

Risk Factors for Surgical Site Infection After Cardiac Surgery in Children

John M. Costello, MD, MPH, Dionne A. Graham, PhD, Debra Forbes Morrow, RN, BSN, Jacqueline Morrow, BS, Gail Potter-Bynoe, BS, CIC, Thomas J. Sandora, MD, MPH, Frank A. Pigula, MD, and Peter C. Laussen, MBBS

Department of Cardiology, Clinical Research Program, Department of Nursing, Infection Control Program, Division of Infectious Diseases, Departments of Medicine and Laboratory Medicine, and Department of Cardiac Surgery, Children's Hospital Boston, Harvard Medical School, Boston, Massachusetts

Background. We sought to identify risk factors for surgical site infections (SSI) in children undergoing cardiac surgery.

Methods. A matched case-control study was conducted in the Children's Hospital Boston Cardiovascular Program. Surgical site infections were identified for 3 years (2004 to 2006). We identified two randomly selected control patients who underwent cardiac surgery within 7 days of each index case. Univariate and multivariate conditional logistic regression analyses were used to identify risk factors for SSI. In a secondary analysis, risk factors for organ space SSI (mediastinitis) were sought. Secondary analyses were also conducted using only those variables known preoperatively.

Results. Seventy-two SSI and 144 controls were included. Independent risk factors for any type of SSI were age younger than 1 year (adjusted odds ratio, 2.28; 95% confidence interval, 1.18 to 4.39) and duration of cardiopulmonary bypass greater than 105 minutes (adjusted

odds ratio, 1.92; 95% confidence interval, 1.02 to 3.62). Independent risk factors for organ space SSI were aortic cross-clamp time greater than 85 minutes (adjusted odds ratio, 5.61; 95% confidence interval, 1.06 to 29.67) and postoperative exposure to at least three separate red blood cell transfusions (adjusted odds ratio, 7.87; 95% confidence interval, 1.63 to 37.92). When only those potential risk factors known preoperatively were considered, age younger than 1 year independently predicted the subsequent development of any type of SSI, and preoperative hospitalization independently predicted the subsequent development of organ space SSI.

Conclusions. Younger patients undergoing longer surgical procedures and those requiring more postoperative blood transfusions are at greatest risk for SSI. Additional preventive strategies, including restrictive blood transfusion policies, warrant further investigation.

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Surgical site infections (SSI) occur in 2% to 5% of all patients who undergo inpatient surgery, and are associated with increases in morbidity and health-care expenditures [1]. Prevention of SSI has become a quality assurance priority for state and federal regulatory agencies, third-party payers, and health-care organizations. A greater understanding of risk factors for SSI may facilitate the efforts of clinicians and health-care organizations to minimize the occurrence of this complication.

In pediatric cardiac surgical patients, reported SSI rates range from 1.7 to 8.0 per 100 cases [2–8]. Prior studies have identified age younger than 1 month, genetic syndrome, preoperative hospitalization for greater than 48 hours, higher American Society of Anesthesiologists preoperative assessment score, intraoperative hypothermia, need for multiple procedures during the same

operation, duration of surgery, and presence of temporary pacing wires for more than 3 days as risk factors for SSI in multivariate analyses [2, 3, 7–10].

In April 2004, we established a multidisciplinary initiative within our Cardiovascular Program to reduce the frequency of hospital-acquired infections (HAI). This initiative included establishing a full-time unit-based infection control nurse position, intensive staff education, and the implementation of evidence-based bundles for prevention of SSI and other common HAI [11]. After these efforts, the rate of SSI in our Cardiovascular Program decreased from 3.0 SSI per 100 cases in 2004 and 2005 to 2.0 SSI per 100 cases in 2007 and 2008. The rate of organ space SSI (including mediastinitis) decreased from 1.4 per 100 cases to 0.6 per 100 cases during these same periods. Further insight into which demographic, procedural, and treatment characteristics are associated with greatest risk will provide targets for additional preventive interventions to further reduce the incidence of SSI. The primary aim of this study was to identify risk factors for any type of SSI in children undergoing cardiac surgery in a large congenital heart program. Given the greater severity illness and need for surgical intervention

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Address correspondence to Dr Costello, Division of Cardiovascular Critical Care, Department of Cardiology, Children's Hospital Boston, 300 Longwood Ave, Bader 600, Boston, MA 02115-5737; e-mail: john.costello@cardio.chboston.org.

associated with organ space SSI, we also sought to identify risk factors for this type of SSI.

Patients and Methods

This study was approved by the Committee on Clinical Investigation at Children's Hospital Boston, and the requirement for written informed consent was waived.

