Death and Emergency Readmission of Infants Discharged After Interventions for Congenital Heart Disease: A National Study of 7643 Infants to Inform Service Improvement

Sonya Crowe, PhD; Deborah A. Ridout, MSc; Rachel Knowles, MBChB, FFPH, PhD, MSc; Jenifer Tregay, PhD; Jo Wray, PhD; David J. Barron, MD, FRCS; David Cunningham, PhD; Roger C. Parslow, PhD; Martin Utley, PhD; Rodney Franklin, MD, FRCS; Catherine Bull, MRCP; Katherine L. Brown, MD, MPH, MRCP

Background—Improvements in hospital-based care have reduced early mortality in congenital heart disease. Later adverse outcomes may be reducible by focusing on care at or after discharge. We aimed to identify risk factors for such events within 1 year of discharge after intervention in infancy and, separately, to identify subgroups that might benefit from different forms of intervention.

Methods and Results—Cardiac procedures performed in infants between 2005 and 2010 in England and Wales from the UK National Congenital Heart Disease Audit were linked to intensive care records. Among 7976 infants, 333 (4.2%) died before discharge. Of 7643 infants discharged alive, 246 (3.2%) died outside the hospital or after an unplanned readmission to intensive care (risk factors were age, weight-for-age, cardiac procedure, cardiac diagnosis, congenital anomaly, preprocedural clinical deterioration, prematurity, ethnicity, and duration of initial admission; c-statistic 0.78 [0.75–0.82]). Of the 7643, 514 (6.7%) died outside the hospital or had an unplanned intensive care readmission (same risk factors but with neurodevelopmental condition and acquired cardiac diagnosis and without preprocedural deterioration; c-statistic 0.78 [0.75–0.80]). Classification and regression tree analysis were used to identify 6 subgroups stratified by the level (3–24%) and nature of risk for death outside the hospital or unplanned intensive care readmission based on neurodevelopmental condition, cardiac diagnosis, congenital anomaly, and duration of initial admission. An additional 115 patients died after planned intensive care admission (typically following elective surgery).

Conclusions—Adverse outcomes in the year after discharge are of similar magnitude to in-hospital mortality, warrant service improvements, and are not confined to diagnostic groups currently targeted with enhanced monitoring. (J Am Heart Assoc. 2016;5:e003369 doi: 10.1161/JAHA.116.003369)

Key Words: congenital heart defects • health policy and outcomes research • pediatrics • risk model • risk stratification

The main focus in the audit of pediatric cardiac surgery has been operative mortality, expressed as either 30-day mortality1 or mortality at hospital discharge.2 These very early outcomes have improved significantly over time,3,4 but while relevant to quality assurance, they cannot inform service improvements outside the hospital setting. There remains a significant risk of death or clinical deterioration following discharge after “successful” surgery. For instance, “interstage mortality” for infants with hypoplastic left heart syndrome (HLHS) was 12% within a recent multicenter trial.5 Single-center reports indicate that home monitoring programs of enhanced postdischarge surveillance for HLHS reduce interstage mortality,6–9 but this practice is not universally implemented5 and local protocols vary.10 Studies of postdischarge outcomes for congenital heart disease (CHD) other than HLHS are sparse,11 and a greater understanding of the risk of adverse
outcomes after discharge among the broader patient population could usefully inform quality improvement efforts.

To this end, we undertook a national study of outcomes in the first year after discharge from hospital among infants undergoing intervention for CHD. Our first aim was to measure the rates of adverse outcomes at 1 year among this population and then identify patient-level factors independently associated with these outcomes. Our second, complementary aim was to identify groups of patients who might benefit from different interventions because of the differing nature and scale of risk that they face. The adverse events of interest to us were deaths in the community and any unplanned readmissions to intensive care, regardless of the differing nature and scale of risk that they face. The adverse outcomes after discharge among the broader patient population and then identify patient-level factors independently associated with these outcomes. Our second, complementary aim was to identify groups of patients who might benefit from different interventions because of the differing nature and scale of risk that they face. The adverse events of interest to us were deaths in the community and any unplanned readmissions to intensive care, regardless of the differing nature and scale of risk that they face.

This national study was possible because of the United Kingdom’s unique combination of mandatory national audit data sets for pediatric cardiac procedures (the National Congenital Heart Disease Audit [NCHDA]\(^1^2\)) and pediatric intensive care unit (PICU) admissions (the Paediatric Intensive Care Audit Network [PICANet]\(^1^3\)), which is augmented in England and Wales with independently ascertained life status tracking.

Methods

Ethics

Approval was obtained from the London Central Research Ethics Committee (reference No. 12/LO/1398) and the National Health Service (NHS) Health Research Authority Confidentiality Advisory Group (reference No. ECC 6-02 (FT5)/2012). Requirement for consent was waived.

Constructing the Data Set for Analyses

Data sources and patient population

Two national audit data sets were used: NCHDA\(^1^2\) and PICANet\(^1^3\). Data submission to each audit is mandatory, subject to external data validation\(^1^4,1^5\) and each audit has approval from the relevant regulatory authorities for use of patient identifiable data. The survival status of patients in NCHDA is independently verified for patients of English and Welsh centers by the UK Health and Social Care Information Centre by using their patients’ unique identifier (NHS number).

All children who underwent their first interventional catheterization or cardiac surgery when younger than 1 year in the United Kingdom between January 1, 2005 and December 31, 2010 were identified in NCHDA (overseas patients without an NHS number were removed at this stage; patients treated in Northern Ireland and Scotland were later identified and excluded). Records within PICANet for these patients were then identified by a trusted third party using patient NHS number, and patients with record(s) in NHCDA but not in PICANet were removed and analyzed separately. Separate data extracts from each audit were provided to the study team, each with the same patient-level identifier (pseudonymized NHS number). A single patient potentially had multiple procedure-based records in the NCHDA extract and multiple admission-based records in the PICANet extract. The study team constructed a single patient-based analysis data set by linking events for the same patient using the patient-level identifier, including cardiac-related details and life status (NCHDA) and rich comorbidity and emergency PICU admission information (PICANet).

Defining the index admission and index procedure

The index admission for each child was defined as the continuous period as an inpatient within the pediatric cardiac center, including admission(s) to PICU, that included their first surgical procedure or their first definitive or initial staging interventional catheter procedure (see Data S1 for included catheterizations). This period defined the index length of stay (LOS). Within the NCHDA data set, each procedure is described based on up to 8 individual procedural Interventional Paediatric and Congenital Cardiac Codes (IPC6CCs).\(^1^6\) An algorithm developed by the NCHDA Steering Committee defines the specific procedure undertaken, based on the combinations of IPC6CCs recorded. These defined “specific procedures” are listed in hierarchical order with the Norwood operation at the top and, for surgery, ligation of patent ductus arteriosus (PDA) at the bottom, with interventional catheter procedures appearing below surgeries in the hierarchy (see Data S1 for further details). For children who underwent >1 procedure during their index admission, their index intervention was chosen to be the most complex according to this hierarchy.

Exclusions

Children who underwent only catheter procedure(s) listed as exclusions in Data S1, premature babies who had ligation of PDA only, and cardiac transplant patients were excluded from our analysis because they have their own discharge and follow-up care pathways. Patients treated in Northern Ireland and Scotland were also removed because they do not have verified life status.
Candidate Patient Risk Factors

Candidate nonmedical, preoperative and postoperative risk factors available in the patient-based analysis data set that would be known at the point of discharge were identified: these are provided in Table 1 (with further details regarding the definitions in Data S1 and Tables S1–S4). Each child’s primary cardiac diagnosis was identified based on a hierarchical IPCCC coding map,21 which also identified records where there was a concurrent acquired cardiac diagnosis. Other clinical information, including the presence of comorbid conditions and postoperative complications, was based on a mapping of Read codes.22 Where both audits contained information on a particular risk factor, the most complete source was used. Clinical variables with multiple parameters were necessarily collapsed into broad groups before statistical analyses to reduce the degrees of freedom and, hence, the risk of overfitting.23 Table 2 lists the diagnostic categories within each of the 4 primary cardiac groups used in the analyses.

**Missing data**

Where ethnic group was not available from PICANet, the NCHDA ethnic code was used to assign White, Asian, or Black...
Outcomes Following Intervention for Infant CHD  Crowe et al

Table 2. Primary Cardiac Diagnosis Categories

| Cardiac Diagnosis Group                                      | Primary Cardiac Diagnosis Category                                      |
|-------------------------------------------------------------|-------------------------------------------------------------------------|
| Hypoplastic left heart syndrome (HLHS)                       | HLHS                                                                    |
| Functionally univentricular heart (UVH) or pulmonary atresia (PA) with an intact ventricular septum (IVS) | UVH; PA+IVS                                                             |
| Isolated ventricular septal defect (VSD)                     | Isolated VSD+interatrial communication (atrioventricular septal defect (ASD)+patent ductus arteriosus (PDA) |
| Other                                                       | Common arterial trunk (truncus arteriosus); transposition of the great arteries (TGA)-VSD/double outlet right ventricle (DORV)-TGA type; interrupted aortic arch; TGA (concordant atroventricular and discordant ventriculoatrial connections) and intact ventricular septum; PA+VSD (including Fallot type); miscellaneous congenital primary diagnoses; ASD; Fallot/DORV-Fallot type; aortic valve stenosis (isolated); tricuspid valve abnormality (including Ebstein); mitral valve abnormality (including supravalvar, subvalvar); totally anomalous pulmonary venous connection; aortic arch obstruction±VSD/ASD; pulmonary stenosis; subaortic stenosis (isolated); aortic regurgitation; interatrial communication (ASD); PDA; acquired noncongenital heart disease; arrhythmia; miscellaneous congenital terms; noncardiac or uncoded diagnosis |

The 4 primary cardiac diagnosis groups used in the analyses, which aggregate a set of 26 primary cardiac diagnosis categories, thereby reducing the degrees of freedom and, hence, the risk of overfitting.23 The primary cardiac diagnosis categories themselves are based on a hierarchical IPCCC coding map21 (see Table S2).

ethnicity (which showed strong concordance across the 2 audits); sensitivity analyses were performed excluding records without PICANet-derived ethnicity. Weight-for-age outside the range ±5 z-scores was assumed to be erroneous and treated as missing.

Outcomes

For the majority of our analyses, an adverse event was defined as either death outside a PICU admission (ie, “in the community”) or any emergency unplanned readmission to PICU, regardless of outcome, within 1 year after discharge from the index admission. We note the inclusion of nonfatal unplanned readmissions to PICU as these were considered “near misses” of relevance to informing service improvement. However, for the purposes of comparison with in-hospital mortality rates and risk modeling, some analyses were restricted to fatal adverse events only (deaths outside a planned admission)—where this was the case, we state this clearly in the text. Note that this research was designed to inform improvements in services at discharge and in the community; therefore, we did not consider death within 1 year of discharge from the index admission that occurred during a planned readmission to intensive care (typically for elective surgery as part of a staged treatment pathway) as an adverse outcome. Such patients were important to include in the analysis, however, as the period before the second elective surgery in a staged treatment pathway is known to be particularly high risk for many patients.5 Age at death (if applicable) and life status were available in NCHDA, while emergency unplanned admissions to PICU were extracted from PICANet.

Statistical Methods

Descriptive and univariate analyses

Descriptive analyses were performed to characterize the data set, and univariate logistic regression analysis on complete case data was used to assess the relation of each candidate predictor with each outcome by using fractional polynomials to investigate departure from linearity. This informed which variables were considered in two additional, complementary strands of analysis: first, the development of a risk model for adverse event and, separately, for fatal adverse events only, to generate generalizable knowledge about the individual underlying risk factors; and second, the identification of patient groups differentiated by risk of adverse event to inform potential interventions that might benefit certain subgroups of the population.

Developing risk models for adverse events and for fatal adverse events only

The significant variables from the univariate analysis (P<0.10) were investigated in a multivariable model for each outcome in turn. Initially, models were developed in which the continuous predictors were used and, where appropriate, suitable transformations were included. For the final model presentation, continuous predictors were categorized based on considerations of model interpretability as well as statistical performance.

