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Risk factors for surgical site infection in pediatric cardiac surgery patients undergoing delayed sternal closure

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Objectives: To determine the incidence of surgical site infections (SSIs) in congenital heart surgery (CHS) patients undergoing delayed sternal closure (DSC) and to evaluate risk factors for SSI.

Methods: A nested case–control study was performed within a cohort of CHS patients undergoing DSC at our institution between 2005 and 2009. Cases met 2008 Centers for Disease Control and Prevention criteria for SSI; control subjects were matched based on year of surgery. Uni- and multivariate logistic regressions were performed to identify SSI risk factors.

Results: Of 375 patients who underwent DSC, 43 (11%) developed an SSI. The analysis included 172 patients (43 cases, 129 controls); 118 (69%) were neonates, 80 (47%) had undergone Norwood procedure, and 150 (87%) had DSC initiated in the operating room. Case and control subjects were similar based on pre- and intraoperative characteristics. Duration of mechanical ventilation, intensive care unit and hospital length of stay, and mortality were significantly greater in patients with an SSI. Multiple periods of DSC, longer duration of DSC, greater dependence on parenteral nutrition, and extracorporeal membrane oxygenation were significantly associated with SSI in univariate analyses. Multivariate analysis demonstrated that multiple periods of DSC (adjusted odds ratio, 5.9; 95% confidence interval, 1.7-20.1) and extracorporeal membrane oxygenation (adjusted odds ratio, 2.9; 95% confidence interval, 1.1-7.6) remained independent risk factors for SSI.

Conclusions: For CHS patients undergoing DSC, extracorporeal membrane oxygenation and multiple periods of DSC are independent risk factors for SSI. New strategies for prevention and prophylaxis of SSI may be indicated for these high-risk patients who have worse outcomes and greater health care resource utilization. (J Thorac Cardiovasc Surg 2013;146:326-33)

Delayed sternal closure (DSC) is frequently required in the care of pediatric patients who have undergone cardiac surgery to minimize postoperative respiratory and hemodynamic instability.[1-3] Although necessary for the treatment of unstable patients, DSC may expose patients to an increased risk of hospital-acquired infections, including bloodstream[4] and surgical site infections (SSIs).[5-7] SSI remains a rare complication for patients undergoing congenital heart surgery (CHS), but when present it is associated with significant morbidity, mortality, and health care costs.[8,9]

Recent studies demonstrate that the incidence of SSI and associated mortality rate in CHS patients undergoing DSC is highly variable.[6,7,10] Vulnerable patient populations likely to be at high risk of SSI, such as those requiring extracorporeal membrane oxygenation (ECMO) support, have been excluded from previous studies.[5,6] Furthermore the potential causative factors for SSI in this patient population have been as yet incompletely explored or characterized.[6,7] A clear understanding of outcomes and risk factors is essential because they may affect clinical decision making for cardiac surgeons and intensivists caring for these patients.

The purpose of this study was to determine the incidence and risk factors for SSI in CHS patients undergoing DSC. Our analysis of risk factors focused on processes of care in an intensive care unit, because these are potentially modifiable. Examples of modifiable processes of care include use of postoperative stress steroids and dependency on parenteral nutrition. We hypothesized that CHS patients undergoing DSC would have a higher incidence of SSI compared with non-DSC patients, and that duration to chest closure would be an independent risk factor for SSI.

METHODS

Study Cohort

We studied a cohort of pediatric patients (aged <18 years) from our institution who underwent DSC after cardiac surgery between January 1, 2005, and December 31, 2009. Study approval with waiver of written informed consent was obtained from our institutional review board. A total of 375 patients who underwent DSC were identified. All patients

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Abbreviations and Acronyms

CDC	= Centers for Disease Control and Prevention
CHS	= congenital heart surgery
CICU	= cardiac intensive care unit
DSC	= delayed sternal closure
ECMO	= extracorporeal membrane oxygenation
SSI	= surgical site infection

undergoing DSC, including those who required ECMO or emergency sternotomy for hemodynamic instability in our cardiac intensive care unit (CICU), were included. Elective DSC defines any patient for which a decision was made by an attending surgeon to leave the chest open in the operating room. Because this decision can be made a priori or due to intraoperative hemodynamic instability, the location the chest was opened was determined rather than classifying DSC as elective or emergent. At our center, we perform DSC for all patients who undergo stage 1 palliation for single-ventricle disease regardless of intraoperative status. Subjects who survived <48 hours after surgery were excluded from the analysis.