Surgical Site Infection Prevention Strategies

The bundle of practices used to prevent SSI in our Cardiovascular Program and the date that each individual intervention was implemented are found in Table 1. A prophylactic antibiotic (usually cefazolin) is administered within 60 minutes before skin incision and after separation from cardiopulmonary bypass. The prophylactic antibiotic is routinely discontinued after all chest tubes are removed. Although this practice is not consistent with current guidelines suggesting that prophylactic antibiotics are discontinued within 24 to 48 hours after cardiac surgery, it is supported by the pediatric cardiac surgical literature [4]. Operating room ventilation is compliant with the American Institute of Architects guidelines, and cleaning and disinfection of environmental surfaces and appropriate sterilization of surgical equipment are done in accordance with published guidelines [12].

Selection of Cases and Controls

A case-control study design was used to identify risk factors for SSI. Cases consisted of all patients experiencing any type of SSI after undergoing cardiac surgery at Children's Hospital Boston from January 2004 through December 2006. Patients having primary sternal closure in the operating room as well as those having delayed sternal closure were included. A cardiac intensive care unit (ICU) -based infection control nurse (D.F.M.) and the manager of the hospital's Infection Control Program (G.P.B.) identified all patients who experienced an SSI during this period using prospective surveillance mech-

anisms. Patients were categorized as having a superficial incisional, deep incisional, or organ space SSI if they met surveillance criteria used by the National Healthcare Safety Network (Appendix Table 1) [13].

For each case, the Cardiovascular Program database was queried to randomly select 2 control patients who underwent cardiac surgery at our center. During the period that cases were identified for this study, a quality improvement initiative aimed at preventing SSI and other HAI was implemented in our Cardiovascular Program (Table 1) [11]. Therefore, control patients were matched by date of surgery (± 7 days) to optimize the likelihood that similar preoperative, intraoperative, and postoperative preventive practices were being used for cases and control patients.

Assessment of Exposure

A list of demographic, cardiac, comorbidity, and perioperative exposure variables was compiled by literature review, and additional variables were included if they were thought to be biologically plausible based on the opinion of the study investigators (Appendix Table 2) [14, 15]. To ensure that only exposures occurring before the outcome of interest were recorded, exposure variables for cases were recorded from the date of cardiac ICU admission until the day before the SSI. For control patients, exposure variables were recorded from the cardiac ICU admission date through the date of hospital discharge. We only recorded blood products that were administered while the patient was in the cardiac ICU; blood products administered in the operating room were not included in the analysis because of incomplete data. The Risk Adjustment in Congenital Heart Surgery (RACHS-1) category was recorded for those cardiac surgery patients in whom this scoring system could be applied [16]. The RACHS-1 is a validated scoring system that groups cardiac surgical procedures with similar expected short-term mortality rates into six predefined risk categories, in which category 1 has the lowest risk for death (eg,

Table 1. Surgical Site Infection Prevention Bundle Currently Used in the Cardiovascular Program at Children's Hospital Boston

Variable	Intervention	Date of Introduction
General	Renewed hospital-wide hand hygiene campaign with regular auditing	October 2004
	Staff education and feedback	November 2004
Preoperative	Chlorhexidine bathing or showering of patient the night before surgery	January 2005
Intraoperative	Clippers replace razors for hair removal	February 2006
	OR nurses replace surgical residents for skin preparation	November 2005
	Campaign to reemphasize focus on administering antimicrobial prophylaxis 0-60 minutes before incision through active auditing and feedback	November 2006
Postoperative	Chlorhexidine replaces povidone-iodine as skin antiseptic	February 2006
	Standardized occlusive dressing $\times 48$ hours	November 2004
	Early removal of temporary pacing wires	December 2004
	Sterile technique for transthoracic echocardiograms performed within 5 days of surgery ^a	December 2004

^a Sterile implies use of individual ultrasound gel packets, sterile gloves, and a sterile probe sheath as would be used for an intraoperative epicardial echocardiogram.

OR = operating room.

secundum atrial septal defect closure) and category 6 has the highest risk for death (eg, Norwood operation).