Multiple imputation (assuming data were missing at random) was used to account for missing data when fitting the multivariable models. The imputation models included all risk factors considered in the univariate analysis (which we assume includes all predictors of missingness). We generated
Identifying patient groups differentiated by risk of adverse event

Classification and regression tree (CART) analysis was used to identify patient groups with different “profiles of risk” that could usefully inform the development of interventions targeted at different groups. For other examples of CART applications in health care, see references 29–31. The CART algorithm recursively partitioned the data into subsets that were as homogeneous as possible with respect to adverse event (ie, into subsets of increasing “purity”).32 All variables significantly associated with adverse event in univariate analysis were included in the CART analysis, with continuous variables entered in their categorized form as per final risk model development. To prevent overfitting, the CART groups were developed in a random 60% of the data and, for reasons of statistical robustness and potential usability, we restricted the tree depth to 4 and required a minimum of 100 cases for branching to continue, with at least 50 cases in either branch. The resulting classification tree was applied to the remaining 40% of the data set and the occurrence of adverse events among patients at each node was compared with the corresponding group in the development set to assess model stability. For both data sets, the c-statistic was calculated by assessing the final group characterizations obtained in the derivation data set as a predictor for adverse event. All analysis was performed in SPSS 22.33

Results

Data Set

A total of 12 390 infants meeting the inclusion criteria and with a valid patient identifier were identified in NCHDA, of whom 9385 (76%) were linked to ≥1 record in PICANet. Of these, 115 children who had an excluded catheter procedure only, 765 premature babies who had ligation of PDA only, 24 cardiac transplant patients, and 505 patients from Scotland or Northern Ireland were removed. Of 3005 patients who had no linked PICANet record, 1225 would not have been included in our study as they were either from Scotland or Northern Ireland or were premature and undergoing a PDA procedure only. The remaining 1780 demonstrated a greater prevalence of minor forms of CHD than did patients in the study data set.

Of the 7976 patients included in our study, 333 (4.2%) died during their index admission and were excluded from our analyses, leaving a final analysis data set of 7643 infants who were discharged alive from their index admission. Of these, 246 (3.2%) died within 1 year after discharge from the index admission and not during a planned admission (fatal adverse events), and 514 (6.7%) either died or had an emergency unplanned readmission to PICU within 1 year (all adverse events). Finally, 115 (1.5%) children died during a planned admission to PICU within 1 year after discharge from the index admission (not considered an outcome in our analysis), giving an overall mortality within the year after discharge from index admission of 4.7%.

Descriptive and Univariate Analyses

A summary of the descriptive and univariate logistic regression analyses is presented in the Data S2. There was no association identified with either outcome (fatal adverse events or all adverse events) and with either sex or the performance of additional cardiac catheterizations during the index procedure.

Developing Risk Models for Adverse Events and for Fatal Adverse Events Only

In the multivariable analysis in which continuous variables were treated as such, the significant risk factors for both outcomes were age at procedure, weight-for-age z-score, index procedure group, cardiac diagnosis group, noncardiac congenital anomaly, prematurity, ethnicity, and LOS in a specialist center. Preprocedural clinical deterioration was additionally significant to fatal adverse events only, while neurodevelopmental condition and acquired cardiac diagnoses were additionally significant to all adverse events.
Details of these continuous regression models are presented in the Data S2. In the final model development, the continuous predictors were categorized as follows: age at index procedure (>3 months old, 1–2 months old, 10–30 days, 0–10 days old); weight-for-age z-score (>-2 SDs, -2 to -4 SDs, <-4 SDs); and length of stay (0–7 days, 7–30 days, >1 month). Details of the final regression models for fatal adverse events and all adverse events are shown in Tables 3 and 4. For all models, adjusting for clustering at either the hospital or regional level had no statistically significant impact on results when comparing models using Akaike criteria (we present the unadjusted results).

The c-statistic of the final (categorical) model for fatal adverse events was 0.78 (95% CI 0.75–0.82), indicating good discrimination (and only marginally less discriminative than the continuous model, c-statistic 0.80). The final (categorical) model for all adverse events also showed good discrimination with a combined c-statistic of 0.78 (0.75–0.80) compared with 0.78 for the continuous model. Calibration of the final categorical and continuous models for both outcomes was also good, with Hosmer–Lemeshow P-values ranging from 0.10 to 0.75 across the models fitted on the 20 imputed data sets, indicating no statistically significant differences between observed and expected number of deaths when calculated in deciles of predicted risk for each of the imputed data sets.

Identifying Patient Groups Differentiated by Risk of Adverse Event

The Figure depicts the final tree generated with the CART analysis including the rate of adverse events and number of patients within each of the 6 discrete patient groups that were generated (further details presented in Table 5). Of the 18 candidate risk factors entered in the analysis, CART identified presence/absence of a neurodevelopmental condition (24% risk among 307 patients) as the best single discriminator between patients experiencing an adverse event or not. For those without a neurodevelopmental condition, the next best discriminator was whether the cardiac diagnosis was HLHS or (functionally univentricular heart/pulmonary atresia with an intact ventricular septum) (15.2% risk among 868 patients). For patients with neither of the 2 risk factors, the next best discriminator was presence/absence of a congenital anomaly followed by the LOS (threshold 1 month) (8.6% risk in patients with a congenital anomaly and LOS of <1 month, 24% in patients with congenital anomaly and LOS of >1 month, and 9.3% in patients with no congenital anomaly and LOS of >1 month). The remaining 4778 low-risk patients with none of the above factors had an adverse event rate of 2.8%. The development and test sets had c-statistics of 0.73 and 0.74, respectively.

Discussion

Outcomes and Risk Factors

The causes of attrition after hospital discharge are poorly understood compared with adverse events occurring in hospital, yet as in-hospital care improves, these postdischarge deaths are becoming increasingly numerically significant. Of 7976 patients who had undergone an intervention for CHD in infancy, representing the caseload for England and Wales over a 6-year period, 333 (4.2%) died during their index admission. Of those discharged alive, 246 (3.2%) died either outside the specialist hospital or after an emergency unplanned PICU readmission within 1 year (fatal adverse events). An additional 268 patients (3.6%) experienced unplanned urgent readmission to an intensive care unit but subsequently survived (“near misses”), giving a combined total of 514 (6.7%) adverse events. The data set was generated by linking 2 national audits, each documenting variables potentially associated with these postdischarge outcomes.

The following risk factors have previously been linked to adverse postdischarge outcomes: primary diagnosis (in particular, HLHS and other diagnoses requiring an initial palliative [staged] procedure), noncardiac congenital anomalies, prematurity, prolonged LOS (indicating greater complexity and perhaps a surrogate for postprocedural complications), and ethnicity. The risk models in our study further identified lower weight-for-age at procedure (which may correlate with feeding difficulties in infancy, a known risk factor); additional acquired cardiac diagnoses and preoperative clinical deterioration (which may relate to studies indicating that severer forms of a given type of CHD are at risk of poor postdischarge outcomes); neurodevelopmental conditions (which may overlap with noncardiac anomalies); and younger age at surgery (which, in contrast to studies specifically relating to HLHS that indicate older age at surgery increases risk of interstage death, may reflect a broader effect such as young neonates being at higher risk than older infants).

Informing Quality Improvement

The data presented reflect outcomes within the context of recent historical provision of services for infants with major CHD and are potentially insightful for ongoing quality improvement initiatives. To this end, we used CART analysis to identify patient groups with different “profiles of risk” (ie, defined by both their level of risk and the nature of that risk) who might benefit from specific interventions. The 6 groups that were identified have levels of risk of adverse event between 3% and 24%, which is informative when considering which groups may be a priority for intervention, while the clinical characteristics underlying the risk of each patient
Table 3. Final Logistic Regression Model for Fatal Adverse Events Only

| Patient Variable          | Overall No. (%) | No. of (%) Fatal Adverse Events | Odds Ratio | SE     | 95% CI   |
|---------------------------|-----------------|---------------------------------|------------|--------|----------|
| **Ethnicity**             |                 |                                 |            |        |          |
| White                     | 5728 (75.0)     | 166 (2.9)                       | Reference category |       |          |
| Mixed                     | 196 (2.6)       | 4 (2.0)                         | 0.68       | 0.35   | 0.25–1.88 |
| Asian                     | 867 (11.3)      | 38 (4.4)                        | 1.38       | 0.26   | 0.95–2.01 |
| Black                     | 345 (4.5)       | 12 (3.5)                        | 1.00       | 0.31   | 0.54–1.85 |
| Chinese                   | 28 (0.4)        | 3 (3.6)                         | 1.46       | 1.53   | 0.19–11.43 |
| Other                     | 133 (1.7)       | 12 (9.0)                        | 2.82       | 0.94   | 1.46–5.44 |
| Not stated                | 346 (4.5)       | 13 (3.8)                        | 1.53       | 0.47   | 0.85–2.78 |
| **Cardiac diagnosis group** |                |                                 |            |        |          |
| VSD                       | 1348 (17.6)     | 25 (1.9)                        | Reference category |       |          |
| HLHS                      | 390 (5.1)       | 48 (12.3)                       | 3.07       | 0.97   | 1.65–5.71 |
| UVH or PA+IVS             | 531 (7.0)       | 41 (7.7)                        | 2.31       | 0.69   | 1.29–4.15 |
| Other                     | 5374 (70.3)     | 132 (2.5)                       | 1.12       | 0.26   | 0.70–1.77 |
| **Specific procedure group** |              |                                 |            |        |          |
| Corrective                | 4973 (65.1)     | 86 (1.7)                        | Reference category |       |          |
| Palliative                | 1629 (21.3)     | 119 (7.3)                       | 2.14       | 0.38   | 1.50–3.04 |
| Ungrouped                 | 1041 (13.6)     | 41 (3.9)                        | 1.77       | 0.36   | 1.20–2.63 |
| **Congenital anomaly**    |                 |                                 |            |        |          |
| No                        | 6035 (79.0)     | 156 (2.6)                       | Reference category |       |          |
| Yes                       | 1608 (21.0)     | 90 (5.6)                        | 2.43       | 0.37   | 1.81–3.27 |
| **Prematurity**           |                 |                                 |            |        |          |
| No                        | 4714 (61.7)     | 161 (3.4)                       | Reference category |       |          |
| Yes                       | 828 (10.8)      | 44 (5.3)                        | 1.64       | 0.30   | 1.16–2.34 |
| **Clinical deterioration**|                 |                                 |            |        |          |
| No                        | 6174 (80.8)     | 161 (2.6)                       | Reference category |       |          |
| Yes                       | 1469 (19.2)     | 85 (5.8)                        | 1.66       | 0.24   | 1.25–2.22 |
| **Age at index procedure**|                |                                 |            |        |          |
| >3 mo                     | 3202 (41.9)     | 55 (1.7)                        | Reference category |       |          |
| 1–2 mo                    | 1427 (18.7)     | 45 (3.2)                        | 1.32       | 0.28   | 0.87–2.01 |
| 10–30 d                   | 1114 (14.6)     | 43 (3.9)                        | 1.89       | 0.45   | 1.19–3.02 |
| 0–10 d                    | 1900 (24.9)     | 103 (5.4)                       | 2.54       | 0.60   | 1.61–4.03 |
| **Weight-for-age z-score**|               |                                 |            |        |          |
| >–2 SDs                   | 4064 (53.2)     | 128 (3.1)                       | Reference category |       |          |
| –2 to –4 SDs              | 2467 (32.3)     | 71 (2.9)                        | 1.59       | 0.28   | 1.12–2.26 |
| <-4 SDs                   | 584 (7.6)       | 19 (3.3)                        | 2.28       | 0.61   | 1.34–3.87 |
| **Index length of stay**  |                 |                                 |            |        |          |
| 0–7 d                     | 2564 (33.5)     | 35 (1.4)                        | Reference category |       |          |
| 7–30 d                    | 4327 (56.6)     | 146 (3.4)                       | 1.56       | 0.31   | 1.06–2.31 |
| >1 mo                     | 752 (9.8)       | 65 (8.6)                        | 2.70       | 0.63   | 1.71–4.26 |

