

Major Infection After Pediatric Cardiac Surgery: A Risk Estimation Model

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Background. In pediatric cardiac surgery, infection is a leading cause of morbidity and mortality. We created a model to predict risk of major infection in this population.

Methods. Using the Society of Thoracic Surgeons Congenital Heart Surgery Database, we created a multivariable model in which the primary outcome was major infection (septicemia, mediastinitis, or endocarditis). Candidate-independent variables included demographic characteristics, comorbid conditions, preoperative factors, and cardiac surgical procedures. We created a reduced model by backward selection and then created an integer scoring system using a scaling factor with scores corresponding to percent risk of infection.

Results. Of 30,078 children from 48 centers, 2.8% had major infection (2.6% septicemia, 0.3% mediastinitis, and 0.09% endocarditis). Mortality and postoperative length

of stay were greater in those with major infection (mortality, 22.2% versus 3.0%; length of stay >21 days, 69.9% versus 10.7%). Young age, high complexity, previous cardiothoracic operation, preoperative length of stay more than 1 day, preoperative ventilator support, and presence of a genetic abnormality were associated with major infection after backward selection ($p < 0.001$). Estimated infection risk ranged from less than 0.1% to 13.3%; the model discrimination was good (c index, 0.79).

Conclusions. We created a simple bedside tool to identify children at high risk for major infection after cardiac surgery. These patients may be targeted for interventions to reduce the risk of infection and for inclusion in future clinical trials.

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Infections in children are frequent (incidence, 13% to 31%) after cardiac surgery [1–7]. Many are surgical site infections (incidence, 2.3% to 8%) [4, 5, 7–9]; however, many are more serious, such as septicemia (incidence, 6.3% to 15%) [3, 7, 10], mediastinitis (incidence, 0.2% to 3.3%) [5, 8, 9, 11–13], and endocarditis (incidence, 0.2%) [14–16]. Infections result in significant morbidity (eg, antibiotic usage, reoperation, prolonged hospital and intensive care unit [ICU] stays, and longer periods of mechanical ventilation and inotropic support), and contribute to an increase in mortality [2, 3, 5, 17].

Several studies have evaluated risk factors for postoperative infection such as longer preoperative and ICU stays, longer length of admission, open chest after surgery, cyanotic heart disease, younger age, and higher complexity score [1, 3, 7]. These studies, however, have been performed at single centers and are limited by small sample sizes. There have been few attempts to use risk factors to create a risk stratification system for postoperative infection; those that have attempted to create such a system have failed to adequately risk stratify patients in the setting of pediatric cardiac surgery [18–20].

The Society of Thoracic Surgeons Congenital Heart Surgery Database is the largest congenital heart surgery registry in North America. We used this dataset to identify risk factors for major infection in children after cardiac surgery, and to create and validate a bedside scoring system that can be used to estimate a patient's risk of major infection.

Patients and Methods

Data Source

The Society of Thoracic Surgeons Congenital Heart Surgery Database was founded in 2002 to support quality improvement in heart surgery. Data elements include demographic information, cardiac and noncardiac anomalies, comorbid conditions, type of operation, and outcomes including in-hospital mortality, major complications, and length of stay. We obtained approval from the Duke Institutional Review Board for waiver of consent on the basis of the unidentified nature of the data.

Patient Population

We evaluated patients 18 years of age or younger at operation from January 1, 2002, to December 31, 2006. We excluded hospitals ($n = 10$) with more than 10% missing data on preoperative risk factors, noncardiac abnormali-

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Table 1. Clinical Characteristics of the Patient Population and Univariate Analysis