Statistical Analysis

We used SAS software, version 9.1 of the SAS System for Windows (SAS Institute, Inc, Cary, NC) for statistical analysis. Continuous variables were converted to binary or categorical variables using median or 75th percentile values or clinically relevant cut points. Selected nominal and ordinal variables were collapsed to binary variables. Conditional logistic regression analysis was used to examine the univariate relationship between each exposure variable and the development of SSI. Odds ratios (OR) with 95% confidence intervals (CI) were calculated. Variables with a probability value of less than 0.10 in univariate analysis were considered for inclusion in a multivariate conditional logistic regression analysis to identify independent predictors of SSI. A secondary analysis was then conducted to identify risk factors for organ space SSI using statistical methodology as described above. Selected continuous variables were dichotomized using new cut points derived using summary data from only the organ space SSI patients and their matched control patients. We were also interested in identifying variables known before surgery that were associated with SSI. Thus, secondary analyses were also conducted using only significant univariate variables that were known at the time of admission (eg, demographics, comorbidities, RACHS-1 category) to identify independent predictors of any type of SSI and organ space SSI.

Results

Between January 1, 2004, and December 31, 2006, there were 2,645 primary cardiac surgical cases, including 2,111

cardiopulmonary bypass cases, performed in our institution. When including secondary procedures performed by our cardiac surgeons after the index case, such as chest reexploration for bleeding or debridement, delayed sternal closure, extracorporeal membrane oxygenator decannulation, or hemidiaphragm plication, there were a total of 3,367 cardiac surgical procedures during this period. During the study period, 73 SSI occurred in 67 patients. Two SSI occurred in a single patient during the same hospitalization, and for this patient only the first episode was analyzed. Five patients experienced an SSI after cardiac surgical procedures performed during separate hospitalizations, and in these instances both SSI were included. Thus, 72 SSI are the subject of this analysis, and these cases were matched by date of operation with 144 control patients. The median number of days from surgery until SSI diagnosis was 15 (range, 3 to 129 days). The type of SSI was superficial incisional in 38 patients, deep incisional in 6 patients, and organ space in 28 patients. Microorganisms identified as the cause of SSI are listed in [Appendix Table 3](#). Blood cultures were obtained at the time of SSI diagnosis in 61 of 72 cases (85%); the 11 patients who did not have blood cultures sent all had superficial incisional SSI. Blood cultures were positive in 6 of 27 cases of superficial incisional SSI (22%), 2 of 6 cases of deep incisional SSI (33%), and 18 of 28 cases of organ space SSI (64%).

Risk Factors for Any Type of Surgical Site Infection

Potential risk factors for SSI are listed in [Appendix Table 2](#), and those that are significant by univariate analysis are displayed in [Table 2](#). Infants, patients requiring preoperative hospitalization, and those requiring more complex procedures, as evidenced by higher RACHS-1 categories and longer cardiopulmonary bypass times, were at greater

Table 2. Significant Risk Factors for Any Type of Surgical Site Infection by Univariate Analysis^a

Exposures	SSI (N = 72) %	Control (N = 144) %	Crude OR (95% CI) for SSI	p Value
Demographics				
Age <1 year	79	58	2.56 (1.35–4.87)	0.004
Surgical variables				
Preoperative hospitalization	61	40	2.22 (1.27–3.91)	0.006
Single ventricle cardiac disease	42	28	1.90 (1.03–3.52)	0.04
RACHS-1 category ≥4	40	26	1.94 (1.04–3.62)	0.04
Cardiopulmonary bypass >105 minutes	61	43	2.20 (1.20–4.02)	0.01
Postoperative severity of illness				
Postoperative oxygen saturation ≤85%	36	19	2.16 (1.18–3.97)	0.01
Postoperative device utilization				
Arterial line ≥5 days	53	36	1.93 (1.09–3.42)	0.02
Mechanical ventilation ≥3 days	56	38	2.09 (1.16–3.76)	0.01
CICU course				
≥6 days CICU admit to SSI for cases, or CICU admit to discharge for controls	57	41	1.88 (1.06–3.34)	0.03

^a Data shown in the SSI and control columns are percentiles. Data for nonsignificant risk factors are found in [Appendix Table 2](#).

CI = confidence interval; CICU = cardiac intensive care unit; OR = odds ratio; RACHS-1 = Risk Adjustment in Congenital Heart Surgery, version 1; SSI = surgical site infection.

Table 3. Independent Risk Factors for Surgical Site Infection

All Variables	Adjusted OR (95% CI)	p Value	Variables Known Preoperatively	Adjusted OR (95% CI)	p Value
Any type of SSI					
Age <1 y	2.28 (1.18-4.39)	0.01	Age <1 y	2.56 (1.35-4.87)	0.004
CPB >105 min	1.92 (1.02-3.62)	0.04			
Organ space SSI					
Aortic cross-clamp >85 min	5.61 (1.06-29.67)	0.04	Preoperative hospitalization	3.30 (1.26-8.59)	0.01
PRBC transfusion ≥3 units	7.87 (1.63-37.92)	0.01			

CI = confidence interval; CPB = cardiopulmonary bypass; OR = odds ratio; PRBC = packed red blood cells; SSI = surgical site infection.

odds for developing an SSI. Postoperatively, patients with cyanosis and those with greater duration of mechanical ventilation, arterial line use, and cardiac ICU stay were also at greater risk. However, in multivariate analysis, the only independent risk factors for SSI were age younger than 1 year and duration of cardiopulmonary bypass greater than 105 minutes, which was the median cardiopulmonary bypass time for all patients in the study (Table 3). When only those potential risk factors known preoperatively were considered, age younger than 1 year independently predicted the subsequent development of SSI (Table 3).