Study Design and Primary Outcome Definition

A nested case-control study was conducted within the DSC cohort comparing subjects with SSI to those without SSI. Cases of SSI were defined and classified as superficial incisional, deep incisional, or organ/space using published Centers for Disease Control and Prevention (CDC) criteria.[11] Mediastinitis and endocarditis are categorized as organ/space SSI according to these definitions. Complete CDC criteria for SSI are displayed in Appendix 1. Consistent with the criteria, the follow-up period during which a SSI could occur was up to 30 days after surgery for patients without surgical implants and 1 year for patients with implants. Control subjects were matched to case subjects in a 3:1 ratio based on year of surgery.

Surgical Technique

Our standard technique for patients with DSC is closure with a silicone elastomer membrane sutured to the skin edges with a monofilament suture. No antibiotic ointment is placed on the skin edges. Polyurethane, iodine-impregnated, occlusive film is then applied over the membrane. This dressing remains in place until sternal closure or further mediastinal procedures are indicated.

The decision to close a sternum is at the discretion of the attending cardiac intensivist and surgeon. Typically, the sternum is closed when the patient is hemodynamically stable with an established diuresis. Sternal closure occurs under sterile conditions in either a CICU or operating room. A deep tissue sample is taken from the mediastinum for culture and sensitivity at the time of sternal closure in all cases. The mediastinum is irrigated with warm vancomycin irrigation. Chest tubes are cleared of all clots and repositioned. All intracardiac catheters are removed and only replaced if clinically indicated. Following adequate hemostasis, the sternal edges are reapproximated with either interrupted stainless steel wires or braided absorbable sutures. The soft tissues and skin are closed using braided absorbable sutures in a running fashion. Sedation, analgesia, and neuromuscular blockade are provided during sternal closure using ketamine (1 mg/kg/dose), midazolam (0.1 mg/kg/dose), fentanyl (5 μg/kg/dose), and vecuronium (0.1 mg/kg/dose). There were no changes to the standard techniques for DSC or sternal closure during the study period.

Antibiotic Prophylaxis and Therapy

Patients undergoing DSC receive intravenous vancomycin and gentamicin for the duration of open chest and continuing until 48 hours after sternal closure. Vancomycin is initially dosed at 10 mg/kg/dose every 12 hours and adjusted to achieve a trough level of 5 to 10 μg/dL. Gentamicin is initially dosed at 2.5 mg/kg/dose every 12 hours and was adjusted to achieve a trough level <2 μg/dL. Cefotaxime (50 mg/kg/dose every 12 hours) was substituted for gentamicin in patients who developed renal insufficiency. After discontinuation of this regimen, prophylactic antibiotic coverage for indwelling mediastinal and pleural chest tubes (intravenous cefazolin) is initiated. Prophylaxis is continued until all chest tubes are removed. Antibiotic coverage is broadened based on clinical judgment in patients who develop fever or other clinical evidence of infection. Our standard practice is to treat all patients who have a positive mediastinal culture with a 6-week antibiotic course.

Data Collection

All CHS patients who underwent DSC during the study period were identified using our institution's surgical database and a database search of the medical records in the clinical data repository. Two search methods were used to minimize selection error and to ensure accurate identification of all cases. We reviewed the records of all patients identified by both search tools using the Electronic Medical Record Search Engine. This search tool is an internally developed computer application designed to perform detailed searches of the medical documents in our electronic medical record and has been shown to improve efficiency and accuracy of electronic medical record review.[12,13] This methodology allowed us to resolve the discrepancies and accurately identify the number of patients who underwent DSC during the study period.

Infection control data at our institution are obtained by a dedicated nurse specialist team that independently reviews and classifies all cases, including those requiring readmission for management of SSI remote from the initial surgical procedure. Use of a nurse specialist team has been shown to improve the accuracy of reported rates of hospital-acquired infections[14] so we used our institution's infection control data to identify subjects with SSI during the study period. We also searched our institutional surgical database to try and identify any additional cases for consideration, and no additional cases were identified.