Variable	Level	Total N (30078)	Overall %	Number With Infection (n = 857)	Percentage With Infection	p Value
Preoperative assessment						
Aristotle Basic Complexity level	N/A	325	1.1	6	1.9	<0.0001
	1	3,512	11.7	29	0.8	
	2	13,895	46.2	296	2.1	
	3	8,163	27.1	240	2.9	
	4	4,183	13.9	286	6.8	
RACHS-1 category	N/A	2,252	7.5	73	3.2	<0.0001
	1	4,090	13.6	28	0.7	
	2	11,819	39.3	201	1.7	
	3	8,387	27.9	276	3.3	
	4	2,246	7.5	113	5.0	
	5	6	<0.1	1	16.7	
Demographics						
Age	<30 days	6,621	22.0	426	6.4	<0.0001
	1-3 mo	2,702	9.0	104	3.9	
	4-12 mo	8,603	28.6	205	2.4	
	1-9 y	9,095	30.2	107	1.2	
	≥10 y	3,057	10.2	15	0.5	
Weight (kg)	<2.50	1,005	3.3	80	8.0	<0.0001
	2.50-4.99	9,911	33.0	508	5.1	
	≥5.00	19,162	63.7	269	1.4	
Weight for age/sex (percentile)	>50th percentile	11,633	38.7	239	2.1	0.0005
	5th to 50th percentile	7,864	26.2	261	3.3	
	<5th percentile	10,581	35.2	357	3.4	
Sex	Male	16,537	55.0	472	2.9	0.9379
	Female	13,541	45.0	385	2.8	
Race	Missing	5,488	18.3	143	2.6	0.1269
	Caucasian	13,209	43.9	368	2.8	
	Black	3,105	10.3	112	3.6	
	Hispanic	5,042	16.8	161	3.2	
	Asian	756	2.5	19	2.5	
	Native American	153	0.5	8	5.2	
	Other	2,325	7.7	46	2.0	
Surgery year	2002	3,276	10.9	120	3.7	0.0310
	2003	4,523	15.0	150	3.3	
	2004	5,685	18.9	182	3.2	
	2005	7,825	26.0	213	2.7	
	2006	8,769	29.2	192	2.2	
Operative						
Operative type	Bypass	24,971	83.0	716	2.9	0.4899
	Nonbypass Cardiovascular	5,107	17.0	141	2.8	
Procedure stratum ^a	Low complexity	12,917	43.0	152	1.2	<0.0001
	Medium complexity	12,831	42.7	406	3.2	
	High complexity	4,330	14.4	299	6.9	
Risk factors						
Preoperative length of stay (days)	Missing	8	<0.1	0	0.00	<0.0001
	0	18,537	61.6	237	1.3	
	1	2,389	7.9	74	3.1	
	2	1,549	5.2	64	4.1	
	≥3	7,595	25.3	482	6.4	
Previous cardiac operation	Missing	563	1.9	37	6.6	0.0867
	No	21,337	70.9	608	2.9	
	Yes	8,178	27.2	212	2.6	

Continued

Table 1. Continued

Variable	Level	Total N (30078)	Overall %	Number With Infection (n = 857)	Percentage With Infection	p Value
Preoperative acidosis	No	29,462	98.0	811	2.8	<0.0001
	Yes	616	2.1	46	7.5	
Preoperative circulatory support	No	30,022	99.8	853	2.8	0.0518
	Yes	56	0.2	4	7.1	
Preoperative shock	No	29,740	98.9	836	2.8	0.0011
	Yes	338	1.1	21	6.2	
Preoperative tracheostomy	No	29,982	99.7	845	2.8	0.0016
	Yes	96	0.3	12	12.5	
Preoperative ventilatory support	No	26,922	89.5	564	2.1	<0.0001
	Yes	3,156	10.5	293	9.3	
Any genetic abnormality	No	21,811	72.5	487	2.2	<0.0001
	Yes	8,267	27.5	370	4.5	
Mortality						
Discharge mortality	Missing	36	0.1	1	2.8	<0.0001
	No	28,963	96.3	666	2.3	
	Yes	1,079	3.6	190	17.6	

^a Low complexity is defined as ABC < 3 and RACHS-1 < 3; high complexity is defined as ABC ≥ 4 or RACHS-1 ≥ 5; medium complexity is defined as all others.

