DETAILED PROJECT DESCRIPTION

Improving risk adjustment in the PRAiS model for mortality after paediatric cardiac surgery and improving public understanding of its use in monitoring outcomes.

SUMMARY OF RESEARCH

BACKGROUND

In a previous NIHR HSDR project, we developed a risk model for the purpose of routine local in-house monitoring of risk-adjusted 30-day outcomes within UK paediatric cardiac surgical units (1,2). The PRAiS (Partial Risk Adjustment in Surgery) model incorporates information on the procedure performed, diagnosis, the number of functioning ventricles, age, weight and comorbidity. A comorbidity is any other health problem a patient has alongside their cardiac condition (e.g. prematurity, renal problems, genetic abnormalities). Because of issues around completeness and quality in the dataset used for model development, our treatment of comorbidity had to be simplistic.

Clinical teams are now using software that implements the PRAiS model (3) to monitor outcomes on a regular basis, the National Institute of Cardiovasular Outcomes Research (NICOR) use it in their audit work (4) and its use has been adopted as a quality standard by NHS England. In our visits to surgical units to support them in using PRAiS, the importance of accounting for comorbidity in more detail was stressed and teams were very supportive of us revisiting this aspect of the model once better and more complete data were available.

The availability of PRAiS triggered events resulting in the temporary suspension of surgery at one unit and a consequent drive to improve data completeness at all units. The media scrutiny and public anger that surrounded this service suspension illustrated the need for additional public resources to support appropriate interpretation of outcome data.

AIMS AND OBJECTIVES

We aim to

1. improve the PRAiS risk model for 30-day mortality following paediatric cardiac surgery by incorporating more detailed information about comorbid conditions.

2. develop resources for families, the public and the media to support interpretation of mortality data.

To achieve **aim 1** we will:

1.1 revisit with better data the potential for using within PRAiS comorbidity groups devised but ultimately not used during the original PRAiS study; **1.2** modify or refine these comorbidity groups and explore options for changing our handling of procedure and diagnostic data; and **1.3** assign individual comorbidity codes to the agreed comorbidity groups and devise an algorithm for usefully combining multiple comorbidities.

We will then: **1.4** explore trade-offs between the detail used for procedural, diagnostic and comorbidity information within PRAiS while maintaining a robust calibration; **1.5** calibrate a new version of the PRAiS risk model, after deciding on the final risk factors by consideration of statistical goodness of fit and clinical face validity; and **1.6** update the PRAiS software with the new parameterisation.

To achieve **aim 2** we will:

2.1 confirm our understanding of the current and planned presentations of mortality data in national audit; **2.2** co-produce with users a web-tool to facilitate interpretation of mortality outcomes in the formats

established at 2.1; **2.3** perform a mixed-methods evaluation of the web-tool to improve the final version **2.4** disseminate the final web-tool via the Children's Heart Federation, Sense about Science and other specialist charities and evaluate the final tool with formal experiments. The output will also be shared with the NICOR Congenital Audit.

METHODS

For **objective 1.1** we will seek to extend an existing data sharing agreement between our research team and NICOR for use of a cleaned dataset held by CORU that includes outcomes for the period 2009-12. This dataset has higher completeness and quality of comorbidity data than the dataset used for the initial PRAiS model development. We will use this dataset to perform descriptive, univariate and multivariate analyses, including logistic regression, to explore the scope for using a classification scheme developed by clinician **KB** during our initial project. This scheme classified individual comorbidity codes into six mutually exclusive groups to improve risk-adjustment. In the current version of PRAiS, these 6 groups are collapsed to 2, but the reported prevalence of comorbidity has doubled and so these 6 groups may be feasible and so a good starting place.

For **objective 1.2**, an expert advisory panel will revisit **KB**'s original classification of comorbidity, applying clinical insight but also informed by and feeding into the iterative analysis conducted for objective 1.1, including potential adaptation of the current treatment of procedure and diagnostic information. This will feed into work for **objective 1.3** where we will follow methods similar to those we adopted in the analysis, assignment and combination of diagnostic codes (5). Work on both of these objectives will benefit from the experience and insights of experienced data managers to ensure that the schemes adopted are resilient to historical centre-to-centre differences in coding practice.