Of the 67 study patients, 5 experienced separate SSI after cardiac procedures that were performed during two different hospitalizations (3.5 to 6 months apart). To assess the possibility that these 5 patients biased the results, a sensitivity analysis was conducted after the exclusion of these 5 patients and their matched control patients. The findings of the univariate analyses were essentially unchanged (data not shown). In multivariate

analysis, RACHS-1 category of 4 or greater (adjusted OR, 2.20; 95% CI, 1.11 to 4.34; $p = 0.02$) and cardiopulmonary bypass time greater than 105 minutes (adjusted OR, 1.97; 95% CI, 1.03 to 3.77; $p = 0.04$) were independent predictors of any type of SSI. Age younger than 1 year was the final variable removed from the regression model.

Risk Factors for Organ Space Surgical Site Infection

All of the variables found in Appendix Table 2 were included in a secondary analysis as potential risk factors for organ space SSI (n = 28). Those variables for which there was a trend ($p \leq 0.10$) or significant univariate association with the subsequent development of organ space SSI are displayed in Table 4. In multivariate analysis, risk factors that remained associated with organ space SSI were an aortic cross-clamp time greater than 85 minutes and postoperative exposure to at least three separate red blood cell transfusions (Table 3). When only those potential risk factors known before surgery were considered, the need for preoperative hospitalization

Table 4. Univariate Risk Factors for Organ Space Surgical Site Infection^a

Exposures	SSI (N = 28) %	Control (N = 56) %	Crude OR (95% CI)	p Value
Demographics				
Weight ≤5.2 kg	61	41	2.25 (0.87-5.83)	0.04
Comorbidities				
Chromosomal anomaly	4	25	0.12 (0.02-0.95)	0.04
Surgical variables				
Preoperative hospitalization	71	39	3.30 (1.26-8.59)	0.01
Aortic cross-clamp >85 min	43	16	7.10 (1.53-32.91)	0.01
Delayed sternal closure	39	18	3.68 (1.12-12.12)	0.03
Postoperative device utilization				
Arterial line ≥4 days	64	30	4.25 (1.51-11.98)	0.006
Chest tube ≥4 days	46	18	4.21 (1.10-16.16)	0.04
Mechanical ventilation ≥3 days	75	34	5.89 (1.94-17.90)	0.002
Medications and blood products				
Parenteral nutrition ≥3 days	46	14	6.61 (1.83-23.81)	0.004
Postoperative RBC transfusion ≥3 units exposure	46	13	9.44 (2.08-42.78)	0.004
CICU course				
≥6 days CICU admit to SSI for cases, or CICU admit to discharge for controls	68	41	2.82 (1.11-7.19)	0.03
≥12 days hospital admit to SSI for cases, or hospital admit to discharge for controls	61	36	2.97 (1.09-7.80)	0.03

^a All variables in Appendix Table 2 were assessed; only those with a $p \leq 0.05$ are displayed. Data shown in the SSI and control columns are percentiles.

CI = confidence interval; CICU = cardiac intensive care unit; OR = odds ratio; RBC = red blood cell; SSI = surgical site infection.

independently predicted the subsequent development of organ space SSI (Table 3).

Comment

Our Cardiovascular Program has undertaken a systematic initiative to prevent HAI since 2004, and since that time we have seen a reduction but not complete elimination of SSI and other HAI [11]. This study was conducted to determine which patient-specific and procedural variables are most strongly associated with the subsequent development of SSI. Younger age and longer cardiopulmonary bypass times were found to be independent predictors of any type of SSI. Independent risk factors for organ space SSI were preoperative hospitalization and longer aortic cross-clamp time. A greater number of red blood cell transfusions was also independently associated with the subsequent development of organ space SSI. Of note, delayed sternal closure was associated with organ space SSI by univariate analyses, but this relationship did not retain significance after multivariate analyses. We did not find associations between factors such as growth failure, comorbidities, perioperative hyperglycemia, hypothermia, duration of surgery, indices of perfusion, and the need for extracorporeal membrane oxygenation, each of which could plausibly increase or has been reported to increase the risk for development of SSI.