After all case and control subjects were identified, the primary author reviewed the medical record for all preoperative, intraoperative, and postoperative variables. When possible, these data were exported from the institutional surgical database. Review for each patient was completed up to the date of maximum possible SSI surveillance period defined by the CDC criteria[11] or until no further records were available. Surgical procedures were grouped into stage I palliation for single ventricle, other single-ventricle procedures, aortic arch reconstruction, and other 2- ventricle procedures. Aortic arch reconstructions were separated from other 2-ventricle procedures because these cases are performed using hypothermic circulatory arrest. Total duration of DSC was a cumulative total of the number of days the sternum remained open during the hospital admission, including all periods of DSC. Mediastinal procedures included ECMO cannulation/decannulation, mediastinal exploration, and epicardial pacemaker lead placement.

Statistical Analysis

Data are presented as frequencies with percentage for categorical variables and median with interquartile range for continuous variables. The incidence of SSI was reported as the cumulative incidence proportion. The comparison of the incidences of SSI between patients with DSC versus all CHS patients at our institution was made using χ^2 test. Demographics, intraoperative, postoperative, and clinical outcome variables were compared between cases and controls using χ^2 test or Fisher exact test, as appropriate, for nominal variables, Mantel-Haenszel test for ordinal variables, and Wilcoxon rank sum test for continuous variables. Continuous variables in the intraoperative and postoperative data were also evaluated categorically using the median, with the exception of the duration of initial DSC, for which we used an optimal cutoff obtained from a receiver operating characteristic curve. Variables found to be significantly associated with SSI in the univariate analyses ($P < .10$) were investigated further by building multivariate logistic regression models to determine independent relations of risk factors with SSI. Model selection from multivariate logistic regressions was conducted using backward elimination method and improvements in the model fit were evaluated by the model χ^2 statistics. Results of the logistic regression are presented as odds ratio (OR) with 95% confidence intervals (CIs). All analyses were performed using SAS version 9.3 (SAS Institute Inc, Cary, NC).

RESULTS

Our cohort included 375 patients who underwent DSC during the study period. Of these, 43 (11%) patients met CDC criteria for SSI (12 superficial incisional, 3 deep incisional, and 28 organ/space). There were 27 cases of mediastinitis and 1 case of endocarditis within the group of patients with organ/space SSI. The incidence of SSI within the DSC cohort was 11% (43 out of 375) and the incidence of organ/deep space SSI was 7.5% (28 out of 375). The incidence of SSI amongst CHS patients who did not undergo DSC at our center during the study period was 1.4% (41 out of 2891), significantly lower than the DSC cohort ($P < .0001$ from χ^2 test).

A total of 172 patients (43 cases and 129 controls) were included in the analysis. Demographic and intraoperative data are shown in Table 1. There were no significant differences between case subjects and control subjects based on race, age at surgery, or sex. Intraoperative factors were similar in both groups, including surgical complexity and cardiopulmonary bypass times. A small but similar percentage of case and control subjects required emergent sternotomy in the CICU (14% vs 12%; $P = .79$). Stage I single-ventricle palliation represented the most frequently performed surgical procedure in both groups. The distribution of the primary surgical procedures performed on patients in the analysis is displayed in Appendix 2.

Multiple postoperative factors differed significantly between cases and controls on univariate analysis (Table 2). A majority (92%) of all patients requiring DSC had only a single period of DSC. The median total duration of DSC for cases was 9 (interquartile range [IQR], 3-14) and was significantly increased compared with controls (median, 4; IQR, 3-6; $P = .0003$). The duration of initial DSC of 5 days obtained from receiver operating characteristic curve had relatively high negative predictive value (83%) but limited positive predictive value (34%). Cases more frequently required multiple periods of DSC and ECMO during the hospital stay, and had greater dependence on parental nutrition. Amongst patients with SSI, the median intensive care unit length of stay was 29 days (IQR, 13-48) and the rate of intensive care unit mortality was 42%, both were significantly increased compared with control subjects ($P < .004$ and $P < .0001$, respectively) (Table 3).

