexity of surgical cases using Risk Adjustment for Congenital Heart Surgery (RACHS) score were similar between the two groups. Patients with SWI in the pre-and post-intervention groups had similar ages (median 40 days vs. 130 days; $p=0.30$), and similar presence of underlying conditions (28% vs. 42% $p=0.30$). The proportion of inpatients to outpatients undergoing planned surgery receiving SWPB were similar pre and post intervention (75% vs. 53%; $p=0.10$). In addition, rates of DSC (47% vs. 37%, $p=0.50$) and median number of post-operative days to SWI diagnosis (13 vs. 12, $p=0.60$) were alike among groups.

Measures

Primary Outcome Measures: SWI rates

Among patients undergoing PC, there was no difference in SWI between the pre-intervention and post-intervention groups (2.4% vs. 1.6%; $p=0.35$). However, for patients with DSC, SWI rates were significantly higher in the pre-intervention group (10.6% vs. 3.9%; $p=0.02$). The majority of SWI infections in the pre-intervention group were classified as organ space surgical site infections (63% vs. 26%; $p=0.02$) (Table 2). Figure 3 contains three statistical process control (SPC) U charts showing the quarterly overall SWI rates separated between PC and DSC over the study duration.

Methicillin sensitive *Staphylococcus aureus* (MSSA) or coagulase negative *Staphylococcus* (CoNS) was present in 19 (60%) of cultures obtained from the sternum during the pre-intervention period. No pre-intervention patient was culture positive MRSA infection. In contrast, MRSA was cultured from the sternum in 2 patients (10%) in the post-intervention group. Bacteremia was concurrently documented in similar proportions (38% vs 26%). 12% of SWI cases pre-intervention compared to 10% post-intervention did not have sternal cultures obtained prior to antibiotic administration (Table 3).

Process Measures: SWBP Compliance

Pre-operative compliance for mupirocin was difficult to track. Mupirocin was dispensed in 100% of patients; however, compliance regarding administration by nursing staff could not be readily verified due to the multi-dosing nature of the medication packaging. Pre-operative CHG compliance reached 70% in the post-intervention group as documented by the bedside nursing flowsheet. Post-intervention compliance for the intraoperative use of CHG skin antisepsis and intra-op antibiotic administration reached 100%, as did timing and duration of post-operative antibiotic. This is likely attributable to dedicated OR staff, routine screening and auditing of cases by cardiac anesthesia, pharmacy participation in daily rounds, and the use of pre-printed order sets at the time of CICU admission after surgery.

Balancing Measures: Resource utilization

Table 4 shows resource utilization of patients with SWI by study period. SWI accounted for over three weeks of hospital days (median 22 days) and did not differ between study periods. Likewise, the proportion of patients who remain hospitalized after surgery when SWI was diagnosed, PICC line use, antibiotics 4 weeks as well as the fraction treated with surgical debridement, was similar in both groups. However, use of VAC was over twice as common in the post intervention group (RR 2.4; 95% CI 1.1–5.3) the HLOS of SWI patients treated with and without VAC (50 days vs. 20 days; $p=0.08$) was not different.

Among SWI patients, mortality was similar across the pre and post-intervention periods (3% vs. 10%; $p=0.14$). During the pre-intervention period, 2 patients (6%) received ECMO compared to 1 patient (5%) in the post-intervention group. Neither SWI nor sepsis was the direct cause of death for any patient during the study period.

Discussion

We report SWI rates both before and after the implementation of a SWPB in children undergoing cardiac surgery. The use of a SWPB in pediatric cardiac patients resulted in both a standardization of the perioperative care to prevent SWI as well as a significant reduction in SWI rates in patients with DSC.

Because best practices have not been established for infants and children, we emulated care of adult patients modified by data from pediatrics when available (10–13). We found that compliance with the recommended number of CHG baths and mupirocin nasal ointment was difficult among critically ill neonates and not optimal compared to the other compliance elements. This was due in part to variability in the pre-operative days and the unique medical record system of our institution.