N/A = not assigned; RACHS-1 = Risk Adjustment for Congenital Heart Surgery.

ties, or postoperative complications. We excluded all solely thoracic surgical operations by excluding those that did not meet the criteria for “cardiopulmonary bypass” or “no cardiopulmonary bypass cardiovascular” (n = 7,191) and those that consisted of procedures not related to congenital heart disease surgery (n = 6,044). In addition, we excluded 803 operations for which both the Risk Adjustment for Congenital Heart Surgery (RACHS-1) category and the Aristotle Basic Complexity (ABC) score were undefined. We also excluded those patients that underwent a heart or lung transplant (n = 505), a catheter-related procedure (n = 6), and ligation of a patent ductus arteriosus in infants weighing less than 2,500 grams (n = 2,954). We excluded patients if they had preoperative endocarditis (n = 154) or septicemia (n = 309), if there were missing data on age (n = 3), weight (n = 83), or sex (n = 8), if the recorded weight was implausible (n = 244; defined as 7 standard deviations below or 5 standard deviations above the patient’s predicted weight according to growth charts from the Centers for Disease Control and Prevention [21]), or if there were no data on postoperative complications regarding infection (n = 147). Finally, we included the first operation per hospital admission and excluded subsequent operations (n = 1,073) within the same admission. The final population consisted of 30,078 patients from 48 institutions.

Clinical End Point

The primary end point of the analysis was “major infection,” defined as septicemia, mediastinitis, or endocarditis before hospital discharge, or after discharge if it was attributed to the operation. Mediastinitis was defined as postoperative infection involving the sternum or medi-

astinum including at least one of the following: (1) wound opened with drainage of fluid or excision of tissue, (2) culture positive for infection, or (3) treatment with antibiotics or antifungals. Septicemia was defined as postoperative bloodstream infection requiring positive blood cultures and excluded catheter contaminants. Endocarditis was defined as postoperative intracardiac infection with echocardiographic or blood culture confirmation. However, in equivocal cases, clinical data such as splenic infarcts, Janeway lesions, and thromboemboli were sufficient to make the diagnosis. It should be noted, however, that these definitions were adopted in 2006, after much of the data had been collected.

Statistical Analysis and Model Development

We selected candidate variables based on risk factors for infection after cardiac surgery previously identified [1, 3–5, 7–9, 17, 22–25] as well as potential risk factors based on clinical suspicion of the authors (including pediatric cardiologists, cardiovascular surgeons, and an infectious disease specialist). We included only risk factors identified before the operation. Candidate risk factors were procedure type (grouped into categories by ABC [26] and RACHS-1 [27] scores); age; weight-for-age-and-sex percentile [21]; previous cardiac surgery; preoperative length of stay of more than 1 day; preoperative mechanical ventilation or tracheostomy; preoperative acidosis, circulatory support, or shock; identified genetic abnormality; and year of surgery. Weight (as opposed to weight-for-age-and-sex) was not included as a candidate variable because of its correlation with age.

After the selection of candidate variables, we performed a univariate analysis to determine the incidence of major infection in relationship to the candidate vari-

ables. We then developed a logistic regression model including all of the candidate explanatory variables (full model). Age was modeled continuously using restricted cubic splines with knots at 90 days, 1 year, and 3 years. Weight-for-age-and-sex was modeled as three categories: less than 5th percentile, 5th through 50th percentile, and greater than 50th percentile. Variables in the logistic model were estimated using generalized estimating equations methodology with an exchangeable working correlation structure to account for clustering of subjects within hospitals.

We adjusted for procedure by grouping procedure types into strata and entering them in the model as a set of category indicator variables. Initially, we allowed any procedure with at least 20 occurrences to be its own stratum. Remaining procedures were categorized by cross-classifying the procedure's ABC score with its RACHS-1 score. This approach resulted in 37 strata. For simplicity, we also developed a model using only 3 strata ("low complexity", defined as ABC < 3 and RACHS-1 < 3; "high complexity" defined as ABC ≥ 4 or RACHS-1 ≥ 5; and "medium complexity" defined as all others). Results were similar; therefore, we used the model using only these three strata for the remainder of the analysis. Of note, when there were multiple procedures per operation, they were assigned to the stratum of the most complex procedure.