Details of the final regression model for fatal adverse events (death within a year after discharge from the index admission and not during a planned admission). For each patient variable the number (percentage) of fatal adverse events, multivariable odds ratios, standard errors and 95% confidence intervals are presented and the reference category indicated. The overall number (percentage) of patients within each category for a given patient variable is also noted. HLHS indicates hypoplastic left heart syndrome; PA+IVS, pulmonary atresia with an intact ventricular septum; PICU, pediatric intensive care unit; UVH, functionally univentricular heart; VSD, ventricular septal defect.
Table 4. Final Logistic Regression Model for Adverse Event

| Patient Variable         | Overall Number (%) | Number (%) Adverse Events | OR   | SE  | 95% CI       |
|--------------------------|--------------------|---------------------------|------|-----|--------------|
| **Ethnicity**            |                    |                           |      |     |              |
| White                    | 5728 (75.0)        | 348 (6.1)                 |      |     | Reference    |
| Mixed                    | 196 (2.6)          | 9 (4.6)                   | 0.63 | 0.23| 0.31–1.29    |
| Asian                    | 867 (11.3)         | 73 (8.4)                  | 1.21 | 0.17| 0.92–1.61    |
| Black                    | 345 (4.5)          | 34 (9.9)                  | 1.43 | 0.29| 0.96–2.12    |
| Chinese                  | 28 (0.4)           | 1 (3.6)                   | 0.65 | 0.68| 0.09–5.02    |
| Other                    | 133 (1.7)          | 19 (14.3)                 | 2.39 | 0.65| 1.40–4.08    |
| Not stated               | 346 (4.5)          | 30 (8.7)                  | 1.76 | 0.37| 1.16–2.65    |
| **Cardiac diagnosis group** |                 |                           |      |     |              |
| VSD                      | 1348 (17.6)        | 60 (4.5)                  |      |     | Reference    |
| HLHS                     | 390 (5.1)          | 70 (18.0)                 | 2.46 | 0.58| 1.55–3.90    |
| UVH or PA+IVS            | 531 (7.0)          | 73 (13.8)                 | 2.15 | 0.46| 1.41–3.28    |
| Other                    | 5574 (70.3)        | 311 (5.8)                 | 1.20 | 0.19| 0.88–1.64    |
| **Specific procedure group** |              |                           |      |     |              |
| Corrective               | 4973 (65.1)        | 219 (4.4)                 |      |     | Reference    |
| Palliative               | 1629 (21.3)        | 205 (12.6)                | 1.65 | 0.21| 1.28–2.13    |
| Ungrouped                | 1041 (13.6)        | 90 (8.7)                  | 1.61 | 0.22| 1.23–2.11    |
| **Congenital anomaly**   |                    |                           |      |     |              |
| No                       | 6035 (79.0)        | 305 (5.1)                 |      |     | Reference    |
| Yes                      | 1608 (21.0)        | 209 (13.0)                | 2.71 | 0.29| 2.19–3.35    |
| **Neurodevelopment condition** |              |                           |      |     |              |
| No                       | 7336 (96.0)        | 439 (6.0)                 |      |     | Reference    |
| Yes                      | 307 (4.0)          | 75 (24.4)                 | 2.81 | 0.44| 2.06–3.82    |
| **Prematurity**          |                    |                           |      |     |              |
| No                       | 4714 (61.7)        | 340 (7.2)                 |      |     | Reference    |
| Yes                      | 828 (10.8)         | 93 (11.2)                 | 1.59 | 0.21| 1.22–2.06    |
| **Acquired diagnosis**   |                    |                           |      |     |              |
| No                       | 7164 (93.7)        | 457 (6.4)                 |      |     | Reference    |
| Yes                      | 479 (6.3)          | 57 (11.9)                 | 1.85 | 0.30| 1.35–2.53    |
| **Age at index procedure** |                  |                           |      |     |              |
| >3 months old            | 3202 (41.9)        | 129 (4.0)                 |      |     | Reference    |
| 1–2 months old           | 1427 (18.7)        | 110 (7.7)                 | 1.59 | 0.23| 1.20–2.10    |
| 10–30 days               | 1114 (14.6)        | 90 (8.1)                  | 2.21 | 0.37| 1.59–3.06    |
| 0–10 days old            | 1900 (24.9)        | 185 (9.7)                 | 2.93 | 0.48| 2.12–4.04    |
| **Weight-for-age z-score** |                  |                           |      |     |              |
| >−2SD                    | 4064 (53.2)        | 243 (6.0)                 |      |     | Reference    |
| −2 to −4 SD              | 2467 (32.3)        | 168 (6.8)                 | 1.72 | 0.22| 1.34–2.21    |
| <−4SD                    | 584 (7.6)          | 50 (8.6)                  | 2.60 | 0.48| 1.81 to 3.75 |
| **Index length of stay** |                    |                           |      |     |              |
| 0–7 days                 | 2564 (33.5)        | 84 (3.3)                  |      |     | Reference    |
| 7–30 days                | 4327 (56.6)        | 302 (7.0)                 | 1.54 | 0.21| 1.19–2.00    |
| >1 month                 | 752 (9.8)          | 128 (17.0)                | 2.73 | 0.44| 1.99–3.75    |

Details of the final regression model for adverse event (either death or an emergency unplanned readmission to PICU within 1 year after discharge from the index admission). For each patient variable, the number (percentage) of adverse events, the multivariable odds ratios, SEs, and 95% CIs are presented and the reference category indicated. The overall number (percentage) of patients within each category for a given patient variable is also noted. HLHS indicates hypoplastic left heart syndrome; PA+IVS, pulmonary atresia with an intact ventricular septum; PICU, pediatric intensive care unit; UVH, functionally univentricular heart; VSD, ventricular septal defect.

DOI: 10.1161/JAHA.116.003369
Journal of the American Heart Association
group (defined in terms of neurodevelopmental conditions; cardiac diagnosis of HLHS, functionally univentricular heart, or pulmonary atresia with an intact ventricular septum; congenital anomalies; LOS >1 month) can inform the type of intervention that might be most appropriate. For example, group 3 consists of those patients most widely recognized as vulnerable to late death and offered enhanced surveillance, namely patients with cardiac diagnoses of HLHS and other functionally univentricular heart conditions. For example, single-center studies from the United States and Germany suggest that postdischarge packages for HLHS (home monitoring programs) reduce interstage mortality. However, groups 1 and 2 have a higher occurrence of adverse events, suggesting that it may also be important to mitigate risks arising from patient factors beyond cardiac diagnosis, in particular clinically significant neurodevelopmental conditions and congenital anomalies. The type of intervention appropriate for these typically complex and lifelong comorbidities may be very different from those currently aimed at mitigating the cardiac risk of functionally single-ventricle and shunt-dependent infants.

Strengths and Weaknesses

The national audit data underpinning this study offer a unique opportunity for a population-based analysis of surgically treated infants with CHD. First, the data are of high quality as demonstrated by the results of a regular systematic independent validation process. Second, the NHS number enabled late deaths outside treatment centers to be reliably ascertained by using life status tracking and enabled linkage between the two national audit data sets allowing their

Figure. Classification and regression tree (CART) analysis. The stratification tree generated by the CART analysis and evaluated across the entire data set (see Table 5 for a breakdown by development and test set). The number and rate of adverse events and the total number of patients are given for each node. HLHS indicates hypoplastic left heart syndrome; PA, pulmonary atresia; UVH, functionally univentricular heart; VSD, ventricular septal defect.
Table 5. Patient Groups Identified by Using CART Analysis

| Patient Group | Group Characteristics | Possible Additional Risk Factors | No. of Patients | No. (%) of Adverse Events |
|---------------|----------------------|----------------------------------|----------------|----------------------------|
|               |                      |                                  |                | Development Set | Test Set | Entire Dataset | Development Set | Test Set | Entire Dataset |
| 1             | Neurodevelopmental condition(s) | May also have: Congenital anomalies [52%], HLHS, UVHPA+IVS [17%], LOS >1 mo [26%] | 192 | 115 | 307 | 53 (28%) | 22 (19%) | 75 (24%) |
| 2             | No neurodev. conditions VSD/other Congenital anomalies LOS >1 mo | — | 95 | 76 | 171 | 20 (21%) | 21 (28%) | 41 (24%) |
| 3             | No neurodev. conditions HLHS, UVHPA+IVS | May also have: congenital anomalies [10%], LOS >1 mo [20%] | 524 HLHS=219 UVHPA+IVS=305 | 344 HLHS=147 UVHPA+IVS=197 | 868 HLHS=366 UVHPA+IVS=502 | 82 (16%) HLHS=37 (17%) UVHPA+IVS=45 (15%) | 50 (15%) HLHS=28 (19%) UVHPA+IVS=22 (11%) | 132 (15%) HLHS=65 (18%) UVHPA+IVS=67 (13%) |
| 4             | No neurodev. conditions VSD/other No congenital anomalies LOS >1 mo | — | 189 | 135 | 324 | 20 (11%) | 10 (7%) | 30 (9%) |
| 5             | No neurodev. conditions VSD/other Congenital anomalies LOS <1 mo | — | 701 | 494 | 1195 | 60 (9%) | 43 (9%) | 103 (9%) |
| 6             | No neurodev. conditions VSD/other No congenital anomalies LOS <1 mo | — | 2898 | 1880 | 4778 | 88 (3%) | 45 (2%) | 133 (3%) |

We list the patient characteristics that define each group in terms of combinations of ≥1 of the following: absence/presence of neurodevelopmental (neurodev.) condition; absence/presence of congenital anomaly; low-risk/high-risk primary cardiac diagnosis; index length of stay >1 or <1 month. For each group, the number of patients and occurrence of adverse events in the development, test, and overall data set are provided. For patient group 3, figures are also provided for the 2 subcategories of primary cardiac diagnosis within the high-risk group, namely hypoplastic left heart syndrome (HLHS) or functionally univentricular heart (UVH)/pulmonary atresia with intact ventricular septum (PA+IVS). CART indicates classification and regression tree; LOS, length of stay (index admission).
Our study outcomes inevitably reflect recent health services specific to the United Kingdom as provided by the NHS and, further, relate to the English and Welsh populations in terms of ethnicity, which has known links to the distribution of congenital anomalies.\(^\text{44}\) Evidence from North American studies suggests higher mortality for infants with CHD from Black and Hispanic ethnic groups, this being linked to reduced access to care\(^\text{45-48}\); however, these ethnic groupings are not representative of our study population. The ethnicity category “Other” in our data set was found to be at greater multivariable risk of adverse late outcome, whereas the more prevalent Asian and Black ethnic groups were not. Information from the UK Census suggests this category is largely comprised of individuals born in the Far East (Philippines, Japan, Thailand, and Vietnam), Middle East, and North Africa.\(^\text{49}\) Infants with CHD from these ethnic groups could be in newly immigrant families where treatment may occur later in the disease process or access to care may be compromised for cultural or linguistic reasons. Interestingly, in our analysis, socioeconomic status (English index of multiple deprivation\(^\text{17}\)) was not associated with outcome, in contrast to related data from North America.\(^\text{5,37}\)

**Conclusion**

Our findings demonstrate that later unexpected deaths are comparable in scale to early deaths after major intervention for CHD and that, while further improvements in early mortality are possible and important, there may arguably be a diminishing return to improvement initiatives in the perioperative period compared with the postdischarge period because of the relative lack of attention to the latter to date. We note that guidelines for the entire discharge process in “high-risk infants” (not including CHD) have been proposed by the American Academy of Pediatrics with the aim of reducing variability and maintaining predetermined levels of care,\(^\text{50}\) and our study suggests that something similar is warranted for CHD. This would require the development of appropriate intervention packages for patients with different needs, and our findings provide a valuable starting point in designing these. In particular, they show that adverse late outcomes are not confined to diagnostic groups currently targeted with enhanced monitoring in some services (ie, HLHS patients) and that subgroups of patients with neurodevelopmental conditions or congenital anomalies could also benefit from targeted intervention. Finally, to stimulate improvement initiatives aimed at reducing late adverse outcomes and to align activity across organizations responsible for the care of these patients, 1-year outcome after intervention for CHD in infancy may be a useful quality metric for pediatric cardiac surgery programs to complement the current focus on early mortality rates of surgery at 30 days or hospital discharge.

**Sources of Funding**

This project was funded by the National Institute for Health Research (NIHR) Health Services and Delivery Research (HS&DR) Programme (Project No: 10/2002/29). The views and opinions expressed therein are those of the authors and do not necessarily reflect those of the NIHR HS&DR Programme or the Department of Health. Further information about the Infant Heart Study can be found on the following NIHR website: http://www.nets.nihr.ac.uk/projects/hsdr/10200229. Additional support was provided by the Health Foundation, an independent charity working to continuously improve the quality of health care in the United Kingdom. The National Congenital Heart Disease Audit and the Paediatric Intensive Care Audit Network are funded by the National Clinical Audit & Patient Outcomes Programme, administered by the Healthcare Quality Improvement Partnership. PICANet
Outcomes Following Intervention for Infant CHD  Crowe et al

is also funded by Welsh Health Specialised Services Commit-tee; National Health Service (NHS) Lothian/National Service Division NHS Scotland, the Royal Belfast Hospital for Sick Children, National Office of Clinical Audit Ireland, and HCA International. Dr Utley was in part supported by the National Institute for Health Research (NIHR) Collaboration for Lead-ership in Applied Health Research and Care North Thames at Bart’s Health NHS Trust. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, or the Department of Health.

Disclosures
None.

References

1. Crowe S, Brown KL, Pagel C, Muthialu N, Cunningham D, Gibbs J, Bull C, Franklin R, Utley M, Tsang VT. Development of a diagnosis- and procedure-based risk model for 30-day outcome after pediatric cardiac surgery. J Thorac Cardiovasc Surg. 2013;145:1270–1278.

2. Jacobs JP, O’Brien SM, Pasquali SK, Jacobs ML, Lacour-Gayet FG, Tchervenkov CI, Austin EH, Pizarro C, Pournaghadam KK, Scholl FG, Welke KF, Mavroudis C. Variation in outcomes for benchmarking operations: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. Ann Thorac Surg. 2012;92:2184–2192.

3. Vinocur JM, Menk JS, Pasquali SK, Jacobs ML, Lacour-Gayet FG, Tchervenkov CI, Austin EH, Pizarro C, Pournaghadam KK, Scholl FG, Welke KF, Mavroudis C. Variation in outcomes for benchmarking operations: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. Ann Thorac Surg. 2012;92:2184–2192.

4. Brown K, Crowe S, Franklin R, McLean A, Cunningham D, Barron D, Tsang V, Pagel C, Utley M. Trends in 30-day mortality and case mix for paediatric cardiac surgery in the UK between 2000 and 2010. Open Heart. 2015;2:e000157.