Our results differ slightly from those reported by Adler et al, who also implemented SWPB and reported significantly decreased rates of SWI for both PC and DSC procedures (10). However, our study found a significant decrease in SWI by DSC. Although DSC is often used to mitigate post-operative hemodynamic and respiratory instability in select patients, it can be associated with post-operative morbidity, mortality and prolonged hospital length of stay (17). Because the integument is violated, it is not surprising that DSC, which is primarily used in critically ill neonates, is an important risk factor for SWI (17). Our SWI

rates following DSC are difficult to compare to previously reported data because the definition of SWI in DSC patients has changed. Prior to 2016, the CDC's National Healthcare Safety Network (NHSN) surveillance of SSI did not include infections occurring after DSC. In addition, definitions of SWI infections changed in 2013 and reduced the duration of surveillance from 1 year to 90 days for procedures utilizing prosthetic materials. It is possible that the 2013 definition excluded patients previously identified as SSI; however, readmission after cardiac surgery in our institution is consistently captured in the cardiothoracic surgery database. Applying the NHSN classification, a higher proportion of patients had an organ occupying space infection in the pre-intervention while a higher proportion of superficial infections occurred in the post-intervention period.

The present study reports lower SWI rates caused by Staphylococcal species in the post-intervention group (42% vs. 60%); however, MRSA contributed to 10% of those infections. During the pre-intervention period, the most predominant organisms cultured from sternum were MSSA and CoNS with no cases of MRSA. This could be due in part to the emergence of MRSA in the general population and the increasing bacterial resistance of *Staphylococcus aureus* to mupirocin during the post-intervention period (18). This is an important finding, as MRSA is associated with higher mortality rates, longer hospital length of stays, and higher hospital costs compared with other infections (19). Despite these findings, there is still a high proportion of SWI in our cohort that was either culture negative or no culture sent, although clinical findings demonstrated a significant sternal wound infection.

Not surprisingly, the SWI patients entailed high resource utilization. Surgical use of VAC increased more than 2-fold in the post intervention period, although HLOS did not differ when comparing pre- and post-intervention groups or HLOS of SWI patients treated with and without VAC. Although more than half of the SWI infections in the post-intervention period were classified as superficial, a high proportion had surgical debridement and VAC application. VAC dressings are used in the treatment of post sternotomy mediastinitis and works by increasing peristernal blood flow, leading to enhanced granulation tissue formation. At the same time, VAC treatment assists in facilitating wound edge approximation and stabilization of the chest (20).

This study has some important limitations. Due to our unique electronic medical record, compliance to the SWPB cannot be easily tracked. This is especially evident with mupirocin multiuse ointment and CHG baths that do not require scanning from pharmacy prior to administration. Moreover, prior to 2012, the infection control department in our institution worked independently and had limited interaction with both the CICU and cardiothoracic surgery teams. Following this QI initiative, increased collaboration between infection control, the CICU, and cardiothoracic surgery made surveillance of SWI in post-operative cardiac patients more consistent between groups. It is possible the infections reported to HAI prior to 2012 may have been under or overestimated due to changes in both the surveillance and CDC SWI definitions during that period. The CDC guidelines were strictly followed to create hospital-wide baseline rates that could be followed and compared over time.

CONCLUSIONS

Implementation of SWPB in patients undergoing cardiac surgery resulted in a significant and clinically important reduction in SWI rates in children undergoing procedures with DSC. This QI process demonstrates the importance of SWPB in the prevention of post-operative sternal wound infections and the collaborative effort of a multidisciplinary team at different stages of the patient's hospitalization.

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Figure 1.
Timeline of Interventions

Figure 2.

Key Driver Diagram for reducing Sternal Wound Infections

SWI= sternal wound infection; SWPB= sternal wound prevention bundle; PC= primary closure; DSC= delayed sternal closure; CICU= cardiac intensive care unit; CHG=chlorhexidine; CT= cardiothoracic

Figure 3.
 Statistical Process Control U Charts with Quarterly Sternal Wound Infections Rates
 Separated by Primary Closure and Delayed Sternal Closure
 SWI= sternal wound infection
 SWPB= sternal wound prevention bundle
 UCL= Upper Control Limit
 LCL= Lower Control Limit

Ubar= Center Line

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Table 1

Clinical Characteristics and Demographics of Patients with Sternal Wound Infection in the Pre-intervention and Post-intervention Groups.