Reduced Model and Bedside Tool

We created a reduced model by applying backward selection to the set of candidate variables, using a significance criterion of 0.05 for eliminating variables. To facilitate bedside scoring, we replaced the spline terms

Table 2. Full Model

Variable	OR (95% CI)
Age	
7 days (vs 1 y)	1.82 (1.43, 2.31)
30 days (vs 1 y)	1.74 (1.39, 2.18)
90 days (vs 1 y)	1.56 (1.31, 1.87)
3 y (vs 1 y)	0.66 (0.59, 0.73)
10 y (vs 1 y)	0.39 (0.29, 0.52)
Weight (for age and sex)	
5th–50th percentile	0.91 (0.79, 1.04)
<5th percentile	1.18 (0.97, 1.43)
Previous cardiothoracic operation	2.14 (1.71, 2.68)
Preoperative stay >1 day	1.78 (1.54, 2.07)
Preoperative ventilatory support	2.02 (1.66, 2.45)
Preoperative acidosis, circulatory support, shock	0.90 (0.69, 1.16)
Genetic abnormality	1.69 (1.44, 1.98)
Surgery year	0.90 (0.82, 0.98)
Medium complexity ^a	1.84 (1.51, 2.24)
High complexity ^b	3.00 (2.24, 4.03)

^a Aristotle Basic Complexity Score = 3 or RACHS-1 = 3–4 (and not "high complexity"). ^b Aristotle Basic Complexity Score > 3 or RACHS-1 > 4.

CI = confidence interval; OR = odds ratio.

Table 3. Reduced and Integer Models

Variable	OR (95% CI)	Points	p Value
Age <90 days	6.3 (4.1–9.8)	9	<0.0001
Age 90 days–3 y	4.1 (2.7–6.1)	7	<0.0001
Age 3–5 y	1.9 (1.1–3.4)	3	0.027
Medium complexity ^a	1.8 (1.5–2.2)	3	<0.0001
High complexity ^b	3.0 (2.4–3.7)	6	<0.0001
Preoperative length of stay >1 day	1.8 (1.5–2.2)	3	<0.0001
Preoperative ventilator support	2.1 (1.8–2.5)	4	<0.0001
Previous cardiothoracic operation	2.1 (1.7–2.5)	4	<0.0001
Genetic abnormality	1.9 (1.7–2.2)	3	<0.0001

^a Aristotle Basic Complexity Score = 3 or RACHS-1 = 3–4 (and not "high complexity"). ^b Aristotle Basic Complexity Score > 3 or RACHS-1 > 4.

CI = confidence interval; OR = odds ratio.

for age with a set of age categories (0–30 days, 31–90 days, 90 days–1 year, 1–3 years, 3–5 years, 5+ years). We forced year of surgery into the model to ensure that the weighting of patient-level risk factors would not be confounded by changes in risk factor prevalence and infection risk with time. To create the bedside risk tool we multiplied each regression coefficient by 5 and rounded to the nearest integer. Although year of surgery was included in the model, it was omitted from the bedside risk tool. The risk score for each patient was defined by summing the points across risk factors. Finally, we determined the

Table 4. Bedside Tool Risk Look-up Table

Risk Score	Probability of Infection (%)	95% CI
0	0.0	0.0–0.2
3	0.1	0.1–0.2
4	0.2	0.1–0.3
6	0.3	0.3–0.5
7	0.5	0.4–0.6
8	0.6	0.5–0.8
9	0.9	0.7–1.0
10	1.1	1.0–1.3
11	1.5	1.3–1.7
12	1.9	1.7–2.1
13	2.4	2.2–2.7
14	3.0	2.7–3.3
15	3.8	3.4–4.1
16	4.6	4.2–5.0
17	5.5	5.1–6.0
18	6.5	6.0–7.1
19	7.6	6.9–8.3
20	8.7	7.9–9.5
21	9.8	8.9–10.8
22	10.8	9.8–12.0
23	11.8	10.4–13.4
24	12.7	10.6–15.1
25	13.3	10.4–16.9

CI = confidence interval.