For **objective 1.4**, we anticipate having access to updated NICOR data covering the period 2009-14. We will iteratively develop and assess the stable parameterisation of models that include more detailed comorbidity information using cross-validation methods (objectives **1.1**-**1.3)**. In doing so we will reduce the detail used in describing procedural data with the aim of producing a better but no less parsimonious model. Model improvement will be determined through Hosmer-Lemeshow tests of goodness of fit, analysis of deviance, information criteria and residuals, AUC analysis of discrimination and visual assessment of MADCAP charts. For objective **1.5** we will first test the model chosen at **1.4** using 5x5 cross-validation. Subject to adequate performance, we will calibrate this new version of the PRAiS model across the entire dataset. For objective **1.6**, we will encode the new parameterisation of the model in the PRAiS software, working with end users of the software to co-design any necessary changes to the current user-interface.

For **objective 2.1** we will work with **RF & KB**, chair and member of the NICOR congenital clinical steering group respectively, and use the current outcomes information available on the NICOR website (6) to confirm our understanding of the current and planned format of published results. For **objective 2.2**, we will identify and prioritise messages that would ideally be included in a web animation and accompanying text, using relevant patient feedback from a NICOR patient day (held 8 May 2014), informal feedback from parents to members of the advisory panel and working with two sets of focus groups facilitated by Sense about Science. **DS**, an international expert in the public understanding of risk, will work with **CP** and an expert in animation (**MP**), to develop a web-tool together with regular focus groups of families and other interested users throughout year 1. Concurrent with objective 2.2, for **objective 2.3** we will run formal experiments (**TR**) using methods from experimental psychology already used to assess the interpretability of funnel plots and survival curves to evaluate aspects of the developing web-tool. Insights from these experiments will be used to further improve the final tool. For **objective 2.4**, we will use the network of partners (**CHF, SaS**), strengthened through the conduct of the research, to disseminate the animation and accompanying text. We will also invite other specialist charities, individual hospitals performing paediatric heart surgery and NICOR to host or link to the material via their own websites if they wish. We will also run a final set of formal experiments (**TR**) as a global evaluation of the final tool in terms of its usability and efficacy in aiding comprehension.

PATIENT AND PUBLIC INVOLVEMENT

The involvement of patient and family groups is integral to aim 2 of this work, with families and the public involved as partners in the research, co-producing the resources that will be useful for them in interpreting risk-adjustment and national audit data on mortality following paediatric cardiac surgery. This will build on an ongoing collaboration on research to select, identify and measure the impact of important surgical morbidities in this specialty funded by NIHR HDSR (7).

DISSEMINATION

As a result of the original PRAiS project and our subsequent work, mechanisms exist for ensuring that this research is disseminated and enters into practice. All UK units performing paediatric cardiac surgery are license holders for the current version of the PRAiS software and will have access to a free download of the new version. We will publish details of the process and outcomes of the work on comorbidity in a relevant specialist journal and will make the full specification of the risk model available online.

The web animation and accompanying text to support interpretation of mortality data will be published online, with partner organisations anticipated to host the material, and surgical units performing this work invited to link to it from their own websites. Sense about Science have developed a detailed and extensive dissemination plan that will greatly enhance the web-tool's reach.

THE TEAM

The team has a mix of analytical (**CP, SC, MU**), clinical (**KB, RF, VT, DA, DB, KE, ST**), data management (**TW**, **JS**) and non-clinical (**CHF, SaS**) expertise augmented by experts in the communication and public understanding of risk (**DS, MP, TR**). We have also included the support of an expert project facilitator (**LM**) to support the development of web materials for the public (Aim 2).The chief investigator has a successful track record of working with the project partners to produce analytically sound work that is clinically relevant and subsequently adopted.

DETAILED DESCRIPTION

BACKGROUND AND RATIONALE

Why is mortality monitored and why should we try to adjust for risk?

Approximately 3500 children under the age of 16 have heart surgery each year in the United Kingdom (4). While overall 30-day survival is over 97%, congenital heart disease is a spectrum of disorders and the more serious and complex abnormalities are an important cause of childhood mortality, morbidity and disability.