Age younger than 1 year was an independent predictor for SSI in our study. Interestingly, when age was further explored, using children older than 1 year of age as a reference group, infants (1 to 12 months of age) had a slightly higher odds of developing SSI (OR, 2.8) than neonates (<28 days of age; OR, 2.4). Allpress and associates [2] reported that neonatal age independently predicted the development of SSI after congenital heart surgery. It is possible that the relative immunodeficient state of these younger patients or the routine use of intraoperative methylprednisolone could predispose these patients to infection.

Allpress and colleagues [2] and Nateghian and coworkers [3] found that longer duration of cardiac surgery was independently associated with any type of SSI in children. Holzmann-Pazgal and associates [8] found that the need for multiple cardiac procedures during the same operation was an independent predictor of SSI. On the surface, the independent relationships present in our study between longer cardiopulmonary bypass and aortic cross-clamp times and SSI appear to be consistent with this literature. However, longer duration of surgery, defined as the time from skin incision to skin closure, was not associated with SSI in our study. Longer cardiopulmonary bypass times may contribute to imbalances in the systemic inflammatory response and compensatory antiinflammatory response syndromes, contributing to possible immunoparesis [17]. Adult cardiac surgery guidelines suggest administering another dose of prophylactic antibiotic every two half-lives (eg, within 3 to 4 hours for cefazolin) [18]. An additional antibiotic dose is routinely given after cardiopulmonary bypass in our center.

We made the important observation that receipt of three or more units of red blood cells during the postoperative ICU stay was independently associated with subsequent development of organ space SSI after pediatric heart surgery. We and others have found that exposure to blood products is associated with the development of bloodstream infections in critically ill patients, and volume of red blood cell transfusion has been associated with increased SSI risk after cardiac surgery in adults [19, 20]. Blood product transfusions may have immunomodulatory effects, including decreased natural killer cell function, defective antigen presentation, decreased helper-to-suppressor T-lymphocyte ratio, and reduced cell-mediated immunity [21]. Additionally, the need for red blood cell transfusion may be a marker for surgical bleeding, which was not directly quantified in our study. Clotted blood within the mediastinum provides a rich substrate for the proliferation of microorganisms. Efforts to improve surgical hemostasis and minimize postoperative red blood cell transfusion warrant further consideration.

We did not identify any relationship between perioperative glucose levels and SSI, similar to findings of another pediatric cardiac surgical study [8]. Hyperglycemia is common after cardiac surgery in adults and children, and diabetes is an independent risk factor for SSI after adult cardiac surgery [22, 23]. The current recommendation for strict glycemic control in adults undergoing cardiac surgery as a part of a bundle to limit SSI is based on limited evidence [1, 24]. In the only published randomized trial of strict glycemic control in critically ill children (75% of whom were recovering from cardiac surgery), there were significantly fewer HAI in patients assigned to strict glycemic control (36.8% versus 29.2%; $p = 0.03$) [25]. This trial was underpowered to detect a difference in the rate of SSI, which occurred in 1.4% of control patients and 1.7% of those assigned to intensive insulin therapy. Additional trials are needed in children recovering from cardiac surgery to determine the safety and efficacy of strict glycemic control.

Individual preventive measures in adult SSI bundles may not be applicable to infants and small children undergoing cardiac surgery. Typical adult SSI bundles focus on the appropriate use of prophylactic antibiotics and skin antiseptics, avoidance of razor use for hair removal, glucose control in cardiac surgical patients, and maintenance of normothermia in colorectal surgery patients [1]. Thus, identification of specific risk factors for SSI in pediatric surgical patients is important when considering preventive interventions. Our univariate findings support the importance of early removal of temporary pacing wires, chest tubes, and other invasive devices as soon as they are no longer necessary. The adjusted association between preoperative hospitalization and organ space SSI cannot be fully explained by younger age or greater surgical complexity, as these variables were controlled for in the multivariate analysis. We speculate that greater preoperative skin colonization with pathogenic organisms may be contributory, emphasizing the importance of hand hygiene.

Our study has several limitations. Although the design was retrospective, all SSI were identified in real time using

established surveillance mechanisms. Causality between exposure variables and outcomes cannot be proven using a case-control study design. Data regarding compliance with individual components of our SSI bundles, including the timing of intraoperative prophylactic antibiotic dosing, was inconsistently recorded in the medical record and thus could not be retrospectively analyzed. Finally, given that cases and control patients were matched by date of surgery, we were unable to evaluate whether individual components of our SSI bundle that were introduced during the study period are useful (Table 1).