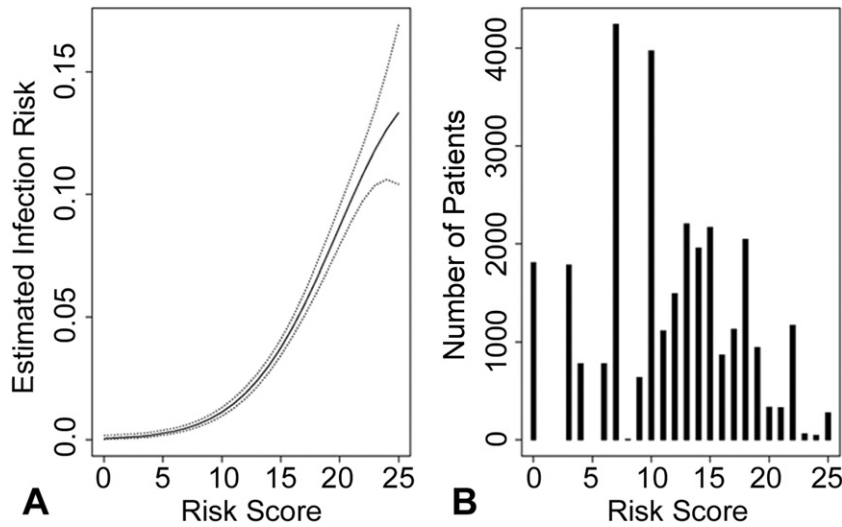


Fig 1. (A) Bedside tool model of predicted risk in relation to risk score. Solid line represents model estimate. Dotted line represents 95% confidence interval. The x axis denotes risk score, and the y axis denotes estimated infection risk. (B) Distribution of study population by risk score category. The x axis denotes risk score, and the y axis represents total number of patients.

relationship between patient-specific risk scores and infection risk using logistic regression. In this model, infection was the outcome variable and risk score (modeled as a cubic polynomial function) was the explanatory variable.

We validated the models internally by calculating measures of calibration and discrimination. We assessed calibration graphically by comparing observed versus predicted values across levels of predicted risk and used the Hosmer-Lemeshow test to assess whether the observed differences were statistically significant. We assessed discrimination by calculating the c statistic. Because the models were developed and validated in the same sample, we used the method of bootstrap resampling to adjust the c statistic to obtain an approximately unbiased assessment of future model performance.

Results

Demographic Characteristics and Infection

We analyzed a total of 30,078 cases in the Society of Thoracic Surgeons Congenital Cardiac Surgery Database. From this cohort, 857 patients (2.8%) had major infection (2.6% septicemia, 0.3% mediastinitis, 0.09% endocarditis). Thirty-two patients had more than one type of infection. Of patients with major infection, the mean age was 6.5 months (versus 2.4 years for the entire cohort). Fifty-five percent of patients were male in both the entire cohort and in those with major infection. Both mortality and length of stay were greater in the group of patients that experienced major infection (mortality, 22.2%; 95% confidence interval [CI], 19.4 to 25.1 versus 3.0%; 95% CI, 2.8 to 3.2; length of stay >21 days, 69.9%; 95% CI, 66.7 to 73.0 versus 10.7%; 95% CI, 10.3 to 11.0). The percentage of patients with infection decreased as a function of time from 3.7% in 2002 to 2.2% in 2006.

A number of variables were associated with major infection in univariate analysis (Table 1), including ABC

score, RACHS-1 score, age, weight, weight-for-age-and-sex, preoperative ventilatory support or tracheostomy, longer preoperative stay, preoperative acidosis, preoperative shock, the presence of certain known genetic abnormalities (eg, 22q11 deletion, DiGeorge syndrome, asplenia), and year of surgery. The presence of a genetic abnormality was also associated with major infection in univariate analysis; however, there were some specific abnormalities that were not associated with an increased risk of infection, such as trisomy 21, Marfan syndrome, Alagille syndrome, and Williams-Beuren syndrome.

Multivariable Regression Model

Independent variables associated with increased infection risk in multivariable analysis were age (modeled as a continuous variable), previous cardiac operation, preoperative length of stay more than 1 day, preoperative ventilator support or tracheostomy, any genetic abnormality, medium or high complexity score, and year of surgery (Table 2). In the reduced model, variables that remained after backward selection were age younger than 90 days, age 90 days to 3 years, age 3 to 5 years, medium complexity score, high complexity score, length of stay more than 1 day, preoperative ventilator support or tracheostomy, previous cardiothoracic operation, and any genetic abnormality (Table 3). The variables most strongly associated with major infection were age younger than 90 days, age 90 days to 3 years, and high complexity score.