Candidate predictors that differed between case subjects and control subjects ($P < .10$) in univariate analyses were included in the multivariate model; total periods of DSC, duration of initial DSC, total number of additional mediastinal procedures, duration of mediastinal chest tubes, prolonged use of parenteral nutrition, use of stress doses of hydrocortisone, and ECMO. The total number of additional mediastinal procedures and the duration of mediastinal chest tubes were highly correlated with use of ECMO (χ^2, 66.4 and 43.1, respectively; both $P < .0001$), and thus excluded from the multivariate model to avoid multicollinearity. Multivariate logistic regression analysis using backward elimination method showed that >1 period of DSC was significantly associated with increased risk of SSI when controlling for other variables (OR, 5.9; 95% CI, 1.7-20.1), whereas the duration of initial DSC was no longer statistically significant (OR, 1.7; 95% CI, 0.7-3.8). Use of ECMO also remained an independent risk factor for SSI in the multivariate model (OR, 2.9; 95% CI, 1.1-7.6) (Table 4).

DISCUSSION

DSC is a necessary postoperative technique used with many CHS patients. It is imperative for surgeons and intensivists to understand the associated risks of this procedure and the extent to which specific care processes may positively or negatively modify this risk. Our retrospective study demonstrates that patients undergoing DSC are at significantly increased risk of SSI compared with other CHS patients. Multivariate analysis identified multiple periods of DSC and the use of ECMO as independent risk factors for SSI in this patient population. We did not identify any specific processes of care that were independently associated with risk of SSI in patients undergoing DSC.

Our incidences of SSI (11%) and organ/deep SSI (7.5%) were both higher than the previously published rates by Tabbutt and colleagues[6] (6.7% and 3.9%, respectively). One explanation for these differences is the inclusion of higher-risk patients in our analysis; in the study by Tabbutt and colleagues[6] patients requiring multiple episodes of DSC or ECMO were excluded, and only 29% of patients had undergone stage I single-ventricle palliation compared with 47% in our cohort.

Two recent retrospective studies also described lower rates of SSI in pediatric patients requiring DSC. Shin and colleagues[7] reported a rate of SSI of 3.3% based on a single institutional review, and Johnson and colleagues[5] reported a rate of SSI of 6.4% in centers with high use of DSC in stage 1 palliation procedures based on multicenter Society of Thoracic Surgeons database review. Neither of these studies adhered strictly to the CDC criteria for SSI and infection data were not identified by a dedicated infection control nurse specialist team. Methodologic differences may have led to an underestimation of the incidence of SSI in these other cohorts. This highlights the importance of using dedicated infection control data for the retrospective analysis of SSIs and other nosocomial infections.

At our center we perform DSC for all patients who undergo stage 1 palliation for single-ventricle heart disease regardless of hemodynamic status in the operating room. For all other patients who have DSC in the OR, the decision is at

TABLE 1. Demographic and intraoperative characteristics

Patient characteristic	All (n = 172)	Surgical site infection Yes (n = 43)	Surgical site infection No (n = 129)	*P* value*
Male	94 (54.7)	20 (46.5)	74 (57.4)	.22
Race				
White	114 (66.3)	28 (65.1)	86 (66.7)	.26
African American	16 (9.3)	7 (16.3)	9 (7.0)	
Other/unknown	28 (16.3)	7 (16.3)	21 (16.3)	
Missing	14 (8.1)	1 (2.3)	13 (10.1)	
Age at surgery (d)	9 (6-105)	12 (6-189)	9 (6-70)	.34
≥30	54 (31.4)	15 (34.9)	39 (30.2)	.57
<30	118 (68.6)	28 (65.1)	90 (69.8)	
Genetic anomaly				
Yes	20 (11.6)	6 (14.0)	14 (10.9)	.58
Trisomy 21	4 (20.0)	1 (16.7)	3 (21.4)	
22q11	6 (30.0)	3 (50.0)	3 (21.4)	N/A
Other	10 (50.0)	2 (33.3)	8 (57.1)	
Prematurity (≤37 wk)	14 (8.1)	4 (9.3)	10 (7.8)	.75
Intraoperative				
Location chest opened				
OR	150 (87.2)	37 (86.1)	113 (87.6)	.79
CICU	22 (12.8)	6 (14.0)	16 (12.4)	
Type of surgical procedure				
Single ventricle—stage I	80 (46.5)	21 (48.8)	59 (45.7)	N/A
Other single ventricle	10 (5.8)	4 (9.3)	6 (4.7)	
Aortic arch reconstruction	13 (7.6)	2 (4.7)	11 (8.5)	
Other 2-ventricle procedure	69 (40.1)	16 (37.2)	53 (41.1)	
Foreign material placed				
Yes	157 (91.3)	38 (88.4)	119 (92.3)	.53
No	15 (8.7)	5 (11.6)	10 (7.8)	
Previous sternotomy				
Yes	36 (20.9)	11 (25.6)	25 (19.4)	.39
No	136 (79.1)	32 (74.4)	104 (80.6)	
Cardiopulmonary bypass time (min)	124 (86-206)	120 (92-187)	128.5 (85.5-207)	.80
≥124	86 (50.0)	21 (48.8)	65 (50.4)	.83
<124 4	85 (49.4)	22 (51.2)	63 (48.8)	
Missing	1 (0.6)	0 (0.0)	1 (0.8)	
Aortic crossclamp time (min)	43 (35-79)	40 (30-64)	44.5 (35-82)	.32
≥43	89 (51.7)	20 (46.5)	69 (53.5)	.40
<43	82 (47.7)	23 (53.5)	59 (45.7)	
Missing	1 (0.6)	0 (0.0)	1 (0.8)	
Hypothermic circulatory arrest (min)	103 (59.9)	24 (55.8)	79 (61.2)	.49