5. Ghanayem NS, Allen KR, Tabbutt S, Atz AM, Clabby ML, Cooper DS, Eghtesady P, Fromme CT, Gruber PJ, Hill KD, Kaltman JR, Laussen PC, Lewis AB, Lurito JK, Minich LL, Ohye RG, Schonbeck JV, Schwartz SM, Singh RK, Goldberg CS, Pediatric Heart Network Investigators. Interstage mortality after the Norwood procedure: results of the multicenter Single Ventricle Reconstruction trial. J Thorac Cardiovasc Surg. 2012;144:896–906.

6. Ghanayem NS, Hoffmann GM, Mussatto KA, Cava JR, Fromme CT, Ruda N, Steltzer MM, Bevandic SM, Frisbee SS, Jaquiss RD, Litwin SB, Tweddell JS. Thorac Cardiovasc Surg Pediatr Card Surg Annu. 2004;7:32–38.

7. Dobralet NC, Nieves JA, Welch EM, Khan D, Rossi AF, Burke RP, Zahn EM. New approach to interstage care for palliated high-risk patients with congenital heart disease. J Thorac Cardiovasc Surg. 2011;142:855–860.

8. Hansen JH, Furck AK, Petko C, Buchholz-Berdau R, Voges I, Schewe J, Rickers C, Kramer H-H. Use of surveillance criteria reduces interstage mortality after the Norwood operation for hypoplastic left heart syndrome. Eur J Cardiothorac Surg. 2012;41:1013–1018.

9. Tregay J, Wray J, Crowe S, Knowles R, Daubeney P, Franklin R, Barron D, Hull S, Barnes N, Bull C, Brown KL. Going home after infant cardiac surgery: a UK experience from a multi-institutional registry. Pediatr Cardiol. 2013;34:1226–1236.

10. Clarke DR, Breen LS, Jacobs ML, Franklin RCG, Tobota Z, Maruszewski B, Jacobs JP. Verification of data in congenital cardiac surgery. Cardiol Young. 2008;18:177–187.

11. Annual report of the Paediatric Intensive Care Audit Network 2014—Tables and Figures [Internet]. Available at: http://www.picanet.org.uk/Documenta-tion/Annual-Reports. Accessed December 13, 2014.

12. IPCCC. International Paediatric and Congenital Cardiac Code (IPCCC) Home Page [Internet]. 2012. Available at: www.ipccc.net. Accessed April 12, 2012.

13. LHO. English Indices of Deprivation 2010—deprivation category lookups and average scores for higher geographies [Internet]. 2011. Available at: http://www.apho.org.uk/resource/view.aspx?RID=111277. Accessed February 13, 2015.

14. Office for National Statistics. Guidance and methodology: Ethnic group [Internet]. 2011. Available at: http://ons.gov.uk/ons/guide-method/measur-ing-equality/equality/ethnic-race-ethnicity/index.html. Accessed February 13, 2015.

15. Harrell FE, Lee KL, Califf RM, Pryor DB, Rosati RA. Regression modelling strategies for improved prognostic prediction. Stat Med. 1984;3:143–152.

16. Heymans MW, van Buuren S, Knot DL, van Mechelen W, de Vet HC. Variable selection under multiple imputation using the bootstrap in a prognostic study. BMC Med Res Methodol. 2007;7:33.

17. Rubin DB. Multiple imputation for nonresponse in surveys [Internet]. John Wiley & Sons, Inc.; 1987. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9780470731646.fmatter#summary. Accessed December 13, 2015.

18. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards: Length/Height-for-age, Weight-for-age, Weight-for-height and Body Mass Index-for age. Methods and Development. 2006. ISBN 92 4 154693 X.

19. Brown KL, Crowe S, Pagel C, Bull C, Muthialu N, Gibbs J, Cunningham D, Utley M, Tsang VT, Franklin R. Use of diagnostic information submitted to the United Kingdom Central Cardiac Audit Database: development of categorisation and allocation algorithms. Cardiol Young. 2013;23:491–498.

20. Health and Social Care Information Centre. Read codes [Internet]. Available at: https://isd.hscic.gov.uk/trud3/user/group/0/f/home. Accessed December 18, 2014.

21. Harrell FE, Lee KL, Califf RM, Pryor DB, Rosati RA. Regression modelling strategies for improved prognostic prediction. Stat Med. 1984;3:143–152.

22. Heymans MW, van Buuren S, Knol DL, van Mechelen W, de Vet HC. Variable selection under multiple imputation using the bootstrap in a prognostic study. BMC Med Res Methodol. 2007;7:33.

23. Rubin DB. Multiple imputation for nonresponse in surveys [Internet]. John Wiley & Sons, Inc.; 1987. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9780470731646.fmatter#summary. Accessed December 13, 2015.

24. Who Multicentre Growth Reference Study Group. WHO Child Growth Standards: Length/Height-for-age, Weight-for-age, Weight-for-height and Body Mass Index-for age. Methods and Development. 2006. ISBN 92 4 154693 X.

25. Rubin DB. Multiple imputation for nonresponse in surveys [Internet]. John Wiley & Sons, Inc.; 1987. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9780470731646.fmatter#summary. Accessed December 13, 2015.

26. Heymans MW, van Buuren S, Knot DL, van Mechelen W, de Vet HC. Variable selection under multiple imputation using the bootstrap in a prognostic study. BMC Med Res Methodol. 2007;7:33.

27. Department of Health. The NHS Plan: a plan for investment, a plan for reform [Internet]. 2000. Available at: http://webarchive.nationalarchives.gov.uk/+/ www.dh.gov.uk/en/publicationsandstatistics/publications/publicationspoli-cyandguidance/dh_4002960. Accessed February 13, 2015.

28. Stata Statistical Software. College Station, TX: StataCorp LP; 2011.

29. Harper PR. A review and comparison of classification algorithms for medical decision making. Health Policy. 2005;71:315–331.

30. Garbe C, Büttnor P, Bertz J, Burg G, d’Hoedt B, Drepper H, Guggemoos-Holzmann I, Lefchner W, Lippold A, Orfanoes C, Peters A, Rassner G, Stadler R, Stroebel W. Primary cutaneous melanoma: Identification of prognostic groups and estimation of individual prognosis for 5093 patients. Cancer. 1995;75:2484–2491.

31. Fonarow GC, Adams HF, Abraham WT, Yancy CW, Boscardin W; ADHERE Scientific Advisory Committee, Study Group, and Investigators f. Risk stratification for in-hospital mortality in acutely decompensated heart failure: classification and regression tree analysis. JAMA. 2005;293:572–580.

32. Breiman L, Friedman J, Olshen R, Stone C. Classification and Regression Trees. Belmont, CA: Wadsworth; 1983:156.

33. IBM SPSS Statistics. Armonk, NY: IBM Corp; 2013.

34. Chang R-KR, Rodriguez S, Lee M, Klitzner TS. Risk factors for deaths occurring within 30 days and 1 year after hospital discharge for cardiac surgery among pediatric patients. Am Heart J. 2006;152:386–393.

35. Kogon B, Jain A, Oster M, Woodall K, Kanter Z, Kirshbom P. Risk factors associated with readmission after pediatric cardiac surgery. Ann Thorac Surg. 2012;94:865–873.

36. Mackie AS, Gauvreau K, Newburger JW, Malyer JE, Erickson LC. Risk factors for readmission after neonatal cardiac surgery. Ann Thorac Surg. 2004;78:1972–1978; discussion 1978.

37. Fixler DE, Nembhard WN, Xu P, Ethen MK, Canfield MA. Effect of acculturation and distance from cardiac center on congenital heart disease mortality. Pediatrics. 2012;129:1118–1124.
38. Brown KL, Ridout DA, Goldman AP, Hoskote A, Penny DJ. Risk factors for long intensive care unit stay after cardiopulmonary bypass in children. Crit Care Med. 2003;31:28–33.

39. Hebson CL, Oster ME, Kirshbom PM, Clabby ML, Wulkan ML, Simsic JM. Association of feeding modality with interstage mortality after single-ventricle palliation. J Thorac Cardiovasc Surg. 2012;144:173–177.

40. Hehir DA, Rudd N, Slicker J, Mussatto KA, Simpson P, Li S-H, Frommelt MA, Tweddell JS, Ghanayem NS. Normal interstage growth after the Norwood operation associated with interstage home monitoring. Pediatr Cardiol. 2012;33:1315–1322.

41. Ashburn DA, McCrindle BW, Tchervenkov CI, Jacobs ML, Lofland GK, Bove EL, Spray TL, Williams WG, Blackstone EH. Outcomes after the Norwood operation in neonates with critical aortic stenosis or aortic valve atresia. J Thorac Cardiovasc Surg. 2003;125:1070–1082.

42. Héhir DA, Dominguez TE, Ballweg JA, Ravishankar C, Marino BS, Bird GL, Nicolson SC, Spray TL, Gaynor JW, Tabbutt S. Risk factors for interstage death after stage 1 reconstruction of hypoplastic left heart syndrome and variants. J Thorac Cardiovasc Surg. 2008;136:94–99, 99.e1–3.

43. Petit CJ, Fraser CD, Mattamal R, Slesnick TC, Cephus CE, Ocampo EC. The impact of a dedicated single-ventricle home-monitoring program on interstage somatic growth, interstage attrition, and 1-year survival. J Thorac Cardiovasc Surg. 2011;142:1358–1366.

44. Sheridan E, Wright J, Small N, Corry PC, Oddie S, Whibley C, Petherick ES, Malik T, Pawson N, McKinney PA, Parslow RC. Risk factors for congenital anomaly in a multiethnic birth cohort: an analysis of the Born in Bradford study. Lancet. 2013;382:1350–1359.

45. Boneva RS, Botto LD, Moore CA, Yang Q, Correa A, Erickson JD. Mortality associated with congenital heart defects in the United States trends and racial disparities, 1979–1997. Circulation. 2001;103:2376–2381.

46. DiBardino DJ, Pasquariello SK, Hirsch JC, Benjamin DK, Kleeman KC, Salazar JD, Jacobs ML, Mayer JE, Jacobs JP. Effect of sex and race on outcome in patients undergoing congenital heart surgery: an analysis of the society of thoracic surgeons congenital heart surgery database. Ann Thorac Surg [Internet]. 2012;94. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3838919/. Accessed April 4, 2015.

47. Benavidez OJ, Gauvreau K, Jenkins KJ. Racial and ethnic disparities in mortality following congenital heart surgery. Pediatr Cardiol. 2006;27:321–328.

48. Gilboa SM, Salemi JL, Nembhard WN, Fixler DE, Correa A. Mortality resulting from congenital heart disease among children and adults in the United States, 1999 to 2006. Circulation. 2010;122:2254–2263.

49. Gardener D, Connolly H. Who are the “Other” Ethnic Groups. London: Office of National Statistics; 2005.

50. Committee on Fetus and Newborn. Hospital discharge of the high-risk neonate. Pediatrics. 2008;122:1119–1126.
SUPPLEMENTAL MATERIAL

Data S1. Supplemental Methods

Specific procedure hierarchy and groupings

Within the NCHDA dataset, each procedure is described by up to 8 individual procedural International Paediatric and Congenital Cardiac Codes (IPCCCs) [1]. An algorithm developed by the NCHDA Steering Committee links the individual IPCCCs for a given record to 1 of 56 specific procedures, i.e. reported surgical operations or transcatheter procedures. Note that the hierarchical system is shown here in its entirety for reference purposes. It is designed for children of any age and many procedures listed would be rarely if ever performed in infancy.

The algorithm imposes a hierarchy with the record assigned the most complex specific procedure consistent with the collection of codes recorded. Approximately 85% of procedures fall into one of these 56 specific procedures. For children that had more than one procedure during their index admission, their index intervention was chosen to be the most complex according to the NCHDA specific procedure hierarchy.