Risk Scoring System

The bedside tool model had good predictive ability (bootstrap-adjusted c index, 0.781). Table 4 was generated to be used clinically to estimate risk of major infection given a specific point score. Estimated risk of infection exhibited a nonlinear relationship with risk score and ranged from 0% to 13.3% (Fig 1A). Distribution of risk scores is shown in Figure 1B.

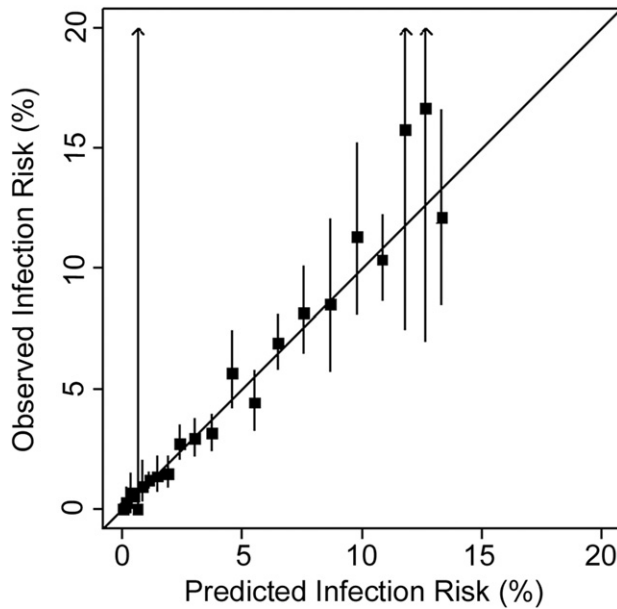


Fig 2. Observed versus predicted risk of infection during internal calibration of bedside model. Squares correspond to observed risk for each unique value of the risk score. Solid lines correspond to 95% confidence intervals. Goodness of fit $\chi^2 = 17.8$; $p = 0.66$. The x axis denotes predicted infection risk, and the y axis shows observed infection risk.

Validation of Model

Each model had good predictive ability, with no difference in the predictive ability of the full model (c index, 0.785) versus the reduced model (c index, 0.786), and only slightly increased predictive ability of both full and reduced models versus the bedside tool (c index, 0.781). Internal calibration of the risk tool was excellent, with close agreement between predicted and observed infection rates (Fig 2; goodness of fit χ^2 , 17.8; $p = 0.66$). Observed versus predicted rates of infection for the 10 most common procedures are listed in Table 5.

Comment

Our study confirms that major infection after congenital heart surgery is a complication with significant sequelae.

Using a large multicenter patient population, we identified risk factors for major infection and created a clinical tool that can be used preoperatively to estimate a patient’s infection risk. We validated the model internally showing that it has good discrimination.

Previous studies have evaluated risk factors for specific types of postoperative infections. Cardiopulmonary bypass, reintubation, and surgical site infection increase the risk of bloodstream infection [22]. Risk factors for surgical site infection include undergoing more than one cardiothoracic procedure, preoperative infection, surgery on a Monday, higher Pediatric Risk of Mortality score, perioperative hypothermia, open chest after surgery, need for reexploration, nasal colonization with *Staphylococcus aureus*, longer duration of surgery, longer preoperative stay, and younger age [4, 5, 7-9, 17, 23, 24]. Previously reported risk factors for mediastinitis include having a genetic syndrome, higher American Society of Anesthesiologists score, and longer duration of pacing wires [25]. In contrast to our study, these studies were done at single centers, with relatively small sample sizes, and none evaluated for a clinically significant composite end point of major infection. Additionally, none of these studies developed a model using preoperative factors that can be used clinically to predict risk of major infection.

