Development of a diagnosis- and procedure-based risk model for 30-day outcome after pediatric cardiac surgery

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Objective: The study objective was to develop a risk model incorporating diagnostic information to adjust for case-mix severity during routine monitoring of outcomes for pediatric cardiac surgery.

Methods: Data from the Central Cardiac Audit Database for all pediatric cardiac surgery procedures performed in the United Kingdom between 2000 and 2010 were included: 70% for model development and 30% for validation. Units of analysis were 30-day episodes after the first surgical procedure. We used logistic regression for 30-day mortality. Risk factors considered included procedural information based on Central Cardiac Audit Database "specific procedures," diagnostic information defined by 24 "primary" cardiac diagnoses and "univentricular" status, and other patient characteristics.

Results: Of the 27,140 30-day episodes in the development set, 25,613 were survivals, 834 were deaths, and 693 were of unknown status (mortality, 3.2%). The risk model includes procedure, cardiac diagnosis, univentricular status, age band (neonate, infant, child), continuous age, continuous weight, presence of non–Down syndrome comorbidity, bypass, and year of operation 2007 or later (because of decreasing mortality). A risk score was calculated for 95% of cases in the validation set (weight missing in 5%). The model discriminated well; the C-index for validation set was 0.77 (0.81 for post-2007 data). Removal of all but procedural information gave a reduced C-index of 0.72. The model performed well across the spectrum of predicted risk, but there was evidence of underestimation of mortality risk in neonates undergoing operation from 2007.

Conclusions: The risk model performs well. Diagnostic information added useful discriminatory power. A future application is risk adjustment during routine monitoring of outcomes in the United Kingdom to assist quality assurance. (J Thorac Cardiovasc Surg 2013;145:1270-8)

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Since one UK center experienced a number of "excess deaths" in children after cardiac surgery,[1] a culture of audit and quality improvement has emerged in the United Kingdom, with particular interest in monitoring outcomes and center performance within pediatric cardiac surgery.[2,3] A major review of pediatric cardiac surgery services in the United Kingdom[4] recently stressed the need for national processes for reporting outcomes to be timely and meaningful. Yet to do such routine monitoring fairly and effectively, one needs to account for the case mix of each center.[5] Adjusting for risk in pediatric cardiac surgery is challenging because of the diversity of the patient population in terms of the diagnoses, operations performed, age at operation, and other factors.[6]

A worldwide effort to collect data for quality assurance and benchmarking[7-9] has seen the evolution of a number of multi-institutional databases. This activity has been underpinned by ongoing work on congenital cardiac diagnostic and procedural coding toward the development of universally applicable codes to describe the pediatric cardiac case mix.[10-12] Accrual of standardized data on case mix and outcomes has led to a shift from the use of consensus-based risk stratification tools (eg, RACHS-1 [Risk Adjustment for Congenital Heart Surgery-1] categories[13] and Aristotle Basic Complexity Levels [ABC Levels][14]) to risk estimates based on empirical data.[15] Of note, this previous work has focused on outcomes according to the procedure performed, without account taken of the range of cardiac diagnoses for which some procedures are performed.

The current article reports the development of the Partial Risk Adjustment in Surgery (PRAiS) model for pediatric cardiac surgery, which is based on empirical data, with

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Abbreviations and Acronyms

CCAD	= Central Cardiac Audit Database
EACTS	= European Association for Cardio-Thoracic Surgery
IPCCC	= International Paediatric and Congenital Cardiac Code
STS	= Society of Thoracic Surgeons

procedural information augmented by information on cardiac diagnosis in addition to age, weight, and comorbidities. The motivation was to develop a model fit for the purpose of adjusting for case-mix severity during routine monitoring of short-term outcomes after pediatric cardiac surgery in the United Kingdom.

MATERIALS AND METHODS

Data Source and Study Population

The pseudonymized dataset used in this study was provided by the Central Cardiac Audit Database (CCAD).[16] Since 2000, mandatory data submissions to CCAD have been requested every 3 months from all hospitals performing cardiac surgery in the United Kingdom, including details about patient diagnoses and comorbidities, and the operation performed. The data are validated and subject to a quality assurance process, with all units undergoing annual inspection in which local records are examined to ensure every case performed in the center has been submitted and a random sample of case notes is examined in detail to assess data quality.[9] Patients' survival status is independently verified through periodic requests to the National Health Service Central Register, as approved by the National Information and Governance Board for Health and Social Care, with consent requested from patients/parents for participation in national audit of outcomes.