For reasons of model reliability and validity of predictive discrimination, the index specific procedures were aggregated into three procedural groups considered clinically meaningful to the focus of the study: definitive, staged and ungrouped. A definitive procedure would be expected to be the final, often only, operation in achieving a biventricular or functionally univentricular circulation, although acknowledging that later procedures may be required in an individual’s lifetime, such as conduit or valve replacement. A staged procedure would be undertaken in the expectation that further operations would be undertaken in the expectation that further operations would be expected to achieve either a definitive biventricular circulation or definitive univentricular repair with a Fontan-type operation in early childhood.

| Specific procedure                                      | NCHDA hierarchy | Procedure group |
|--------------------------------------------------------|-----------------|-----------------|
| Norwood                                                | 1               | Staged          |
| Heart Transplant                                       | 2               | Excluded        |
| Totally anomalous pulmonary venous connection (TAPVC)  | 3               | Staged          |
| Repair + Arterial Shunt                               |                 |                 |
| Fontan procedure †                                     | 4               | Staged          |
| Bidirectional cavopulmonary shunt                      | 5               | Staged          |
| Senning or Mustard procedure                           | 6               | Staged          |
| Truncus and interruption repair                        | 7               | Definitive      |
| Truncus arteriosus repair                              | 8               | Definitive      |
| Tricuspid valve replacement                            | 9               | Ungrouped       |
| Interrupted aortic arch repair                         | 10              | Definitive      |
| Multiple ventricular septal defect (VSD) closure       | 11              | Definitive      |
| Mitral valve replacement                               | 12              | Definitive      |
| Repair of TAPVC                                        | 13              | Definitive      |
| Atrioventricular septal defect and tetralogy repair     | 14              | Definitive      |
| Atrioventricular septal defect (complete) repair       | 15              | Definitive      |
| Atrioventricular septal defect (partial) repair         | 16              | Definitive      |
| Aortic valvotomy (surgical)                            | 17              | Definitive      |
| Aortic valvoplasty                                     | 18              | Definitive      |
| Procedure                                      | Code | Type  |
|-----------------------------------------------|------|-------|
| Anomalous coronary artery repair              | 19   | Definitive |
| Cor triatriatum repair                        | 20   | Definitive |
| Arterial switch + VSD closure                 | 21   | Definitive |
| Arterial switch (for isolated transposition)  | 22   | Definitive |
| Pulmonary atresia & VSD repair                | 23   | Definitive |
| Pulmonary valve replacement                   | 24   | Definitive |
| Tetralogy with absent pulmonary valve repair  | 25   | Definitive |
| Tetralogy repair                              | 26   | Definitive |
| Isolated coarctation repair                   | 27   | Definitive |
| Aortic Valve Replacement - non Ross           | 28   | Definitive |
| Supravalvar aortic stenosis repair            | 29   | Definitive |
| Rastelli procedure                            | 30   | Definitive |
| Aortic valve replacement - Ross               | 31   | Definitive |
| Aortic root replacement (not Ross)            | 32   | Definitive |
| Subvalvar aortic stenosis repair              | 33   | Definitive |
| Aortopulmonary window repair                  | 34   | Definitive |
| Atrial septal defect (ASD) repair             | 35   | Definitive |
| VSD Repair                                    | 36   | Definitive |
| Arterial shunt                                | 37   | Staged  |
| Isolated Pulmonary artery band                | 38   | Staged  |
| Patent ductus arteriosus (PDA) ligation (surgical) | 39 | Definitive |
| Transcatheter pulmonary valve replacement *   | 40   | Excluded |
| VSD closure (catheter) *                      | 41   | Excluded |
| Aortic balloon valvotomy                      | 42   | Definitive |
| Coarctation angioplasty                       | 43   | Definitive |
| Pulmonary artery stenting *                   | 44   | Excluded |
| ASD closure (catheter) *                      | 45   | Excluded |
| PDA closure (catheter)                        | 46   | Definitive |
| Recoarctation angioplasty *                   | 47   | Excluded |
| Pulmonary balloon valvoplasty                 | 48   | Definitive |
| Blade atrial septostomy *                     | 49   | Excluded |
| Coarctation stenting                          | 50   | Definitive |
| PFO closure (catheter) *                      | 51   | Excluded |
| Pulmonary valvotomy (radiofrequency)          | 52   | Definitive |
| Duct Stenting                                 | 53   | Staged  |
| RVOT Stenting                                 | 54   | Staged  |
| Radiofrequency ablation for supraventricular tachycardia * | 55 | Excluded |
| Implantable Cardioverter Defibrillator *      | 56   | Excluded |
| Minor and Excluded Procedures *               | 57   | Excluded |
| Not a specific procedure: surgical **         | 58   | Ungrouped |
| Not a specific procedure: catheter *          | 59   | Excluded |

* Catheter procedure excluded from analysis

** Note that n=53 out of 231 children with a cardiac diagnosis of aortic arch obstruction +/- VSD/ASD and no index specific procedure had either a banding of pulmonary trunk or pulmonary trunk band removal and were therefore classified as a “staged” procedure group rather than “ungrouped”.

† Only one patient in our infant cohort had a Fontan as their index procedure.
Candidate patient risk factors

Potential non-medical, pre-procedure or post-procedure risk factors available in the patient-based analysis dataset that would be known at the point of discharge were pre-specified (Supplemental Table 1). Some variables were simplified prior to the statistical analyses in order to reduce the number of values (degrees of freedom) in the model and hence the risk of overfitting (see Harrell [2]). An appropriate power calculation was performed. The origin of each risk factor (either the PICANet or NCHDA dataset) is noted in Supplemental Table 1. Where both audits contained information on a particular risk factor, the most complete source was used or, in the case of ethnicity, a combination of the two sources (see Supplemental Table 1).

Non-medical variables

Deprivation was based on the residential address at admission and defined using quintiles of the English Index of Multiple Deprivation 2010 (IMD), which is calculated at the level of small (~ 1,500 people) geographic areas covering England [3].

Ethnicity information is recorded in both audits, with NCHDA using a bespoke classification scheme and PICANet using the Census 2001 classification used by the Office for National Statistics (ONS) [4]. PICANet was the primary source for our ethnicity variable due to its comparability with population statistics and was collapsed into seven groups to improve model stability: white, mixed, Asian, black, Chinese, other, and not stated. Where ethnic group was not available from PICANet, the NCHDA ethnic code was used to assign white, Asian or black ethnicity (which showed strong concordance across the two audits) but not to assign Chinese, other or mixed ethnicity (which showed poorer concordance) [5]. The most frequently recorded ethnic group was assigned to the child if they had multiple admission records.

Pre-procedure variables

Cardiac diagnoses and procedure information

Within the NCHDA dataset, each record (interventional procedure) can be described by up to 6 individual diagnostic International Paediatric and Congenital Cardiac Codes (IPCCCs). The combination of these can be mapped to 1 of 24 primary cardiac diagnoses using a hierarchical scheme developed by Brown et al. [6]. For the purposes of this study, this mapping scheme was implemented with two minor adjustments (see Supplemental Table 2): a new category of ‘arrhythmia’ was created (ranked 24th in the modified hierarchy) and the “miscellaneous congenital” diagnostic category was split into “major miscellaneous diagnoses” (ranked 9th in the modified hierarchy) and “minor miscellaneous diagnoses” (ranked 25th in the modified hierarchy).

To reduce the risk of overfitting in the model, we grouped the diagnostic categories into four cardiac diagnosis groups (see Supplemental Table 2): Hypoplastic left heart syndrome (HLHS); Functionally univentricular heart (UVH) or pulmonary atresia (PA) with an intact ventricular septum (IVS); Ventricular septal defect (VSD) and; “Other” (the remaining 22 diagnosis categories). The choice of diagnosis group ‘HLHS’ reflects the body of literature related to ‘inter-stage’ deaths in this population. A separate group of ‘UVH or PA+IVS’ was chosen due to the high-risk nature of these conditions, which are often systemic-to-pulmonary arterial shunt dependent, with a view to distinguishing these from HLHS patients. Of the remaining cardiac diagnosis groups, we elected to review the VSD group separately as a recognizable bi-ventricular comparator group in order for us to evaluate the face validity of comparisons between HLHS or UVH/PA+IVS and the much larger, less homogeneous group of mainly biventricular diagnoses.
In addition to their overall primary cardiac diagnosis, each child was identified as having an acquired cardiac diagnosis if any of their records included an IPCCC diagnostic code mapping to this category, for example, ventricular dysfunction and ventricular hypoplasia. Some non-cardiac IPCCC diagnostic codes were identified as post-procedural morbidities (see below and Supplemental Table 4 for details).

The index (specific) procedures were aggregated into three groups (see above for mappings): Palliative (e.g. Norwood, bidirectional cavopulmonary shunt, arterial shunt), Corrective (e.g. truncus arteriosus repair, atrioventricular septal defect complete repair, tetralogy repair) or “Ungrouped” (if no specific procedure was assigned).

Non-cardiac diagnosis and co-morbidity information

Non-cardiac diagnosis and co-morbidity information was primarily sourced from PICANet, in which any given PICU admission can record up to 24 clinical Read codes [7]. As 3,325 discrete Read codes were present in the dataset, we developed a new scheme linking each code to 1 of 16 system-based categories (see Supplemental Table 3).

Congenital anomaly: If any PICU admission within the index admission contained a Read code for a congenital anomaly then the child was assigned this attribute. Many of these children had Downs syndrome, however other syndromes that are often associated with cardiac defects were also often represented, including DiGeorge syndrome (22q11 deletion). Non-syndromic congenital anomalies were also described, including urogenital/renal malformations, tracheal/trachea-oesophageal malformations, vision/hearing deficits and exomphalos/gastrointestinal malformations. These are major anomalies, some requiring neonatal surgery, and their impact is likely to be life-long.

Neurodevelopmental condition: If any Read code within the index admission was linked to the neurodevelopmental category then the child was assigned this attribute. These comprised a range acquired and congenital conditions most with global effects on the central nervous system and likely to have lifelong impact, the most common examples being (in order of decreasing frequency): epilepsy/seizures, developmental delay, sleep apnoea, hydrocephalus, retinopathy of prematurity, stroke, hemiparesis/hemiplegia, anoxic encephalopathy, cerebral venous sinus thrombosis and cerebral palsy. Within the analysis dataset, n= 95 children were coded as having developmental delay, of which n=64 had no other neurodevelopmental problem coded. On closer inspection of these n=64 children, 41% had a congenital anomaly or syndrome (e.g. Down’s syndrome, DiGeorge syndrome, craniosynostosis, microcephaly) or a comorbidity (e.g. meningitis, preterm birth, brain injury) that could be associated with developmental delay. The remaining 59% had no record of a comorbidity associated with developmental delay but since coding is not comprehensive (e.g. preterm children were not always recorded as such), it is possible that these are nonetheless correct and were used where a degree of neurodevelopmental delay was evident even within infancy.

Prematurity: Finally, a child was assigned the attribute of prematurity (<37 completed weeks gestation) if they had a Read code for this in any admission.

Additional pre-procedure factors

Additional pre-procedure factors considered on the basis of potential clinical relevance were: Gender; Age at procedure; Weight-for-age at procedure (calculated using WHO reference standards [7]); Antenatal diagnosis, Clinical deterioration prior to the index intervention (assigned if the index admission or any prior PICU admissions were urgent and unplanned).

Post-procedure variables

Post-procedure patient variables known at hospital discharge were: Length of stay for the index admission; Requirement for renal support (including dialysis and haemofiltration) or extracorporeal
membrane oxygenation support (ECMO) during the index admission; Any adverse ICU events during the index admission (assigned if any PICU admission contained a Read code for: collapse or cardiac arrest, acquired injury or complications, or a non-cardiac operation (categories 9-11 in Supplemental Table 3)); Whether the index admission was associated with any acquired co-morbidities (categories 1-8 in Supplemental Table 3); Whether the index admission was associated with any post-procedural morbidity (Supplemental Table 4); Any catheter or surgical procedures performed during the index admission in addition to the index procedure (either before or after the index procedure).
Table S1: Summary of candidate patient risk factors

Descriptions of the pre-specified potential risk factors considered in the analysis, including whether a given variable relates to the index procedure, index admission or is a characteristic of the child, its possible values and the source dataset (PICANet or NCHDA). All variables would be known at the point of discharge and are grouped according to whether they are a non-medical, pre-procedure or post-procedure factor.