Since 2000, all UK specialist centres have contributed procedure data to the National Congenital Heart Disease Audit (NCHDA), one of seven national audits with the National Institute of Cardiovascular Outcomes Research (NICOR). Life status is independently obtained from the Office of National Statistics (ONS) and where no ONS tracking available (less than 5% of cases (1,2)), discharge status is used instead and checked with individual units. Centre specific mortality outcomes for individual procedure categories have been published online since 2007 by NICOR (6).

Outcomes following children's heart surgery have long been the subject of clinical, regulatory, media and public scrutiny in the UK. Complex surgical procedures on extremely small hearts are among the most technically challenging and resource-intensive in the field. In the UK, past events (8), public inquiries (9,10) and plans to reduce the number of centres performing such surgery (11) provide a rich source of back-stories and a level of public awareness that makes this specialty ripe for comment and journalism. Mortality

has understandably always been the dominant reported outcome and is often perceived as a straightforward measure of performance by the media and public.

In publishing their outcomes, there is a reasonable expectation from the paediatric cardiac profession that audit will be "fair" to clinical teams. That is, the reporting of outcomes should take account of the hugely diverse set of diagnoses and comorbid conditions that patients present with, the wide range of the surgical procedures performed, differences in case mix between centres and the impact of relatively small numbers of patients on what can reliably be inferred from data. These characteristics of the specialty make risk adjustment in the presentation of outcomes analysis essential, but they also make it very difficult to achieve.

Until recently, the only risk adjustment method easily available to NICOR was to report mortality within procedure categories, thus partially accounting for variations in case mix. One example is the arterial switch operation, a definitive surgical procedure to repair the heart when the main artery and vein connections to the heart are the opposite of what they should be. The structure of such hearts can vary drastically from a "simple" isolated inversion of the great arteries to a complex physiology with several accompanying abnormalities. A child may also have additional non-cardiac problems and / or an underlying chromosomal abnormality. These sorts of issues highlight the importance of incorporating case mix into interpreting observed short-term outcomes following heart surgery in children beyond consideration of the procedure performed (11).

Why did we develop the PRAiS risk model?

There have been several models aiming to incorporate risk assessment into outcome measures. In the early 2000's the Risk Adjustment for Congenital Heart Surgery (RACHS-1) score was introduced (12). This method gathered a panel of experts, who assigned patients to one of six predefined risk categories on the basis of the presence or absence of specific diagnosis and procedure codes. Cases with combinations of cardiac surgical procedures are placed in the category of the highest risk procedure. Around the same time, the Aristotle tool (13) emerged to evaluate quality of care based on complexity of the operation and specific patient characteristics. Based also on a review by a panel of experts, Aristotle gives a precise score for the complexity of 145 specific paediatric cardiac operations. Both RACHS-1 and Aristotle are examples of "consensus-based", subjective, risk stratification tools, essentially meaning that experts have sat down and decided how a particular operation compares with others in terms of risk, which for these systems is usually considered synonymous with complexity. While certainly valuable and useful, these methods have started to give way to recent empirical approaches, based on the emerging availability of databases incorporating the outcomes of tens of thousands of patients. The Society of Thoracic Surgeons-European Association of Cardiothoracic Surgery (STS-EACTS) score (14) or STAT-score, introduced in 2009 was based on data from over 75,000 paediatric cardiac surgery procedures performed between 2002 and 2007 in Europe and North America and was an important step towards monitoring mortality, as clinical teams could benchmark current outcomes against achieved outcomes in the recent past.

None of the above risk models are easy to use in the routine monitoring of outcomes using UK national audit data, none were calibrated on UK data and they all mainly used procedure information. In our previous NIHR HSDR funded project which ended in 2011 (NIHR HSDR 09/2001/13), we (VT, KB, MU, CP, SC) developed a new risk model for 30-day outcome after paediatric cardiac surgery, referred to as PRAiS (Partial Risk Adjustment in Surgery) (1,2). This empirical model was developed for the purpose of routine local in-house monitoring of risk-adjusted outcomes within UK paediatric cardiac surgical units, and incorporated not only the procedure but also cardiac diagnosis, the number of functioning ventricles, age category (neonate, infant, child) as well as continuous age, continuous weight, presence of a non-Down syndrome comorbidity and whether surgery was performed on cardiopulmonary bypass. The model was developed using data from all paediatric cardiac surgery procedures performed in the United Kingdom between 2000 and 2010 and in validation compared well with RACHS-1, Aristotle and the STS-EACTS Score. The intention was that by facilitating local routine monitoring, units could regularly examine their recent outcomes (with a time lag of 30 days), compared to the annual results published by NICOR which could represent a time lag of up to 18 months.