In conclusion, we found that age younger than 1 year and duration of cardiopulmonary bypass greater than 105 minutes were independent risk factors for any type of SSI. Risk factors for organ space SSI included aortic cross-clamp time greater than 85 minutes and postoperative exposure to at least three red blood cell transfusions. When only those potential risk factors known preoperatively were considered, only age younger than 1 year independently predicted the subsequent development of SSI, and preoperative hospitalization independently predicted the subsequent development of organ space SSI. Specific focus on these high-risk patients may be useful during quality improvement initiatives. Efforts to limit postoperative bleeding and red blood cell transfusion seem warranted.

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Appendix

Table 1. Summary of National Healthcare Safety Network Surveillance Criteria for Surgical Site Infections

Superficial incisional SSI	Infection occurs within 30 days of surgery and Involves only skin and subcutaneous tissue of the incision and Patient has at least 1 of the following: Purulent drainage from incision Organism isolated from culture of fluid or tissue from incision At least 1 of following: pain or tenderness, swelling, redness, or heat, and superficial incision is deliberately opened by surgeon, unless incision is culture-negative Diagnosis of superficial SSI by a surgeon or attending physician
Deep incisional SSI	Infection occurs within 30 days postoperatively 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 involves deep soft tissues (eg, fascial and muscle layers) of the incision and patient has at least 1 of the following: Purulent drainage from the deep incision but not from the organ or space component of the surgical site Deep incision spontaneously dehisces or is deliberately opened by surgeon when the patient has at least one of the following signs or symptoms: fever or localized pain or tenderness, unless incision is culture-negative An abscess or other evidence of infection involving deep incision is found on direct examination, during reoperation, or by histopathologic or radiographic examination Diagnosis of a deep incisional SSI by a surgeon or attending physician
Organ space SSI	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 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 patient has at least one of the following: Purulent drainage from a drain that is placed through a stab wound into the organ or space Organisms isolated from a culture of fluid or tissue in the organ or space An abscess or other evidence of infection involving the organ or space that is found on direct examination, during reoperation, or by histopathologic or radiographic examination Diagnosis of an organ or space SSI by a surgeon or attending physician

SSI = surgical site infection.

Table 2. Univariate Risk Factors for Any Type of Surgical Site Infection^a

Exposures	SSI (N = 72) %	Control (N = 144) %	Crude OR (95% CI) for SSI	p Value
Demographics				
Age <1 y	79	58	2.56 (1.35–4.87)	0.004
Weight ≤5.2 kg	58	45	1.71 (0.96–3.08)	0.07
Weight for age <25%	44	50	0.80 (0.45–1.42)	0.44
Male	47	51	0.83 (0.46–1.51)	0.55
White, non-Hispanic race	63	63	1.00 (0.55–1.82)	1.00
Comorbidities				
Prematurity (<37 wk gestational age)	8	7	1.25 (0.40–3.91)	0.70
Chromosomal anomaly	14	15	0.90 (0.40–1.99)	0.79
Noncardiac structural anomaly	10	8	1.19 (0.44–3.20)	0.73
Cardiac surgery during prior hospitalization	35	35	0.98 (0.54–1.74)	0.92
Right internal thoracic artery coil occlusion	6	3	1.60 (0.43–5.96)	0.48
Left internal thoracic artery coil occlusion	1	3	0.40 (0.05–3.42)	0.40
Asplenia or polysplenia	1	6	0.25 (0.03–2.00)	0.19
Gastrostomy tube	7	6	1.11 (0.37–3.32)	0.85
Tracheostomy	0	2	...	