| Pre-specified candidate risk factor | Description                                                                                                                                                                                                 | Variable level | Values                                                                 | Source dataset |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------------------------------------------------------------|----------------|
| Non-medical                       | Quintiles of the English Index of Multiple Deprivation 2010 [2] as recorded for the index procedure.                                                                                                                                                  | Child          | 1-5 (1 most deprived, 5 least deprived)                                | NCHDA          |
| Deprivation                       | Census 2001 classification used by ONS [3], collapsed into seven groups. Most frequently recorded ethnic group if child had multiple records.                                                                                                               | Child          | White, Mixed, Asian, Black, Chinese, Other, Not stated                | PICANet†       |
| Ethnicity                         | Aggregated groupings of the cardiac diagnosis categories assigned through application of a modified version of the hierarchical mapping scheme developed by Brown et al.[5] across all cardiac records for a child (see Table A2).                  | Child          | VSD, HLHS, UVH/PA+IVS, Other                                          | NCHDA          |
| Cardiac diagnosis group           | Assigned if any cardiacl record in the index admission had an IPCCC diagnostic code corresponding to the acquired cardiac diagnosis category (see Table A2).                                                                                      | Index admission| Yes, No                                                               | NCHDA          |
| Acquired cardiac diagnosis        | Aggregated groupings of the index specific procedures assigned through application of the NCHDA specific procedure hierarchy across all interventions within the index admission (see Appendix 1).                                                               | Index procedure| Corrective, palliative, ungrouped                                     | NCHDA          |
| Specific procedure group          | Assigned if any PICU record during the index admission contained a Read code corresponding to the congenital anomaly category.                                                                                                                        | Index admission| Yes, No, Missing                                                      | PICANet        |
| Congenital anomaly                | Assigned if any PICU record during the index admission contained a Read code corresponding to the neurodevelopmental category.                                                                                                                        | Index admission| Yes, No                                                               | PICANet        |
| Neurodevelopment condition        | Assigned if any PICU record for the child contained a Read code corresponding to prematurity or preterm birth (see Table A3).                                                                                                                          | Child          | Yes, No, Missing                                                      | PICANet        |
| Prematurity                       | Most frequently occurring gender across all cardiac records for a patient (or gender at index procedure if tied).                                                                                                                                   | Child          | Male, Female                                                          | NCHDA          |
| Gender                            | Age recorded in cardiac record for the index procedure.                                                                                                                                                                                                                                      | Index procedure| Continuous variable                                                  | NCHDA          |
| Variable                             | Description                                                                                                                                                                                                 | Data Type                     | Audit Source |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------------|
| Weight-for-age z-score             | Standardised weight-for-age at index procedure, calculated from index procedure weight and age using WHO reference standards [6].                                                                       | Index procedure               | NCHDA        |
| Antenatal diagnosis                | Assigned if coded in any cardiac record for the child.                                                                                                                                                        | Child                         | NCHDA        |
| Clinical deterioration             | Assigned if any PICU admissions prior to discharge from the index admission were urgent and unplanned.                                                                                                         | Index admission               | PICANet      |
| **Post-procedure**                 |                                                                                                                                                                                                             |                               |              |
| Length of stay                     | The length in days of the continuous period as in-patient within a specialist paediatric cardiac hospital or PICU that surrounds a child’s first interventional cardiac procedure in infancy.                                | Index admission               | NCHDA        & PICANet |
| Need for renal support             | Assigned if any PICU record within the index admission indicated renal support was required (including dialysis and haemofiltration).                                                                   | Index admission               | PICANet      |
| Need for ECMO                      | Assigned if any PICU record within the index admission indicated ECMO support was required.                                                                                                                                 | Index admission               | PICANet      |
| Acquired comorbidity               | Assigned if any PICU record during the index admission contained a Read code identified an acquired condition (categories 1-8 in Table A3).                                                              | Index admission               | PICANet      |
| Adverse event in PICU              | Assigned if any PICU record during the index admission contained a Read code corresponding to collapse or cardiac arrest, acquired injury or complications, or a non-cardiac operation in PICU (categories 9-11 in Table A3). | Index admission               | PICANet      |
| Post-procedural morbidity          | Assigned if any cardiac record during the index admission contained an IPCCC code identified as a post-procedural morbidity (see Table A4).                                                             | Index admission               | NCHDA        |
| Additional surgical procedures     | Assigned if any surgical procedures were performed during the index admission in addition to the index procedure (before or after).                                                                       | Index admission               | NCHDA        |
| Additional catheter procedures     | Assigned if any catheter procedures were performed during the index admission in addition to the index procedure (before or after).                                                                         | Index admission               | NCHDA        |

ONS = Office for National Statistics; PICU = paediatric intensive care unit; NCHDA = National Congenital Heart Disease Audit; PICANet = Paediatric Intensive Care Audit Network; IPCCC = International Paediatric and Congenital Cardiac Code; ECMO = extracorporeal membrane oxygenation; HLHS = hypoplastic left heart syndrome; UVH = functionally univentricular heart; PA+IVS = pulmonary atresia with intact ventricular septum; VSD = Ventricular septal defect.

† Where ethnic group was not available from PICANet, the NCHDA ethnic code was used to assign white, Asian or black ethnicity (which showed strong concordance across the two audits) but not to assign Chinese, other or mixed ethnicity (which showed poorer concordance).
Table S2: Primary cardiac diagnosis hierarchy and collapsed groupings

The hierarchy used to assign a primary cardiac diagnosis category to each child in the analysis dataset (modified from scheme developed by Brown et al.[5]), along with the mappings from diagnosis category to cardiac diagnosis group (the candidate patient risk factor used in the analyses).

| Primary cardiac diagnosis category | Hierarchy rank† | Cardiac diagnosis group†† |
|-----------------------------------|----------------|--------------------------|
| Hypoplastic left heart syndrome    | 1              | HLHS                     |
| Functionally univentricular heart  | 2              | UVH or PA+IVS            |
| Common arterial trunk (truncus arteriosus) | 3          | Other                    |
| TGA + VSD/DORV-TGA type           | 4              | Other                    |
| Interrupted aortic arch           | 5              | Other                    |
| TGA (concordant AV and discordant VA connections) and intact ventricular septum | 6 | Other                     |
| PA with an intact ventricular septum | 7          | UVH or PA+IVS            |
| Pulmonary atresia + VSD (including Fallot type) | 8 | Other                    |
| Miscellaneous congenital primary diagnoses | 9 | Other                    |
| Atrioventricular septal defect     | 10             | Other                    |
| Fallot/DORV-Fallot type           | 11             | Other                    |
| Aortic valve stenosis (isolated)  | 12             | Other                    |
| Tricuspid valve abnormality (including Ebstein’s) | 13 | Other                    |
| Mitral valve abnormality (including supravalvar, subvalvar) | 14 | Other                    |
| Totally anomalous pulmonary venous connection | 15 | Other                    |
| Aortic arch obstruction +/- VSD/ASD | 16 | Other                    |
| Pulmonary stenosis                | 17             | Other                    |
| Subaortic stenosis (isolated)     | 18             | Other                    |
| Aortic regurgitation              | 19             | Other                    |
| Isolated VSD +/- ASD +/- PDA      | 20             | VSD                      |
| Interatrial communication (ASD)   | 21             | Other                    |
| Patent ductus arteriosus (PDA)    | 22             | Other                    |
| Acquired non-congenital heart disease | 23         | Other                    |
| Arrhythmia                        | 24             | Other                    |
| Miscellaneous congenital terms    | 25             | Other                    |
| Noncardiac or uncoded diagnosis   | 26             | Other                    |

TGA = transposition of the great arteries; VSD = ventricular septal defect; DORV = double outlet right ventricle; AV = atrioventricular; VA = ventriculoarterial; ASD = atrial septal defect.
† The hierarchical scheme developed by Brown et al.[5], modified for the purposes of this study with two minor adjustments: creating a new category of “arrhythmia” and splitting the original “miscellaneous congenital” diagnostic category into “major miscellaneous diagnoses” and “minor miscellaneous diagnoses”.
†† For reasons of model reliability and validity of predictive discrimination, we grouped the diagnostic categories into four cardiac diagnosis groups considered clinically meaningful to the study focus: Hypoplastic left heart syndrome (HLHS); Functionally univentricular heart (UVH) or pulmonary atresia with an intact ventricular septum (PA+IVS); Ventricular septal defect (VSD); “Other”.

TGA = transposition of the great arteries; VSD = ventricular septal defect; DORV = double outlet right ventricle; AV = atrioventricular; VA = ventriculoarterial; ASD = atrial septal defect.
† The hierarchical scheme developed by Brown et al.[5], modified for the purposes of this study with two minor adjustments: creating a new category of “arrhythmia” and splitting the original “miscellaneous congenital” diagnostic category into “major miscellaneous diagnoses” and “minor miscellaneous diagnoses”.
†† For reasons of model reliability and validity of predictive discrimination, we grouped the diagnostic categories into four cardiac diagnosis groups considered clinically meaningful to the study focus: Hypoplastic left heart syndrome (HLHS); Functionally univentricular heart (UVH) or pulmonary atresia with an intact ventricular septum (PA+IVS); Ventricular septal defect (VSD); “Other”.
Table S3: Coding scheme for non-cardiac diagnoses and comorbidities

A new scheme developed and implemented in this work to link each Read code [6] to at most 1 of 16 system-based categories. Given the large number of codes, we present exemplars within each of categories rather than the extensive list: further details are available from authors on request. We note that congenital heart disease/cardiac procedure Read codes in PICANet were not included as a category as they were inconsistently recorded. Cardiac diagnostic and procedure codes for the analysis were derived from the NCHDA dataset only.

| Category                                                                 | Number of codes | Examples of included clinical conditions                                                                 |
|-------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------|
| 1. Acquired endocrine, nutritional and metabolic conditions              | 82              | Diabetes mellitus; alpha-1-antitrypsin disorder; rickets; failure to thrive                               |
| 2. Acquired gastrointestinal (digestive system) conditions              | 166             | Gastritis; constipation; liver failure; jaundice; perianal fistula                                       |
| 3. Acquired infections (in any system except respiratory infections which are included within the category for acquired respiratory system conditions) | 144             | Cytomegalovirus; E coli infection; MRSA; meningitis; otitis media; wound abscess                          |
| 4. Conditions related to haematology, oncology or immunology, which may be acquired or congenital. | 97              | Acute myeloid leukaemia; Factor VIII deficiency; teratoma; sickle cell anaemia                           |
| 5. Acquired musculoskeletal, connective tissue or skin conditions        | 29              | Atopic dermatitis; scoliosis; systemic onset juvenile chronic arthritis                                  |
| 6. Acquired genitourinary system conditions                              | 42              | Acute renal failure; hydronephrosis; rectovaginal fistula                                                 |
| 7. Acquired respiratory system conditions                                | 229             | Stridor; asthma; bronchiolitis; pulmonary oedema; pneumonia; haemothorax                               |
| 8. Conditions originating in or specific to the perinatal period        | 109             | Birth asphyxia; gestational diabetes; meconium ileus; shoulder dystocia                                  |
| 9. Non-cardiac intervention or operation, excluding procedures that are part of routine intensive care | 478             | Adenoidectomy; bone marrow transplant; splenectomy; plication of diaphragm                              |
| 10. Collapse or cardiac arrest                                          | 14              | Cardiac arrest; hypovolaemic shock; fainting; respiratory arrest                                        |
| 11. Acquired injury or complication of surgery/other condition           | 145             | Brain injury; anaesthetic shock; closed rib fracture; vocal cord palsy; limb ischaemia                   |
| 12. Congenital anomalies (all severity)                                 | 342             | Trisomy 18; Pierre-Robin syndrome; cleft palate; club foot; oesophageal atresia                          |
| 13. Neurological or neurodevelopmental conditions – may be congenital or acquired | 126             | Cataract, cerebral palsy; autistic spectrum disorder; epilepsy; optic atrophy                           |
| 14. Additional codes which are non-specific or do not have standardised coding | 429             | e.g. family history of hypothyroidism; child in foster care; central line feeding;                      |
| 15. Premature birth (<37 completed weeks gestation)                     | 11              | Baby born premature/very premature                                                                      |
| 16. Supportive procedures                                               | 7               | Extracorporeal membrane oxygenation (ECMO); ventricular assist device                                  |
Table S4: Post-procedural morbidities
Some non-cardiac diagnostic International Paediatric and Congenital Cardiac Codes (IPCCC) were identified as post-procedural morbidities as set out in the table below. If any NCHDA record during the index admission period for a child contained an IPCCC corresponding to a post-procedural morbidity then their index admission was flagged as having a post-procedural morbidity.