Data are presented as n (%) for categorical variables and median (interquartile range) for continuous variables. *OR*, Operating room; *CICU*, cardiac intensive care unit; *N/A*, not applicable. *From χ^2 test or Fisher exact tests for categorical variables, and Wilcoxon rank sum tests for continuous variables on comparison of each characteristic between patients with/without surgical site infections.

the discretion of the attending surgeon and is typically based on the hemodynamic stability and coagulation status of the patient. This institutional practice results in inclusion of a large number of patients undergoing stage 1 palliation who would not have otherwise required DSC based on clinical status, and affects the interpretation and generalizability of the analysis to other settings. It was impossible for us to determine with confidence the indication for DSC in the remainder of our subjects. This may be an important variable in understanding patterns of and risk factors for SSI in similar future cohorts.

In previous pediatric studies, age <30 days and diagnosis of hypoplastic left heart syndrome were found to be associated with an increased incidence of SSI in patients undergoing DSC.[6,9] Neither age nor diagnosis proved to be a risk factor for SSI in our analysis. Age and diagnosis were likely not identified as independent predictors of SSI due to our institution's use of elective DSC for all patients requiring stage 1 palliation for single-ventricle heart disease. Only multiple periods of DSC and need for ECMO were independent predictors of SSI from our multivariate analysis. ECMO support in the perioperative period may elevate risk of SSI in

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TABLE 2. Postoperative clinical characteristics

Postoperative	All (n = 172)	Surgical site infections Yes (n = 43)	No (n = 129)	P value*
Total periods of DSC				
Once	159 (92.4)	35 (81.4)	124 (96.1)	.004
More than once	13 (7.6)	8 (18.6)	5 (3.9)	
Duration of initial DSC (d)	4 (3-7)	6 (3-13)	4 (3-6)	.004
<3 d	31 (18.0)	6 (14.0)	25 (19.4)	.04
3-4 d	62 (36.1)	10 (23.3)	52 (40.3)	
≥5 d	79 (45.9)	27 (62.8)	52 (40.3)	
Total duration of DSC (d)	4 (3-7.5)	9 (3-14)	4 (3-6)	.0003
Total no. of mediastinal procedures				
None	97 (56.4)	15 (34.9)	82 (63.6)	<.0001
1	29 (16.9)	5 (11.6)	24 (18.6)	
2	27 (15.7)	11 (25.6)	16 (12.4)	
≥3	19 (11.0)	12 (27.9)	7 (5.4)	
Duration of mediastinal chest tube (d)				
≤7 d	75 (43.6)	13 (30.2)	62 (48.1)	.001
8-14 d	73 (42.4)	16 (37.2)	57 (44.2)	
>14 d	24 (14.0)	14 (32.6)	10 (7.8)	
Total duration of total parenteral nutrition (d)	11 (6-19)	17 (8-37)	10 (5-15)	.003
≥11	87 (50.6)	28 (65.1)	59 (45.7)	.03
<11	85 (49.4)	15 (34.9)	70 (54.3)	
Stress hydrocortisone used	80 (46.5)	25 (58.1)	55 (42.6)	.08
Catheter-associated blood stream infection	11 (6.4)	5 (11.6)	6 (4.7)	.15
Positive respiratory culture and antibiotic treatment	54 (31.4)	17 (39.5)	37 (28.7)	.18
ECMO (if yes, then indicate cannulation site)				
Yes				.001†
Chest	27 (15.7)	12 (27.9)	15 (11.6)	
Neck	4 (2.3)	3 (7.0)	1 (0.8)	
No	141 (82.0)	28 (65.1)	113 (87.6)	