Continued

Table 2. Continued

Exposures	SSI (N = 72) %	Control (N = 144) %	Crude OR (95% CI) for SSI	p Value
Surgical variables				
Preoperative hospitalization	61	40	2.22 (1.27-3.91)	0.006
Single ventricle cardiac disease	42	28	1.90 (1.03-3.52)	0.04
RACHS-1 category ≥ 4	40	26	1.94 (1.04-3.62)	0.04
Sternotomy incision	97	94	2.00 (0.43-9.42)	0.38
Cardiopulmonary bypass used	89	89	1.00 (0.40-2.53)	1.00
Cardiopulmonary bypass >105 min	61	43	2.20 (1.20-4.02)	0.01
Aortic cross-clamp >50 min	54	48	1.28 (0.73-2.25)	0.39
Deep hypothermic circulatory arrest used	24	16	1.59 (0.80-3.15)	0.19
Duration of surgery >245 min	56	45	1.48 (0.85-2.75)	0.17
Biologic or prosthetic implant used	63	66	0.85 (0.46-1.57)	0.60
Lowest intraoperative temperature $<26.5^{\circ}\text{C}$	54	48	1.28 (0.73-2.26)	0.39
Highest intraoperative lactate >5 mmol/L	31	23	1.58 (0.79-3.14)	0.20
Highest intraoperative glucose >227 mg/dL	26	24	1.12 (0.58-2.17)	0.73
Mean intraoperative glucose >174 mg/dL	28	24	1.23 (0.68-2.30)	0.52
Antifibrinolytic agent given	50	41	1.43 (0.79-2.60)	0.24
Delayed sternal closure	29	22	1.58 (0.79-3.14)	0.20
Chest reopened in CICU	4	2	2.00 (0.40-9.91)	0.39
Chest exploration in CICU	11	12	0.97 (0.36-2.36)	0.87
Chest open ≥ 4 days	15	13	1.19 (0.53-2.64)	0.68
Cardiac reoperation (same hospitalization)	14	10	1.35 (0.60-3.06)	0.47
Postoperative severity of illness				
Postoperative oxygen saturation $\leq 85\%$	36	19	2.16 (1.18-3.97)	0.01
PRISM-III score (24 h) $\geq 10^b$	50	41	1.44 (0.81-2.56)	0.21
Highest 48-hour inotropic agent score $>10^c$	43	32	1.75 (0.92-3.35)	0.09
Highest 48-hour lactate >5 mmol/L	26	24	1.17 (0.60-2.26)	0.65
Lowest 48-hour temperature $<35^{\circ}\text{C}$	54	43	1.57 (0.88-2.80)	0.13
Laboratory values				
1st postoperative white blood cell count (cells/ μL)				
$\leq 6,000$	26	24	1.03 (0.52-2.06)	0.93
$\geq 13,100$	21	27	0.74 (0.37-1.48)	0.39
6,100-13,000	53	49	Ref.	Ref.
Maximal 48-hour glucose ≥ 180 mg/dL	49	52	0.95 (0.53-1.68)	0.85
Mean 48-hour glucose ≥ 150 mg/dL	46	52	0.79 (0.46-1.37)	0.40
Postoperative device utilization				
≥ 4 central venous lines at once	28	22	1.46 (0.73-2.92)	0.28
Central venous line ≥ 5 days	51	38	1.71 (0.96-3.04)	0.07
Arterial line ≥ 5 days	53	36	1.93 (1.09-3.42)	0.02
Foley catheter ≥ 4 days	53	42	1.56 (0.88-2.75)	0.13
Chest tube ≥ 4 days	40	35	1.30 (0.70-2.40)	0.40
Pacing wires ≥ 6 days	50	42	1.37 (0.77-2.43)	0.29
Mechanical ventilation ≥ 3 days	56	38	2.09 (1.16-3.76)	0.01
Reintubation	33	26	1.46 (0.78-2.72)	0.24
Extracorporeal membrane oxygenation	7	12	0.50 (0.16-1.52)	0.22
Medications and blood products				
Prophylactic antibiotics ≥ 3 days	35	33	1.11 (0.59-2.09)	0.75
Corticosteroids (except hydrocortisone)	24	19	1.35 (0.67-2.72)	0.40
Hydrocortisone (for adrenal insufficiency)	7	13	0.49 (0.17-1.43)	0.19
Immunosuppression	1	3	0.50 (0.06-4.47)	0.54
Parenteral nutrition ≥ 4 days	28	20	1.51 (0.76-2.99)	0.24
Postoperative red blood cell transfusion	71	58	1.70 (0.93-3.10)	0.08
Postoperative platelet transfusion	24	20	1.27 (0.61-2.68)	0.52
Postoperative fresh-frozen plasma transfusion	21	24	0.85 (0.44-1.68)	0.65

Continued

Table 2. Continued

Exposures	SSI (N = 72) %	Control (N = 144) %	Crude OR (95% CI) for SSI	p Value
CICU course				
≥6 days CICU admit to SSI for cases, or CICU admit to discharge for controls	57	41	1.88 (1.06–3.34)	<0.03
≥11 days hospital admit to SSI for cases, or hospital admit to discharge for controls	53	43	1.47 (0.83–2.59)	0.18
Intrahospital transport	32	26	1.32 (0.73–2.40)	0.35

^a Data shown in the SSI and control columns are percentiles. ^b Pediatric Risk of Mortality Score (PRISM-III) was calculated using laboratory and physiologic values during the first 24 hours after cardiac surgery [14]. ^c The 48-hour maximal inotropic agent score was calculated by summing the doses of inotropic agents in micrograms per kilogram per minute: [dose of dopamine + dose of dobutamine + (dose of milrinone × 10) + (dose of epinephrine × 100)] [15].