What happened with PRAiS after the end of the original NIHR grant?

Following the development of the PRAiS risk model, several units expressed an interest in piloting the model for in-house routine monitoring of outcomes. In 2012, the analytical team at the UCL Clinical Operational Research Unit (CORU) (CP, MU, SC) worked with Great Ormond Street Hospital, Evelina London Children's Hospital and Glasgow Royal Hospital for Sick Children in a pilot study to implement the new risk model. We developed prototype software to allow units to use their own routinely collected data to produce Variable Life-Adjusted Display (VLAD) charts (15,16) for 30-day mortality after children's heart surgery after partial risk adjustment with PRAiS. The software was co-designed with the clinical teams to be robust, easy to use and to produce output that was helpful for team discussion of outcomes. The advantage of using VLAD charts is that they show the accumulation of outcomes over time, allowing trends in outcomes (both negative and positive) to be spotted quickly and discussed.

The pilot study was successful (3) with the pilot units keen to continue using the software and other units also showing an interest. As a result, the team at UCL CORU decided to further develop the software that implements PRAiS into a package that could be rolled out across the UK. This involved including comprehensive error checking of any entered data, further work on the software in response to feedback from pilot units, development of user manuals and recalibration of the PRAiS risk model on all national data from 2007-2010 in part to address an observed imbalance in neonatal outcomes in the original development and validation datasets (2). The software to implement PRAiS was licenced by UCL Business in April 2013 and licences were purchased by NICOR with funding from NHS England for all English hospitals that perform children's heart surgery and the NICOR congenital heart audit itself. All units that contribute data to NICOR's congenital heart audit now possess licenced copies of the PRAiS software.

In the following 6 months, all English hospitals downloaded the software to implement PRAiS and it was also used by NICOR to include risk adjustment in the reporting of national outcomes for the first time (4). An important part of the software licence was the inclusion of a half-day consultancy visit to units, not only to discuss practical use of the software but also, and more importantly in the analytical team's view, the caveats of using risk adjustment to monitor outcomes. As the PRAiS model began to be used to monitor outcomes both locally within units and nationally as part of NICOR's audit, data quality for information previously collected but not actively used (like comorbidity and diagnosis codes) improved rapidly (and retrospectively as recent data was revisited by hospitals back to 2009). In particular, the proportion of surgical episodes with a recorded comorbidity (excluding Down syndrome) doubled from 15% (2000-10 original dataset) to 30% of cases. It also appeared that national outcomes between 2009 and 2012 had improved (4) since the time period the PRAiS risk model was calibrated on (2007-10). In July 2013, at NICOR's request, CORU analysts (CP,SC) recalibrated the risk model on the 2009-12 dataset (but leaving the risk factors identified in the original development process (1,2) unchanged) and updated the software to implement the model (17). These changes are documented on CORU's website: https://www.ucl.ac.uk/operational-research/AnalysisTools/PRAiS.

Where next for the PRAiS risk model?

Data completeness and quality for comorbidity information in the original 2000-10 dataset used to develop PRAiS was poor. Although we explored different methods for incorporating information about different types of comorbidity and multiple comorbidity as part of our original project, none of the models using such methods proved to be robust (1). Faced with the choice of excluding comorbidity entirely as a risk factor or using a very crude measure of comorbidity as a "yes/no" variable, we chose the latter. This was because the definite presence of at least one non-Down syndrome comorbidity was significantly associated with mortality in multivariate analysis, comorbidity was considered extremely important in risk adjustment by clinical collaborators (VT, KB) and it was hoped that inclusion of the crude risk factor would drive future improvement in data quality concerning comorbidities (1,2).

Our consultancy visits to English hospitals with the PRAiS software are now complete. Feedback on the software to implement PRAiS and the usefulness of the VLAD charts has been very positive, however a consistent concern expressed during almost all visits was the treatment of comorbidity within the PRAiS risk model, highlighting its perceived importance as a risk factor. On the one hand this justified the inclusion of

comorbidity within PRAiS but on the other emphasises the need to revisit how comorbidity is incorporated within the model. The improvement in national audit data quality since 2009 (noted above) means that by 2015 there will be enough data with better quality comorbidity information to explore a more sophisticated inclusion of comorbidity within the PRAiS risk model.