Characteristics	Pre-Intervention N=32	Post-Intervention N=19	P value
RACHS 2, n (%)	10 (31)	5 (27)	0.80
RACHS 3–4, n (%)	17 (53)	9 (48)	
RACHS 5–6, n (%)	3 (10)	2 (10)	
No RACHS, n (%)	2 (6)	3 (15)	
Age at surgery (days), median (IQR)	40 (7–131)	130 (6–1387)	0.30
Weight at surgery (kg), median (IQR)	3.6 (3.1–5.7)	4.6 (3.3–13.4)	0.10
Inpatient status prior to surgery, n (%)	24 (75)	10 (53)	0.10
Delayed sternal closure, n (%)	15 (47)	7 (37)	0.50
* Underlying condition, n (%)	9 (28)	8 (42)	0.30
Single Ventricle, n (%)	11 (35)	7 (37)	0.80
SWI diagnosis after surgery (days), median (IQR)	13 (7–21)	12 (6–20)	0.70
Bacteremia, n (%)	12 (38)	5 (26)	0.40

IQR = Interquartile range, RACHS = Risk Adjustment for Congenital Heart Surgery; SWI = sternal wound infection; HLOS = hospital length of stay, OR = operating room,

* Underlying condition= genetic syndrome, prematurity (<37 weeks), or chromosomal abnormality (eg. Trisomy 21, 22q11 deletion).

Table 2

Sternal Wound Infection Rates and Classification Before and After the Implementation of a Sternal Wound Prevention Bundle.

Sternal Wound Infection Rates	Pre-SWPB	Post SWPB	P value
Entire Cohort			
Total number SWI cases	32	19	
Total Sternotomies	847	900	
SWI rate	3.8%	2.1%	0.040
Classification of Infection			
Superficial	8 (25%)	12 (63%)	0.009
Organ Space	20 (63%)	5 (26%)	0.020
Non-surgical, Other	4 (12%)	2 (11%)	1.000
Primary Closure (PC)			
Number of PC SWI	17	12	
Total PC Sternotomies	706	721	
PC SWI Rate	2.4%	1.6%	0.350
Delayed Sternal Closure (DSC)			
Number of DSC SWI	15	7	
Total DSC Sternotomies	141	179	
DSC SWI rate	10.6%	3.9%	0.020

SWPB = Sternal wound prevention bundle; SWI = sternal wound infection; PC = Primary Closure; DSC = Delayed sternal closure;

Table 3

Microorganisms Cultured from Sternal Wound Infections

Microorganism from Sternum	Pre-Intervention N=32 N (%)	Post-Intervention N=19 N (%)	P value
MSSA, n (%)	11 (35)	4 (21)	0.30
MRSA, n (%)	0	2 (10)	0.10
CoNS, n (%)	8 (25)	2 (10)	0.20
Enterococcus, n (%)	0	1 (6)	0.30
Enterobacter, n (%)	2 (6)	0	0.50
Pseudomonas, n (%)	0	2 (10)	0.10
Beta Hemolytic Streptococcus, n (%)	0	1 (6)	0.30
Culture negative, n (%)	4 (12)	5 (26)	0.20
No culture obtained prior to antibiotics, n (%)	4 (12)	2 (11)	1.00
Other, n (%)	3 (10)	0	0.30

MSSA = methicillin sensitive staphylococcus aureus; MRSA = methicillin resistant staphylococcus aureus, CONS coagulase negative staphylococcus

Other: Propionibacterium species, Escherichia coli, Streptococcus mitis

Table 4

Balance Measures: Resource Utilization for Sternal Wound Infections Before and After Sternal Wound Prevention Bundle Implementation

Characteristics	Pre-Intervention N=32	Post-Intervention N=19	P value
HLOS, median (IQR)	22 (11–30)	22 (9–87)	0.60
Still hospitalized at the time of SWI, n (%)	18 (56)	10 (53)	0.80
SWI debridement, n (%)	17 (53)	9 (47)	0.70
Wound VAC placement, n (%)	7 (21)	10 (52)	0.02
Antibiotic use 4 weeks, n (%)	14 (43)	12 (63)	0.20
PICC line placement, n (%)	12 (40)	11 (57)	0.20

SWI = sternal wound infection; HLOS = hospital length of stay; PICC = peripherally inserted central catheter; VAC=wound vacuum assisted closure