Data are presented as n (%) for categorical variables and median (interquartile range) for continuous variables. *DSC*, Delayed sternal closure; *ECMO*, extracorporeal membrane oxygenation. *From χ^2 test or Fisher exact tests for nominal variables, Mantel-Haenszel tests for ordinal variables, and Wilcoxon rank sum tests for continuous variables on comparison of each characteristic between patients with/without surgical site infections. †Comparison was made as ECMO Yes (ie, regardless of cannulation site) vs No and *P* value was derived from χ^2 test.

numerous ways. Systemic anticoagulation and subsequent bleeding may require multiple explorations of the mediastinum. Inflammation and immunoparalysis can result from blood–circuit interactions.[15] Multiple metabolic derangements, particularly hyperglycemia, are common during ECMO support.[16] Finally, extracorporeal support necessarily involves the introduction of multiple foreign bodies to the mediastinum. Several general strategies could be targeted to reduce the risk of all infections in patients who require ECMO, but particularly related to SSI, the care team could consider minimizing the number of mediastinal explorations, performing sternal closure in the operating room, or adjusting antibiotic prophylaxis regimens in these cases.

TABLE 3. Clinical outcomes

Outcome	All (n = 172)	Surgical site infections Yes (n = 43)	No (n = 129)	P value*
Total duration of mechanical ventilation (d)	10.5 (5.5-24.5)	15 (10-34)	9 (5-14)	.004
ICU length of stay (d)	16 (9-34.5)	29 (13-48)	15 (8-26)	.004
Hospital length of stay (d)	24 (16-47.5)	37 (18-64)	22 (16-39)	.01
ICU mortality	29 (16.9)	18 (41.9)	11 (8.5)	<.0001
Hospital death	30 (17.4)	19 (44.2)	11 (8.5)	<.0001
Died in hospital or within 30 d of hospital discharge	33 (19.2)	19 (44.2)	14 (10.9)	<.0001

Data are presented as n (%) for categorical variables and median (interquartile range) for continuous variables. *ICU*, Intensive care unit. *From χ^2 test for categorical variables and Wilcoxon rank sum tests for continuous variables on comparison of each clinical outcome between patients with/without surgical site infections.

In the pediatric literature, the overall rate of mortality in patients undergoing DSC varies from 12% to 36%.[6,10,17] In our study population, the overall rate of mortality in patients requiring DSC was 19%, comparable to the recently reported rate of 18% by Shin and colleagues.[7] Higher mortality rates reported in early studies were likely due to the increased proportion of deaths occurring in patients requiring mechanical circulatory support.[10] In patients undergoing DSC, we found that SSIs were significantly associated with an increased risk of mortality and morbidity, including increased hospital length of stay and prolonged duration of mechanical ventilation.

A recent multicenter study of patients who had undergone stage I palliation for single-ventricle heart disease

TABLE 4. Multivariate analysis for risk of surgical site infections

Characteristic	AOR	95% CI	P value*
Duration of initial DSC (d)			
≥5	1.67	0.73, 3.85	.23
<5	Ref		
Total period(s) of DSC			
Once	Ref		.005
More than once	5.90	1.73, 20.14	
ECMO	2.92	1.14, 7.60	.03

AOR, Adjusted odds ratio; *CI*, confidence interval; *DSC*, delayed sternal closure; *Ref*, reference category; *ECMO*, extracorporeal membrane oxygenation. *From multivariate logistic regression model.

similarly demonstrated that centers where DSC is used more frequently had higher incidences of SSI and prolonged length of hospital stay[5] compared with centers where it is used rarely. Studies of adult cardiac surgery patients have also found that SSI is one of the strongest predictors of in-hospital mortality after DSC.[18] Whether SSI is causally related to this increase in morbidity and mortality in patients undergoing DSC or rather merely a reflection of greater underlying illness severity remains unclear.