We now propose to return to PRAiS model development to improve comorbidity information and improve the risk adjustment achieved through use of PRAiS in local and national audit.

Public understanding of mortality outcomes following children's heart surgery

The public and media response relating to the cessation of children's heart surgery in one unit in 2010 (18–21), the brief suspension of heart surgery in another in 2013 (22–26) and other recent coverage (27) prove the immense public interest in understanding what happens to children after heart surgery and, in particular, fears about what deaths after heart surgery mean about the care provided within units. The UK is one of the few countries that publishes mortality outcomes after children's heart surgery and NICOR's results are understandably used by journalists, politicians and the public to make judgements about whether heart surgery is 'safe' (28). Such judgements are fraught with difficulties and very stressful both for families with children who have heart disease and for the clinical teams treating these children.

Although the PRAiS risk model was originally developed for local in-house routine monitoring of outcomes, it has also been adopted by the NICOR's congenital heart audit for reporting annual outcomes for each UK centre (4). Using risk models for comparative audit is fairer than using raw mortality, but risk adjustment does not in and of itself make comparisons 'fair' (3,17). While comparing the number of deaths seen in different units seems straightforward, risk adjustment or not, unfortunately it is not that simple (whether in congenital audit or elsewhere) (17,29,30). We have written on the difficulties of interpreting comparative mortality data using PRAiS (3,17,31) and the NICOR Congenital Audit has also written resources for the public on its public portal (32), however these sources are not easily found without prior knowledge of their existence and are not necessarily easily digested by the non-expert.

We believe that there is a real need to firstly develop better resources for the public about how to interpret evidence on mortality following children's heart surgery and secondly to disseminate these resources widely. We have the enthusiastic support of charities the Children's Heart Federation (a user group for families with children with heart disease) and Sense about Science (a charity dedicated to the public understanding of science and evidence). The second strand of our proposed project will develop a video animation on the interpretation of mortality outcomes for the public with help and user input from both charities.

What our proposed research adds

The PRAiS risk model and the software to implement it is already helping quality improvement initiatives within UK hospitals and is being used by NICOR as part of its audit process.

Using more detailed comorbidity information within PRAiS could strengthen local quality improvement by providing better information to teams during regular monitoring of their own outcomes. There will also be the potential for teams to examine their outcomes within comorbidity and diagnostic groups (facilitated by the PRAiS software) that could provide a richer understanding of their service, further driving improvement.

Given the use of the PRAiS risk model for comparison of units in national audit, better incorporation of comorbidity within the risk model will allow for fairer comparisons given known variations in case mix with respect to comorbidity between units, although the intrinsic limitations of risk adjustment for comparison still hold (17).

These limitations to the use of PRAiS (or any risk adjustment) for comparison of units and in the publication of outcomes are important to understand, especially given continued media and public interest in outcomes after children's heart surgery. Better resources specifically aimed at the public will allow for better public debate about how outcomes are measured in the UK and what they can (and cannot) say about quality of care. These resources will be relevant to outcomes beyond paediatric cardiac surgery and could certainly

help public response to the current drive for greater transparency in surgical outcomes across clinical specialities (33).

WHY THIS RESEARCH IS NEEDED NOW

Within two years of the initial development of the PRAiS risk model, it is being used to monitor outcomes both locally and nationally. Clinical teams have consistently communicated to the analytical team at CORU that they would like more sophisticated incorporation of comorbid information within the next iteration of the PRAiS risk model. Meanwhile, data quality in the factors used for risk adjustment, particularly comorbidity, has improved markedly in the last year (see methods for objective 1.1 for details), so that clinical concerns about comorbidity within risk adjustment can now be addressed.

The new use of PRAiS in national audit, the continuing media scrutiny of outcomes and ongoing discussions about whether to consolidate paediatric heart surgery services in fewer, bigger, units (34) all require better informed public debate on what mortality outcomes can be used for, what they mean and, just as importantly, what they do not mean. A public resource on the interpretation of outcome data could help families who are using children's heart services, journalists who are writing about them and members of the public who read about them.