The data used concerned surgical operations conducted before October 31, 2010, in patients aged less than 16 years. Official transition to adult services in the United Kingdom occurs at 16 years of age, and guidelines recommend the treatment of individuals aged 16 years or more to be in an adult center. The dataset was then split into development (70% of patients) and validation (30% of patients) samples using random allocation stratified by year and institution of first procedure. The development sample contained 34,385 records, corresponding to 22,449 unique patients. The validation sample containing 14,316 records (9354 unique patients) was set aside and not used in risk model development.

Defining Episodes of Surgical Management

To obviate ambiguities in assigning short-term outcomes to operations performed close together in time, we defined 30-day episodes of surgical management. The first such episode for a patient started with his/her first surgical operation and was assigned an outcome of alive or dead according to the vital status of the patient at 30 days. Any reintervention within this 30-day episode was not included in model development but was noted as a secondary outcome of the episode for the purposes of monitoring (not reported in this article). The patient's next surgical operation *more than 30 days after* the start of this first episode was treated as the start of a new episode and so forth. Each episode was treated as independent within the analysis.

Grouping Operations Using the Central Cardiac Audit Database "Specific Procedure" Algorithm

A combination of up to 8 individual procedural International Paediatric and Congenital Cardiac Codes (IPCCCs)[17] may be submitted to CCAD to describe each operation. The Steering Committee of CCAD, which includes experienced pediatric cardiac surgeons and cardiologists, have developed a specific procedure algorithm that links the combinations of individual IPCCCs in a record to at most 1 of 36 recognizable operations. The list of 36 operations (hereafter referred to as "specific procedures") includes generally accepted benchmark operations[18] along with others that were determined by the CCAD Steering Committee between 2000 and 2010. The algorithm imposes a hierarchy with the record assigned the most complex specific procedure consistent with the combination of codes submitted. The 36 specific procedures capture 83% of operations in the data and center-specific outcomes for these specific procedures have been published by CCAD on the Internet[16] and are well known as a core output of CCAD.

Classification of Primary Diagnosis

Each CCAD record contains up to 6 IPCCC diagnostic codes. To explore the potential for this information to add discriminatory power to risk adjustment, we developed a new hierarchical scheme that links the combination of IPCCC diagnostic codes available for a record to at most 1 of 24 primary cardiac diagnoses. We also identified those combinations of IPCCCs that indicated that the patient had a functionally univentricular heart. The process for developing these diagnostic categories is described in detail by Brown and colleagues.[19]

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Other Factors Considered

Given the planned use of the model in quality assurance, only preoperative factors were considered for inclusion in the risk model. In addition to specific procedure and diagnostic information, the factors considered on the basis of potential clinical relevance and availability within the dataset were year of surgery; whether the procedure was performed on bypass; patient sex, age, weight; whether there was an antenatal diagnosis; ethnicity; the Townsend score of socioeconomic deprivationc[20]; and comorbidity.

IPCCCs defining comorbid conditions were grouped into 4 categories: premature (gestational age $<$37 weeks); Down syndrome; congenital non–Down syndrome comorbidity (all genetic syndromes, clinical constellations of features that constitute a recognized syndrome, and congenital structural defects of organs other than the heart[21]); and acquired comorbidity (including preoperative comorbidities acquired as a result of heart disease or its treatments, eg, renal failure or necrotizing enterocolitis).[22] For a given patient record, comorbid conditions appearing as IPCCCs in any of the comorbidity or diagnosis fields were classed as comorbidities. We treated records where no comorbidities were entered as though that patient did not have any comorbidity.

Missing and Unknown Data

Episodes with missing 30-day outcome were removed. Weight-for-age z scores were calculated for each episode on the basis of a subdivision of the development dataset into 23 age bands (narrower at younger ages). Episodes in the development set with an absolute z score of 3 or more were considered infeasible and, along with episodes with missing weights, assigned the mean weight of their corresponding age band. To mimic prospective use, no adjustment of weights of this nature was made in the validation set. Where inconsistencies in any of the data were suspected, for example, between episodes relating to the same patient, the data were confirmed with CCAD.

Model Development

After descriptive analyses that were performed to characterize the development dataset, univariate 30-day, episode-level mortality rates were calculated for the candidate preoperative risk factors, with some removed from consideration on the basis of this univariate analysis. Some risk factors were removed because of considerations of data completeness.

Multiple logistic regression analysis was conducted within PASW Statistics 18, Release Version 18.0.0 (SPSS, Inc, 2009, Chicago, Ill), using