CI = confidence interval; CICU = cardiac intensive care unit; OR = odds ratio; PRISM-III = Pediatric Risk of Mortality Score, version 3; RACHS-1 = Risk Adjustment in Congenital Heart Surgery, version 1; Ref. = reference value; SSI = surgical site infection.

Table 3. Microorganisms Causing Surgical Site Infections

Variable	Organism	All SSI (N = 72)	Superficial + Deep Incisional SSI (N = 44)	Organ Space SSI (N = 28)
Gram-positive		54 (75%)	36 (82%)	18 (64%)
	MSSA	47	33	14
	MRSA	1	1	0
	Coagulase-negative staphylococci	6	2	4
Gram-negative		8 (11%)	2 (5%)	6 (21%)
	<i>Enterobacter cloacae</i>	3	1	2
	<i>Pseudomonas aeruginosa</i>	3	1	2
	<i>Serratia</i> species	2	0	2
Yeast		1 (1%)	1 (2%)	0 (0%)
	<i>Candida albicans</i>	1	1	0
Polymicrobial		6 (8%)	4 (9%)	2 (7%)
No growth		3 (4%)	1 (2%)	2 (7%)

MRSA = methicillin-resistant *Staphylococcus aureus*; MSSA = methicillin-susceptible *Staphylococcus aureus*; SSI = surgical site infection.

DISCUSSION

DR J. WILLIAM GAYNOR (Philadelphia, PA): In terms of your case identification, occasionally we see kids, particularly with superficial infections, who are readmitted. And your population is a lot like ours; we have people from outside our region, they may be readmitted to another hospital. How well did you track patients to be sure that you captured all the readmissions to your own or other hospitals?

DR COSTELLO: All of these cases were identified by prospective surveillance. But your point is a good one; it is quite possible that we didn't capture 100% of the patients, particularly those who had relatively minor superficial infections. I think in the current era there is increased attention given to these complications that frequently we will get phone calls from outside infection control personnel from other hospitals reporting these cases to us. But our referral pattern is similar to that at your program and as a result we may not have captured all of the minor cases.

DR JOSEPH AMATO (Chicago, IL): This was an excellent review of risk potentials. However, while my question may seem insignif-

icant, I wonder if you looked at prenatal and/or postnatal care. I believe that there might be a higher incident of infections in these infants without this care. Did they just come to the hospital to be born without prenatal care or postnatal care? I believe that the possibility of contaminants within their habitats or environment associated with parents and other family members without this care might increase the possibility of infections. Therefore my question is whether you think this makes a difference or not.

DR COSTELLO: We did not look at whether or not the mothers of the neonates that were included in this study had prenatal care or not.

DR AMATO: Although insignificant I think it might be a good point to look at. Thank you.

DR W. MROWCZYNSKI (Geneva, Switzerland): Congratulations for this important and elegant study. I would like to ask you, because you showed that small children had higher preponderance for infection, did you also see some differences in

bacterial flora in comparison to older patients? This is the first question.

And second, in case of mediastinitis, do you use some vacuum-assisted system for healing the wound?

DR COSTELLO: The majority of the surgical site infections were caused by gram-positive organisms. I haven't broken down the organism type yet by age. I can tell you that there were more gram-negative infections, in the neighborhood of 30%, in the patients who had mediastinitis, whereas gram-negative infections were very uncommon in those with superficial infections.

And I believe your second question was regarding the management of mediastinitis. Our general approach would be to take these patients back to the operating room, wash out the mediastinum, and bring them back with a closed chest. It would be uncommon that we would use vacuum-assisted drainage. Generally we just continue IV (intravenous) antibiotics for 2

weeks; we've gotten away from a 6-week course of antibiotics in those patients, and 2 weeks seems to be sufficient.

DR M. BISHAWI (Stony Brook, NY): Just interested about the 105-minute cutoff for the CPB (cardiopulmonary bypass) time. Did you try to use as an ordinal showing a dose-response as cardiopulmonary time increase showed a high risk, or did you have enough numbers to do that?

DR COSTELLO: Of course, the numbers get smaller when you break a variable like CPB time into quartiles, as you're suggesting, compared to just making it a binary variable; but I had broken it down by quartiles and 105 minutes appeared to be where the cut point was. One hundred five minutes was the median cardiopulmonary bypass time in the entire data set that included both cases and controls.