| IPCCC identified as post-procedural morbidities |
|-----------------------------------------------|
| 160101. Pneumothorax                           |
| 160104. Pleural effusion                       |
| 160107. Chylothorax                            |
| 100811. Postpericardiotomy syndrome            |
| 110412. Junctional ectopic tachycardia (His bundle): post-op |
| 110617. Postprocedural complete AV block       |
| 110632. Procedure related complete AV block requiring temporary pacing |
| 110633. Procedure related complete AV block requiring permanent pacemaker system |
| 150001. Cardiac arrest during procedure        |
| 150002. Cardiac arrest following procedure     |
| 150003. Postprocedural low cardiac output      |
| 150005. Myocardial infarction following procedure |
| 150009. Postprocedural requirement for mechanical circulatory support |
| 150030. Postprocedural hypovolaemia            |
| 150200. Postprocedural haemorrhage            |
| 150203. Postprocedural coagulopathy           |
| 150207. Postprocedural haemolysis             |
| 150265. Postprocedural haemorrhage requiring reoperation |
| 150300. Median sternotomy complication         |
| 150303. Infection of median sternotomy wound  |
| 150308. Dehiscence of median sternotomy wound |
| 150315. Keloid-hypertrophic scar of median sternotomy wound |
| 150330. Lateral thoracotomy complication       |
| 150332. Infection of lateral thoracotomy wound |
| 150350. Wound infection                        |
| 150351. Wound dehiscence                      |
| 150352. Mediastinitis                         |
| 152420. Postprocedural femoral arterial complication |
| 154306. Unplanned reoperation during current admission |
| 155000. Cardiac catheterisation complication  |
| 155001. Intramyocardial injection of contrast medium |
| 155003. Perforation of cardiac chamber-vessel during cardiac catheterisation |
| 155011. Lost pulse after cardiac catheterisation |
| 155030. Equipment problem during cardiac catheterisation |
| 155037. Embolisation of catheter introduced device |
| 155040. Failed attempt to implant coil-device during transcatheter intervention |
| 155060. Complication involving device implantation |
| 155070. Complication involving stent           |
| 155702. Extracorporeal Membrane Oxygenation (ECMO) circuit complication |
| 155703. Ventricular assist device complication |
| 155721. Intraaortic balloon pump (IABP) complication |
| 155801. Complication related to echocardiographic procedure |
| 155900. Medication related complication or error |
| 156002. Arrhythmia following procedure         |
| 156738. Wound related complication             |
| 157700. Cardiopulmonary bypass complication    |
| 158000. General systemic complication of cardiac procedure |
| 158001. Postprocedural metabolic derangement   |
| Code | Description |
|------|-------------|
| 158005 | Postprocedural sepsicaemia |
| 158006 | Capillary leak syndrome |
| 158015 | Postprocedural acidosis |
| 158016 | Multiple organ dysfunction syndrome (MODS) |
| 158019 | Systemic inflammatory response syndrome (SIRS) |
| 158020 | Respiratory complication after cardiac procedure |
| 158021 | Postprocedural pulmonary infection |
| 158022 | Postprocedural pulmonary hypertensive crises |
| 158029 | Postprocedural Acute Respiratory Distress Syndrome (ARDS) |
| 158031 | Postprocedural lung collapse (atelectasis) |
| 158032 | Postprocedural requirement for mechanical respiratory support > 7 days |
| 158033 | Postprocedural requirement for reintubation |
| 158050 | Postprocedural pleural effusion |
| 158051 | Postprocedural right pleural effusion |
| 158052 | Postprocedural left pleural effusion |
| 158055 | Postprocedural chylothorax |
| 158056 | Postprocedural haemothorax |
| 158061 | Pleural effusion requiring drainage |
| 158062 | Postprocedural pneumothorax |
| 158070 | Postprocedural complication involving tracheo-bronchial tree |
| 158086 | Postprocedural requirement for tracheostomy |
| 158087 | Postprocedural bronchial compression |
| 158090 | Intraprocedural phrenic nerve injury (paralysed diaphragm) |
| 158093 | Intraprocedural recurrent laryngeal nerve injury (palsy) |
| 158094 | Postprocedural Horner’s syndrome |
| 158200 | Postprocedural renal failure |
| 158206 | Renal failure requiring temporary dialysis |
| 158207 | Renal failure requiring permanent dialysis |
| 158221 | Postprocedural gastrointestinal bleeding |
| 158223 | Postprocedural inability to sustain gastric feeding |
| 158228 | Postprocedural intestinal obstruction |
| 158229 | Postprocedural peritonitis |
| 158230 | Postprocedural necrotising enterocolitis |
| 158232 | Pseudomembranous colitis |
| 158233 | Postprocedural protein losing enteropathy |
| 158238 | Postprocedural feeding difficulties |
| 158243 | Postprocedural hepatic impairment |
| 158247 | Postprocedural acute pancreatitis |
| 158250 | Neurological complication after cardiac procedure |
| 158251 | Postprocedural generalised seizures |
| 158253 | Postprocedural temporary neurological impairment |
| 158257 | Postprocedural permanent neurological impairment |
| 158264 | Postprocedural brain death |
| 158266 | Postprocedural cerebral abscess |
| 158267 | Postprocedural new onset seizures |
| 158268 | Postprocedural neurological impairment persisting at discharge |
| 158281 | Postprocedural cerebral abnormality on imaging |
| 158800 | Vascular line (access) related complication |
| 159001 | Postprocedural complication |
| 159014 | Procedure related complication |
| 159020 | Complication during period of anaesthetic care |
| 165020 | Complication following respiratory tract stent implantation |
| 101824 | Postmyocardial infarction complication |
Data S2. Supplemental Results

Summary of results from descriptive and univariate analyses

Ethnic group was not available from PICANet for 1,703 children in the final dataset. Of these, the NCHDA ethnic code was used to assign white (n=1,001), Asian (n=243) or black (n=113). Excluding records without PICANet-derived ethnicity from the analyses did not significantly affect the results. A total of 528 children had missing or anomalous weight-for-age (assumed erroneous and treated as missing). The variable with the markedly highest level of missing data (n=2,101 (27.5%)) was prematurity (yes/no): sensitivity analysis comparing models with and without prematurity showed a marginally better fit if it was included and very little difference in the odds ratio coefficients for all other factors.

The observed numbers of patients and rate of adverse events and fatal adverse events only for all candidate risk factors are shown below along with the results of the univariate analysis.

The relationship between length of stay and both outcomes was non-linear and the fractional polynomial transformation was used in the subsequent risk model development analyses, whilst for age we used a log transformation. The relationship between weight-for-age and each outcome did not depart significantly from linearity. We used a multi-degree of freedom test for ethnicity, with results for fatal adverse events and all adverse events of p = 0.003 and p = 0.0001 respectively.

| Patient variable | Num. (%) overall |Fatal adverse events only | All adverse events |
|------------------|------------------|--------------------------|--------------------|
|                  | Num. (%) | Univariate OR (p-value) | Num. (%) | Univariate OR (p-value) |
| Non-medical      |           |                         |           |                         |
| Deprivation      |           |                         |           |                         |
| 1 – most         | 2,205 (28.9)| 79 (3.6) | 1 | 157 (7.1) | 1 | |
| 2                | 1,563 (20.5)| 51 (3.3) | 0.91 (0.60) | 104 (6.7) | 0.93 (0.58) | |
| 3                | 1,242 (16.3)| 41 (3.3) | 0.92 (0.66) | 77 (6.2) | 0.86 (0.30) | |
| 4                | 1,078 (14.1)| 38 (3.5) | 0.98 (0.93) | 79 (7.3) | 1.03 (0.83) | |
| 5 – least        | 1,085 (14.2)| 23 (2.1) | 0.58 (0.02) | 64 (5.9) | 0.82 (0.19) | |
| Missing          | 470 (6.2) | - | - | - | - | |
| Ethnicity        |           |                         |           |                         |
| White            | 5,728 (75.0)| 166 (2.9) | 1 | 348 (6.1) | 1 | |
| Mixed            | 196 (2.6) | 4 (2.0) | 0.70 (0.48) | 9 (4.6) | 0.74 (0.39) | |
| Asian            | 867 (11.3) | 38 (4.4) | 1.54 (0.02) | 73 (8.4) | 1.42 (< 0.01) | |
| Black            | 345 (4.5) | 12 (3.5) | 1.21 (0.54) | 34 (9.9) | 1.69 (< 0.01) | |
| Chinese          | 28 (0.4) | 3 (3.6) | 1.24 (0.83) | 1 (3.6) | 0.57 (0.59) | |
| Other            | 133 (1.7) | 12 (9.0) | 3.32 (< 0.001) | 19 (14.3) | 2.58 (< 0.001) | |
| Not stated       | 346 (4.5) | 13 (3.8) | 1.31 (0.36) | 30 (8.7) | 1.47 (0.05) | |
| Pre-operative    |           |                         |           |                         |
| Cardiac diagnosis group | | | | | | |
| VSD              | 1348 (17.6)| 25 (1.9) | 1 | 60 (4.5) | 1 | |
| HLHS             | 390 (5.1) | 48 (12.3) | 7.43 (< 0.001) | 70 (18.0) | 4.70 (< 0.001) | |
| UVH/PA           | 531 (7.0) | 41 (7.7) | 4.43 (< 0.001) | 73 (13.8) | 3.42 (< 0.001) | |
| Other            | 5374 (70.3) | 132 (2.5) | 1.33 (0.19) | 311 (5.8) | 1.32 (0.06) | |
| Acquired diagnosis | | | | | | |
| Yes              | 479 (6.3) | 25 (5.2) | 1.73 (0.01) | 57 (11.9) | 1.98 (< 0.001) | |
| No               | 7164 (93.7)| 221 (3.1) | 1 | 457 (6.4) | 1 | |
| Specific procedure group | | | | | | |
|                      |   |     |     |    |     |
|----------------------|---|-----|-----|----|-----|
| **Corrective**       | 4973 (65.1) | 86 (1.7) | 1   | 219 (4.4) | 1   |
| **Palliative**       | 1629 (21.3) | 119 (7.3) | 4.48 (< 0.001) | 205 (12.6) | 3.13 (< 0.001) |
| **Ungrouped**        | 1041 (13.6) | 41 (3.9) | 2.33 (< 0.001) | 90 (8.7) | 2.05 (< 0.001) |
| **Congenital anomaly** | Yes | 1608 (21.0) | 90 (5.6) | 2.23 (< 0.001) | 209 (13.0) | 2.81 (< 0.001) |
|                      | No  | 6035 (79.0) | 156 (2.6) | 1 | 305 (5.1) | 1 |
| **Neurodevelopment condition** | Yes | 307 (4.0) | 27 (8.8) | 3.13 (< 0.001) | 75 (24.4) | 5.08 (< 0.001) |
|                      | No  | 7336 (96.0) | 219 (3.0) | 1 | 439 (6.0) | 1 |
| **Prematurity**      | Yes | 828 (10.8) | 44 (5.3) | 1.59 (< 0.01) | 93 (11.2) | 1.63 (< 0.001) |
|                      | No  | 4714 (61.7) | 161 (3.4) | 1 | 340 (7.2) | 1 |
| **Gender**           | Male | 4232 (55.4) | 114 (3.4) | 1 | 302 (7.1) | 1 |
|                      | Female | 3410 (44.6) | 102 (3.0) | 0.88 (0.31) | 212 (6.2) | 0.86 (0.11) |
|                      | Not known | 1 (0.0) | - | - | - | - |
| **Age at index procedure** (continuous) | Med. 64 days | Not shown | 0.99 (< 0.001) | Not shown | 0.99 (< 0.001) |
|                      | IQR (11,153) | Not shown | 1.02 (0.69) * | Not shown | 0.95 (0.13) * |
| **Weight-for-age Z-score** (continuous) | Med. -1.7 | Not shown | 2.04 (< 0.001) | 219 (10.2) | 2.03 (< 0.001) |
|                      | IQR (-2.8,-0.6) | Not shown | 2.29 (< 0.001) | 154 (10.5) | 1.89 (< 0.001) |
|                      | Missing | 528 | Not shown | Not shown | Not shown | Not shown |
| **Antenatal diagnosis** | Yes | 2146 (8.1) | 105 (4.9) | 2.04 (< 0.001) | 219 (10.2) | 2.03 (< 0.001) |
|                      | No  | 5046 (66.0) | 124 (2.5) | 1 | 268 (5.3) | 1 |
|                      | Missing | 451 (5.9) | - | - | - | - |
| **Clinical deterioration** | Yes | 1469 (19.2) | 85 (5.8) | 2.29 (< 0.001) | 154 (10.5) | 1.89 (< 0.001) |
|                      | No  | 6174 (80.8) | 161 (2.6) | 1 | 36 (0.8) | 1 |
| **Post-operative**    | Med. 10 days | Not shown | (< 0.001) | Not shown | (< 0.001) |
|                      | IQR (7, 17) | Not shown | (< 0.001) | Not shown | (< 0.001) |
| **Additional surgical procedures** | Yes | 414 (5.4) | 23 (5.6) | 1.85 (< 0.01) | 54 (13.0) | 2.21 (< 0.001) |
|                      | No  | 7229 (94.6) | 223 (3.1) | 1 | 460 (6.4) | 1 |
| **Additional catheter procedures** | Yes | 577 (7.6) | 16 (2.8) | 0.85 (0.53) | 32 (5.6) | 0.80 (0.24) |
|                      | No  | 7066 (92.4) | 230 (3.3) | 1 | 482 (6.8) | 1 |
| **Need for renal support** | Yes | 522 (6.8) | 31 (5.9) | 1.99 (<0.01) | 57 (10.9) | 1.82 (< 0.001) |
|                      | No  | 6721 (87.9) | 207 (3.1) | 1 | 425 (6.3) | 1 |
|                      | Missing | 400 (5.2) | - | - | - | - |
| **Need for ECMO**     | Yes | 64 (0.8) | 5 (7.8) | 2.53 (0.05) | 9 (14.1) | 2.32 (0.02) |
|                      | No  | 7290 (95.4) | 236 (3.2) | 1 | 480 (6.6) | 1 |
|                      | Missing | 289 (3.8) | - | - | - | - |
| **Acquired comorbidity** | Yes | 1481 (19.4) | 84 (5.7) | 2.19 (< 0.001) | 165 (11.1) | 2.15 (< 0.001) |
|                      | No  | 5918 (77.4) | 158 (2.7) | 1 | 326 (5.5) | 1 |
|                      | Missing | 244 (3.2) | - | - | - | - |
### Adverse event in PICU

|       | Num. (%) total | Num. (%) fatal adverse events only | Num. (%) all adverse events |
|-------|----------------|-----------------------------------|---------------------------|
| Yes   | 634 (8.3)      | 47 (7.4)                          | 89 (14.0)                 |
| No    | 6765 (88.5)    | 195 (2.9)                         | 402 (5.9)                 |
| Missing | 244 (3.2)   | -                                 | -                         |

### Post-op morbidity

|       | Num. (%) total | Num. (%) fatal adverse events only | Num. (%) all adverse events |
|-------|----------------|-----------------------------------|---------------------------|
| Yes   | 113 (1.5)      | 9 (8.0)                           | 17 (15.0)                 |
| No    | 7530 (98.5)    | 237 (3.2)                         | 497 (6.6)                 |

PICU = paediatric intensive care unit; IQR = interquartile range; ECMO = extracorporeal membrane oxygenation; HLHS = hypoplastic left heart syndrome; UVH = functionally univentricular heart; PA = pulmonary atresia; VSD = Ventricular septal defect.