We were particularly interested in the possible association between duration of DSC and risk of SSI, hypothesizing that a longer period of DSC would increase the risk of SSI. Multiple authors have reached variable conclusions regarding this question. Anderson and colleagues[17] reported that longer delay to sternal closure was associated with increased risk of infection and mortality for adult patients. A recent large, retrospective review of adult patients showed that although prolonged delay before sternal closure was associated with poor outcome, there was no difference in the incidence of SSI compared with patients with primary closure.[18] Previous pediatric studies have not shown an association between duration of DSC and SSI. Although increased number of days to sternal closure was associated with increased rate of SSI on univariate analysis, it did not remain an independent predictor of SSI in the multivariable analysis. Interestingly, multiple periods of DSC remained independently associated with an increased risk of SSI, suggesting that premature sternal closure resulting in repeat DSC may place patients at higher risk of infection than prolonging their initial period of DSC. These conclusions may have important clinical implications because many of our current CICU practices are aimed at reducing the time to sternal closure. Due to the apparently low risk of delaying sternal closure, CICU practices designed to reduce the risk of requiring repeat DSC should become a focus in the postoperative care for these patients.

We did not identify any postoperative processes independently associated with risk of SSI. Several CICU therapies have been shown previously to be important in modifying the risk of SSI. Recent data suggest that protocol-based management of glucose levels[19] may reduce the risk of SSI. The duration and choice of antibiotic prophylaxis as well as the role of routine mediastinal cultures in the postoperative period remains highly debated.[19,20] The relatively homogenous CICU practice patterns at our own institution and the observational nature of our analysis no doubt limited our ability to identify the importance of processes of care on risk of SSI. Multi-institutional studies, either randomized clinical trial or observational with appropriate statistical models to enhance causal inference, are necessary to define the true risk factors for SSI prophylaxis in this patient population. Results from a 2-center randomized clinical trial on tight glycemic control after cardiopulmonary bypass[21] may address at least 1 of these questions relatively soon. However, many more potentially modifiable practices must be investigated in order to delineate best practice as it relates to SSI prevention.

Limitations

This study was completed at a single center with relatively homogenous intensive care unit practice patterns and as such we had a limited opportunity to analyze the influence of perioperative practice pattern variation on the risk of developing SSI. The retrospective design further limited measurement of certain factors possibly related to risk of SSI, such as decision making regarding the timing of sternal closure. Although thorough review of the hospital and surgical records was completed, long-term follow-up data for a small number of patients followed by primary cardiologists outside our center may have been incomplete. Patients with late infections may not have been identified and thus not included as cases. However, in our experience most serious SSIs (eg, mediastinitis) requiring surgical consultation are treated at our institution rather than at another pediatric cardiac surgical center.

CONCLUSIONS

DSC remains an important perioperative practice for the care of pediatric CHS patients with hemodynamic instability and postoperative hemorrhage. The incidence of SSI in patients undergoing DSC is significantly increased, and SSI confers elevated risk for morbidity, mortality, and greater resource utilization. Further multi-institution collaborative research is necessary to precisely identify the specific care processes that are associated with lower infection rates and in turn implement evidenced-based strategies for prevention of SSI in this high-risk patient population.

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APPENDIX 1. CDC/NHSN CRITERION FOR SURGICAL SITE INFECTIONS[11]

Organ/Space-Organ/Space Surgical Site Infection (SSI)

1. Infection occurs within 30 days after the operative procedure if no implant is left in place or within 1 year if implant is in place and the infection appears to be related to the operative procedure

   And

2. Infection involves any part of the body, excluding the skin incision, fascia, or muscle layers, that is opened or manipulated during the operative procedure

   And

3. Patient has at least 1 of the following:
   - purulent drainage from a drain that is placed through a stab wound into the organ/space
   - organisms isolated from an aseptically obtained culture of fluid or tissue in the organ/space
   - an abscess or other evidence of infection involving the organ/space that is found on direct examination, during reoperation, or by histopathologic or radiologic examination
   - diagnosis of an organ/space SSI by a surgeon or attending physician.