In this study, the factors significantly associated with infection by multivariable analysis were largely similar to risk factors previously identified. The factors that accounted for the greatest increase in risk were young age and high complexity. Weight was associated with infection in univariate analysis, but weight-for-age-and-sex did not remain a risk factor with multivariable analysis. This suggests that weight may be a predictor of major infection as it correlates with age; however, there is no evidence of an association between weight and infection after accounting for age and other risk factors. Likewise, preoperative hemodynamic compromise (preoperative acidosis, circulatory support, or shock) was not a predictor of major infection in either the full or reduced model. Some previous studies have included leaving the chest open postoperatively as a risk factor [4, 7, 24]. Because the purpose of our investigation was to identify preoperative

Table 5. Predicted Versus Observed Rates of Major Infection in the 10 Most Common Procedures

Procedure	Number of Procedures	Infection Rate, Observed (%) (95% CI)	Infection Rate, Predicted (%)
Ventricular septal defect repair	2,527	1.3 (0.9-1.8)	1.1
Atrial septal defect repair	1,240	0.2 (0.1-0.7)	0.4
Complete atrioventricular septal defect repair	1,218	3.6 (2.6-4.8)	3.1
Norwood procedure	1,131	13.4 (11.5-15.6)	8.5
Bidirectional Glenn procedure	1,070	2.1 (1.3-3.1)	2.3
Coarctation repair, end to end, extended	1,030	2.3 (1.5-3.5)	3.8
Modified Blalock-Taussig shunt	1,013	5.9 (4.6-7.6)	5.4
Tetralogy of Fallot repair	943	2.2 (1.4-3.4)	2.6
Patent ductus arteriosus closure	924	1.1 (0.5-2.0)	1.7
Right ventricular outflow tract procedure	897	2.0 (1.2-3.2)	1.4

CI = confidence interval.

risk factors, and whether or not the chest will be left open cannot always be determined before surgery, we did not include this candidate variable in our study.

The incidence of infection in our population was less than that previously reported. This may be because of the types of infections included. In this study, only major infections were included, defined as sepsis, mediastinitis, and endocarditis, whereas previous studies have often included other types of infection, such as superficial surgical site infection and pneumonia. The incidence of sepsis in this study was less than that reported in previous studies [3, 7, 10]. The incidence of mediastinitis in this study was similar to some of the previous studies [8, 12, 13], although somewhat lower than in others [5, 9, 11]. Incidence of endocarditis in our population was lower than that previously reported [28].

In this study, the rate of infection decreased during the period studied. One possible explanation is that with more clinical experience, centers may be more efficient and are decreasing surgical time and the length of ICU and hospital stays, all of which contribute to decreased infection rates. This period has also correlated with greater emphasis on ICU techniques such as proper hand-washing and protocols regarding central catheters. It is possible that this decreasing infection rate is related to underreporting in the sample, although this would be less likely to cause a trend within the dataset than to cause decreased rates when compared with other studies.

The strengths of this study are that it is based on a large multicenter cohort, the data were collected prospectively, and the model created can be easily used in clinical situations. However, there are several limitations. Pneumonia, a common complication, was not included in the scoring system because case definitions are difficult to differentiate from atelectasis, and therefore the model cannot predict this complication. Also, it is possible that complications may be underreported, especially if they occurred after discharge. On-site auditing of roughly 7% of participating centers has not revealed underreporting of major infectious complications, although the data verification audit process was not implemented until 2007 [29]. In addition, when many of these data were being collected, standard definitions of complications had not yet been adopted, and as such, there may be some variability as to infections reported between or within sites. Preoperative antibiotic protocols were not recorded in the database, so it is impossible to know what influence this may have had on the results. Finally, this study does not address practices to prevent major infection in high-risk individuals. There have been some studies evaluating various practices with some success [1, 30].

Although the incidence of major infection may be decreasing as a function of time, it remains a source of morbidity and mortality in postoperative pediatric cardiac patients. Further research needs to be done to develop better protocols to decrease infection rates in this setting. This model can be used as a tool for risk stratification as various interventions are studied. Al-

though the model created here has good internal validity, it needs to be validated externally. Additionally, further studies are needed to identify intraoperative and postoperative risk factors for major infection, as some of these may be modifiable.

The model created and validated in this study can have important clinical impact as it provides a preoperative estimate of an individual patient's risk for major infectious complications. Identification of these high-risk patients is useful in preoperative counseling by helping parents and providers to know what obstacles may lie ahead. In addition, these identified high-risk patients may be targeted for future clinical trials and interventions to reduce this complication of cardiac surgery.

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