* Weight-for-age z-score (continuous) showed no univariate association with either outcome but was nonetheless taken forward to the multivariable analyses.

Details regarding the categorization of age at procedure, weight-for-age z-score and length of stay are presented below: these were initially continuous variables that were categorised due to considerations of potential model usability and clinical face validity. The observed numbers of patients and rate of fatal adverse events and all adverse events in the dataset in each category are shown for each categorized variable.

| Age at index procedure | Num. (%) overall | Num. (%) Fatal adverse events only | Num. (%) All adverse events |
|------------------------|------------------|-----------------------------------|---------------------------|
| > 3 months old         | 3202 (41.9)      | 55 (1.7)                          | 129 (4.0)                 |
| 1-2 months old         | 1427 (18.7)      | 45 (3.2)                          | 110 (7.7)                 |
| 10-30 days             | 1114 (14.6)      | 43 (3.9)                          | 90 (8.1)                  |
| 0-10 days old          | 1900 (24.9)      | 103 (5.4)                         | 185 (9.7)                 |

| Weight-for-age z-score | Num. (%)          | Num. (%) Fatal adverse events only | Num. (%) All adverse events |
|------------------------|-------------------|-----------------------------------|---------------------------|
| >-2SD                  | 4064 (53.2)       | 128 (3.1)                         | 243 (6.0)                 |
| -2 to -4 SD            | 2467 (32.3)       | 71 (2.9)                          | 168 (6.8)                 |
| <-4SD                  | 584 (7.6)         | 19 (3.3)                          | 50 (8.6)                  |
| Missing                | 528 (6.9)         | 28 (5.3)                          | 53 (10.0)                 |

| Length of stay         | Num. (%)          | Num. (%) Fatal adverse events only | Num. (%) All adverse events |
|------------------------|-------------------|-----------------------------------|---------------------------|
| 0-7 days               | 2564 (33.5)       | 35 (1.4)                          | 84 (3.3)                  |
| 7-30 days              | 4327 (56.6)       | 146 (3.4)                         | 302 (7.0)                 |
| > 1 month              | 752 (9.8)         | 65 (8.6)                          | 128 (17.0)                |

**Multiple imputation results**

For both outcomes there was very little difference in the significance of risk factors between the imputed data sets; there was a clear set of significant factors (p < 0.01) with an inclusion frequency of 100% and a clear set of factors that did not reach statistical significance with an inclusion frequency of 0%. For fatal adverse events only there were two factors (prematurity and acquired diagnosis) and for all adverse events three factors (prematurity, antenatal diagnosis and clinical deterioration) that were borderline significant, with an inclusion frequency of approximately 50%. These borderline risk factors were investigated further along with the set of significant risk factors and only prematurity remained statistically significant. The Multiple Imputation suite of programs in Stata was used to conduct the imputation analysis.
Continuous logistic regression models

Details of the continuous regression model for fatal adverse events only (death within 1-year following discharge from the index admission and not during a planned admission) are shown below. For each patient variable the number (percentage) of fatal adverse events, multivariable odds ratios, standard errors and 95% confidence intervals are presented and the reference category indicated. The overall number (percentage) of patients within each category for a given patient variable is also noted. HLHS = hypoplastic left heart syndrome; UVH = functionally univentricular heart; PA+IVS = pulmonary atresia with an intact ventricular septum; VSD = ventricular septal defect. † Log transformation ‡ Fractional polynomial transformation.

| Patient variable          | Overall number (%) | Number (%) fatal adverse events | OR      | S.E. | 95% CI |
|---------------------------|--------------------|--------------------------------|---------|------|--------|
| **Ethnicity**             |                    |                                |         |      |        |
| White                     | 5,728 (75.0)       | 166 (2.9)                      | Reference category |
| Mixed                     | 196 (2.6)          | 4 (2.0)                        | 0.69     | 0.36 | 0.25   | 1.91   |
| Asian                     | 867 (11.3)         | 38 (4.4)                       | 1.38     | 0.26 | 0.95   | 2.01   |
| Black                     | 345 (4.5)          | 12 (3.5)                       | 0.98     | 0.31 | 0.53   | 1.83   |
| Chinese                   | 28 (0.4)           | 3 (3.6)                        | 1.61     | 1.68 | 0.21   | 12.46  |
| Other                     | 133 (1.7)          | 12 (9.0)                       | 2.97     | 0.99 | 1.54   | 5.73   |
| Not stated                | 346 (4.5)          | 13 (3.8)                       | 1.49     | 0.46 | 0.82   | 2.71   |
| **Cardiac diagnosis group**|                    |                                |         |      |        |
| VSD                       | 1348 (17.6)        | 25 (1.9)                       | Reference category |
| HLHS                      | 390 (5.1)          | 48 (12.3)                      | 2.70     | 0.86 | 1.45   | 5.04   |
| UVH or PA+IVS             | 531 (7.0)          | 41 (7.7)                       | 2.29     | 0.68 | 1.28   | 4.11   |
| Other                     | 5374 (70.3)        | 132 (2.5)                      | 1.14     | 0.27 | 0.72   | 1.80   |
| **Specific procedure group**|                    |                                |         |      |        |
| Corrective                | 4973 (65.1)        | 86 (1.7)                       | Reference category |
| Palliative                | 1629 (21.3)        | 119 (7.3)                      | 2.15     | 0.39 | 1.51   | 3.06   |
| Ungrouped                 | 1041 (13.6)        | 41 (3.9)                       | 1.78     | 0.36 | 1.20   | 2.64   |
| **Congenital anomaly**    |                    |                                |         |      |        |
| No                        | 6035 (79.0)        | 156 (2.6)                      | Reference category |
| Yes                       | 1608 (21.0)        | 90 (5.6)                       | 2.29     | 0.35 | 1.70   | 3.09   |
| **Prematurity**           |                    |                                |         |      |        |
| No                        | 4714 (61.7)        | 161 (3.4)                      | Reference category |
| Yes                       | 828 (10.8)         | 44 (5.3)                       | 1.55     | 0.28 | 1.09   | 2.20   |
| **Clinical deterioration**|                    |                                |         |      |        |
| No                        | 6174 (80.8)        | 161 (2.6)                      | Reference category |
| Yes                       | 1469 (19.2)        | 85 (5.8)                       | 1.59     | 0.23 | 1.19   | 2.12   |
| **Age at index procedure**| †                   |                                |         |      |        |
|                           |                    |                                | 0.77     | 0.05 | 0.68   | 0.87   |
| **Weight-for-age z-score**|                    |                                | 0.83     | 0.05 | 0.74   | 0.92   |
| **Index length of stay**  | ‡                   |                                | 3239     | 4361 | 231    | 45332  |
| First degree of polynomial|                    |                                | 0.00     | 0.00 | 0.00   | 0.00   |
Details of the continuous regression model for all adverse events (either death or an emergency unplanned readmission to PICU within 1-year following discharge from the index admission) are shown below. For each patient variable the number (percentage) of adverse events, the multivariable odds ratios, standard errors and 95% confidence intervals are presented and the reference category indicated. The overall number (percentage) of patients within each category for a given patient variable is also noted.

HLHS = hypoplastic left heart syndrome; UVH = functionally univentricular heart; PA+IVS = pulmonary atresia with an intact ventricular septum; VSD = ventricular septal defect.

† Log transformation ‡Fractional polynomial transformation.

| Patient variable                  | Overall number (%) | Number (%) adverse events | OR   | S.E.   | 95% CI |
|-----------------------------------|--------------------|--------------------------|------|--------|--------|
| Ethnicity                         |                    |                          |      |        |        |
| White                             | 5,728 (75.0)       | 348 (6.1)                | Reference category |
| Mixed                             | 196 (2.6)          | 9 (4.6)                  | 0.64 | 0.23   | 0.32   | 1.31   |
| Asian                             | 867 (11.3)         | 73 (8.4)                 | 1.22 | 0.18   | 0.92   | 1.62   |
| Black                             | 345 (4.5)          | 34 (9.9)                 | 1.40 | 0.29   | 0.94   | 2.09   |
| Chinese                           | 28 (0.4)           | 1 (3.6)                  | 0.70 | 0.72   | 0.09   | 5.32   |
| Other                             | 133 (1.7)          | 19 (14.3)                | 2.52 | 0.68   | 1.48   | 4.29   |
| Not stated                        | 346 (4.5)          | 30 (8.7)                 | 1.71 | 0.36   | 1.13   | 2.58   |
| Cardiac diagnosis group           |                    |                          |      |        |        |
| VSD                               | 1348 (17.6)        | 60 (4.5)                 | Reference category |
| HLHS                              | 390 (5.1)          | 70 (18.0)                | 2.08 | 0.49   | 1.31   | 3.30   |
| UVH or PA+IVS                     | 531 (7.0)          | 73 (13.8)                | 2.06 | 0.44   | 1.35   | 3.14   |
| Other                             | 5374 (70.3)        | 311 (5.8)                | 1.18 | 0.19   | 0.87   | 1.61   |
| Specific procedure group          |                    |                          |      |        |        |
| Corrective                        | 4973 (65.1)        | 219 (4.4)                | Reference category |
| Palliative                        | 1629 (21.3)        | 205 (12.6)               | 1.72 | 0.22   | 1.34   | 2.22   |
| Ungrouped                         | 1041 (13.6)        | 90 (8.7)                 | 1.62 | 0.22   | 1.24   | 2.13   |
| Congenital anomaly                |                    |                          |      |        |        |
| No                                | 6035 (79.0)        | 305 (5.1)                | Reference category |
| Yes                               | 1608 (21.0)        | 209 (13.0)               | 2.62 | 0.28   | 2.12   | 3.24   |
| Neurodevelopment condition        |                    |                          |      |        |        |
| No                                | 7336 (96.0)        | 439 (6.0)                | Reference category |
| Yes                               | 307 (4.0)          | 75 (24.4)                | 2.71 | 0.43   | 1.99   | 3.69   |
| Prematurity                       |                    |                          |      |        |        |
| No                                | 4714 (61.7)        | 340 (7.2)                | Reference category |
| Yes                               | 828 (10.8)         | 93 (11.2)                | 1.50 | 0.20   | 1.15   | 1.95   |
| Acquired diagnosis                |                    |                          |      |        |        |
| No                                | 7164 (93.7)        | 457 (6.4)                | Reference category |
| Yes                               | 479 (6.3)          | 57 (11.9)                | 1.76 | 0.28   | 1.28   | 2.41   |
| Age at index procedure†           |                    |                          |      |        |        |
| Weight-for-age z-score            |                    |                          |      |        |        |
| Index length of stay‡             |                    |                          |      |        |        |

First degree of polynomial         -                   -                  2254 2151 347 14633
Second degree of polynomial        -                   -                  0.00 0.00 0.00 0.00
Supplemental References

1. IPCC (2012) International Paediatric and Congenital Cardiac Code (IPCCC) Home Page. Available: www.ipccc.net. Accessed 12 April 2012.

2. Harrell FE, Lee KL, Califf RM, Pryor DB, Rosati RA (1984) Regression modelling strategies for improved prognostic prediction. Stat Med 3: 143–152.

3. LHO (2011) English Indices of Deprivation 2010 - deprivation category lookups and average scores for higher geographies. Available: http://www.apho.org.uk/resource/view.aspx?RID=111277. Accessed 13 February 2015.

4. Office for National Statistics (2011) Guidance and methodology: Ethnic group. Available: http://ons.gov.uk/ons/guide-method/measuring-equality/equality/ethnic-nat-identity-religion/ethnic-group/index.html#1. Accessed 13 February 2015.

5. Brown K, Wray J, Knowles R, Crowe S, Tregay J, et al. (2015) Project grant report: Infant deaths in the UK community following successful cardiac surgery - building the evidence base for optimal surveillance.

6. Brown KL, Crowe S, Pagel C, Bull C, Muthialu N, et al. (2013) Use of diagnostic information submitted to the United Kingdom Central Cardiac Audit Database: development of categorisation and allocation algorithms. Cardiol Young 23: 491–498. doi:10.1017/S1047951112001369.

7. Health and Social Care Information Centre (n.d.) Read codes. Available: https://isd.hscic.gov.uk/trud3/user/guest/group/0/home. Accessed 18 December 2014.