Deep Incisional Surgical Site Infection

1. Infection occurs within 30 days after the operative procedure if no implant is left in place or within 1 year if implant is in place and the infection appears to be related to the operative procedure

   And

2. Involves deep soft tissues (eg, fascial and muscle layers) of the incision

   And

3. Patient has at least 1 of the following:
   - purulent drainage from the deep incision but not from the organ/space component of the surgical site
   - a deep incision spontaneously dehisces or is deliberately opened by a surgeon and is culture-positive or not cultured when the patient has at least 1 of the following signs or symptoms: fever (>38°C), or localized pain or tenderness. A culture-negative finding does not meet this criterion.
   - an abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation, or by histopathologic or radiologic examination
   - diagnosis of a deep incisional SSI by a surgeon or attending physician.

Superficial Incisional Surgical Site

1. Infection occurs within 30 days after the operative procedure

   And

2. Involves only skin and subcutaneous tissue of the incision

   And

3. Patient has at least 1 of the following:
   - purulent drainage from the superficial incision
   - organisms isolated from an aseptically obtained culture of fluid or tissue from the superficial incision
   - at least 1 of the following signs or symptoms of infection: pain or tenderness, localized swelling, redness, or heat, and superficial incision is deliberately opened by surgeon and is culture positive or not cultured. A culture-negative finding does not meet this criterion.
   - diagnosis of superficial incisional SSI by the surgeon or attending physician.

APPENDIX 2. Primary surgical procedure (N = 172)

Characteristics	All	Surgical site infections Yes (n = 43)	Surgical site infections No (n = 129)
Surgical category			
Ventricular septum surgery	1 (0.6)	—	1 (0.8)
Atrioventricular canal surgery	3 (1.7)	2 (4.7)	1 (0.8)
Single ventricle palliation	90 (52.3)	25 (58.1)	65 (50.4)
Great vessel surgery	51 (29.7)	10 (23.3)	41 (31.8)
Left heart surgery	9 (5.2)	1 (2.3)	8 (6.2)
Right heart surgery	15 (8.7)	4 (9.3)	11 (8.5)
Chest procedures	3 (1.7)	1 (2.3)	2 (1.6)
Surgical procedure			
VSD repair	1 (0.6)	—	1 (0.8)
Complete atrioventricular canal repair	3 (1.7)	2 (4.7)	1 (0.8)
BT shunt	6 (3.5)	4 (9.3)	2 (1.6)
Norwood (modified BT shunt)	57 (33.2)	10 (23.3)	47 (36.5)
Norwood (RV-PA conduit)	17 (9.9)	7 (16.3)	10 (7.8)
Bi-directional Glenn/ hemi-Fontan	2 (1.2)	—	2 (1.6)
Fontan procedure	8 (4.7)	4 (9.3)	4 (3.1)
Aortic arch reconstruction	11 (6.4)	1 (2.3)	10 (7.8)
Interrupted aortic arch repair	2 (1.2)	1 (2.3)	1 (0.8)
Arterial switch operation	9 (5.2)	—	9 (7.0)
Rastelli procedure	14 (8.1)	4 (9.3)	10 (7.8)
Truncus arteriosus repair	6 (3.5)	2 (4.7)	4 (3.1)
Arterial switch operation/ VSD repair	1 (0.6)	1 (2.3)	—
Double-switch procedure	5 (2.9)	1 (2.3)	4 (3.1)
Other great vessel surgery	3 (1.7)	—	3 (2.3)
Coronary artery surgery	1 (0.6)	—	1 (0.8)
Ross procedure	1 (0.6)	—	1 (0.8)
Subaortic membrane resection	1 (0.6)	—	1 (0.8)
Mitral valve repair/replacement	2 (1.2)	—	1 (1.6)
TAPVR repair	3 (1.7)	—	3 (2.3)
Pulmonary vein stenosis surgery	1 (0.6)	1 (2.3)	—
Tetralogy of Fallot repair	7 (4.1)	2 (4.7)	5 (3.9)
Pulmonary valvotomy	1 (0.6)	—	1 (0.8)
Unifocalization of pulmonary arteries	5 (2.9)	1 (2.3)	4 (3.1)
Other right heart surgery	2 (1.2)	1 (2.3)	1 (0.8)
Cardiac tumor surgery	1 (0.6)	—	1 (0.8)
Heart transplant	2 (1.2)	1 (2.3)	1 (0.8)

Data are presented as n (%). *VSD*, Ventricular septal defect; *BT*, Blalock-Taussig; *RV-PA*, right ventricle to pulmonary artery; *TAPVR*, total anomalous pulmonary venous return.