AIMS AND OBJECTIVES

Aim 1: Improve the PRAiS risk model for 30-day mortality following paediatric cardiac surgery by incorporating more detailed information about comorbid conditions.

Aim 2: Develop, test, and disseminate online resources for families affected by congenital heart disease in children, the public and the media to facilitate appropriate interpretation of published mortality data following paediatric cardiac surgery.

Objectives to achieve Aim 1:

1.1 Explore the relationship between the existing six comorbidity groupings (defined as part of the original risk model development process (1) but not included in final model) and mortality, both in the presence and absence of other risk factors and consequent potential impact on the robustness of the PRAiS risk model.

1.2 Decide on the suitability of existing comorbidity groups in light of initial exploratory analysis, devise any necessary modifications and consider options for changing current groupings of specific procedure and diagnosis categories, with expert input from clinicians and data managers from multiple centres.

1.3 Modify the existing mapping of individual comorbidity codes to broader comorbidity categories and to a single 30-day patient episode with expert clinical input.

1.4 Explore trade-offs in reducing detail in existing risk factors (e.g. specific procedure categories) to incorporate new comorbidity categories within the PRAiS risk model while maintaining a robust calibration.

1.5 Calibrate a new PRAiS risk model, after deciding on the final risk factors by consideration of statistical goodness of fit and clinical face validity.

1.6 Update the software that implements PRAiS with the new parameterisation.

Objectives for Aim 2:

2.1 Confirm our understanding of the current and planned presentations of mortality outcome data by the NICOR congenital audit.

2.2 Co-produce a web-tool with patient groups and interested users that includes an explanatory website, an interactive animation and a short video to facilitate the interpretation of mortality outcomes.

2.3 Undertake a formative mixed-methods evaluation of the web-tool to strengthen the final outputs.

2.4 Disseminate the developed material via the Children's Heart Federation and Sense about Science and evaluate the usability and efficacy of the final web-tool as an aid to the public understanding of outcome data. Additionally share the material with other charities such as the British Heart Foundation and also with the NICOR Congenital Audit.

METHODS

In this interdisciplinary project involving analysts from University College London, an expert panel drawn from 5 UK paediatric cardiac surgery units, experts in the public communication of risk at the University of Cambridge and King's College London, two charities and an independent expert project facilitator we shall achieve aims 1 and 2 as follows:

AIM 1

Data for Aim 1

The analysts at CORU currently have a data sharing agreement in place with NICOR to analyse the national UK audit dataset from April 2009 to March 2012 for the purpose of recalibration of the PRAiS risk model. We will seek to extend this data sharing agreement to allow us to use the existing dataset held by CORU to carry out exploratory development work for objectives 1.1 and 1.2 if we do not yet have access to an updated dataset. This dataset has already been cleaned as part of the recalibration exercise. We note that this dataset does not contain any information about which units procedures were performed in and so we shall seek additional data sharing agreements with participating hospitals (Great Ormond Street, Evelina London, Royal Brompton, Birmingham and Leeds) to investigate variation in comorbidity coding within hospitals. We would not require information about life status for this purpose.

On confirmation of award of NIHR funding, we will submit a new data application to NICOR for the national dataset covering the period April 2009 to March 2014 (or later if more recent data have been validated). Given existing data sharing agreements, the potential benefit of improved risk adjustment for NICOR's audit mandate and co-applicant Dr Franklin's role as Clinical Lead for NICOR's congenital audit, we expect that this application would be successful. We will use this dataset to address objectives 1.4 to 1.6.

Note that on receipt of an updated dataset, some time will be spent cleaning the dataset and checking for inconsistencies (using the cleaning done as part of the original project as a template). This will include:

- Checking completeness of weight information and imputing missing weights using average weight-for-age bands;
- Checking for infeasible weight/age combinations (in discussion with KB as in the original project (1));
- Checking diagnosis, procedure and comorbidity codes that are incomplete or not recognised as valid EPCC codes;
- Checking that age and other information is consistent with patient IDs (errors in hospital numbers can become hard to spot once IDs have been pseudonymised);
- Checking for any records that are likely to be duplicates;

- Checking that dates are consistent, i.e. that dates of birth, procedure and death are in the correct sequence;
- Checking that no patient has more than one date of death.

Objective 1.1: Explore the relationship between existing comorbidity groupings and mortality (Months 1 to 3)

During the original project, Dr Kate Brown assigned each EPCC comorbidity code to one of six broader comorbidity categories: Normal, Congenital Non-Downs, Downs Syndrome, Acquired comorbidity, Prematurity and Unclassifiable.

Using all of these groups within the original development of PRAiS resulted in parameterisations that were not robust (1). This is likely due to two reasons: (i) the completeness of comorbidity information within the original 2000-10 dataset was poor so that many episodes with no recorded comorbidity do not in fact correspond to the absence of comorbidity and (ii) there were relatively few events within each comorbidity group where a comorbidity was recorded. As already mentioned, the stability of the parameterisation improved markedly when comorbidity was simply included as a binary indicator. We note that 15% of episodes in the original dataset, after 2007 (when data quality was best), were associated with at least one non-Downs comorbidity.

The existing national audit dataset held by CORU with data covering 2009-12 contains approximately 12,000 surgical 30-day episodes of care with a mortality rate of 2.6% (4) and approximately 30% of episodes are associated with at least one non-Down syndrome comorbidity. In all, over 50% of episodes were associated with at least one comorbidity of any type. Of the approximately 6,500 comorbid episodes, almost half of the first recorded comorbidities are classified as “Acquired comorbidity” while the remainder are roughly equally split between “Prematurity”, “Downs syndrome” and “Congenital Non-Downs”. Additionally, 15% of all episodes have more than one recorded comorbidity (of any type) and 6% have 3 or more comorbidities. Thus the question on how to categorise the comorbidity of these patients is not straightforward even without revisiting Dr Brown’s original classification of individual EPCC codes.

It is finally also important to recognise that given that the raw mortality rate is low (<3%), there is a practical upper limit to how many free parameters can be reasonably included in the model. Thus it is likely that a desire to include more detailed information about comorbidity will necessitate a trade-off in grouping together some other categorical risk factors, most probably the current 30 specific procedure groupings used within PRAiS.

The expert advisory panel (objective 1.2) will inform the categorisation of comorbidity information within an updated PRAiS model and also discuss any consequent trade-offs in the amount of detail included in other risk factors. However, to be able to do this they will need good information on potential categorisations of comorbidity using existing classifications.

The PRAiS1 model was validated by splitting the data into a development set (80%) and a test set (20%). All analysis was carried out on the development set, and after calibration within the development set the model was validated on the test set (1,2) and this was the original protocol for PRAiS2. However, there are inherent problems with this method of model validation. As the data is only split once, natural variation in the episodes included in the development and test set can lead to an imprecise estimate of predictive accuracy. It is also not an efficient method since 20% of the data is never used as part of model development. This happened in the validation of PRAiS1, as the mortality rate for certain specific procedures was markedly different in the development and test set. This method of validation also means that 20% of the data are not used in the development of the model and if the whole data set is used for the final model after testing, this final model has not been validated. (53) After discussion with our independent statistical expert Professor David Spiegelhalter as well two further independent statisticians, one based at the UCL Institute of Child Health

and the other within UCL Statistical Science, we have decided to use 5x5 cross-validation to develop the PRAiS2 risk model (54-56). Further details on cross-validation given are given in objective 1.4 below.

We will use the entire new 2009-2014 dataset to:

- establish frequency and mortality rates for 30-day surgical episodes with existing comorbidity groups;
- establish frequency and mortality rates for 30-day surgical episodes with different numbers of comorbidities and different combinations of comorbidity groups;
- establish frequency and mortality rates for the full list of 28 broad diagnosis groups (5), recently updated by co-applicants KB and RF;
- explore associations between comorbidities and age groups, specific procedures and diagnoses;
- explore differences in recorded comorbidity coding between centres;
- explore frequency and mortality within specific procedure, taking account of age and diagnosis to suggest possible ways of grouping some specific procedures together;
- explore robustness of parameterisation of PRAiS risk model with inclusion of existing comorbidity groups and/or number of comorbidities;
- explore robustness of parameterisation of PRAiS risk model with inclusion of more diagnosis groupings.

A summary of these analyses will be sent to members of the expert advisory panel (see 1.2 below) before the first meeting.

Objective 1.2: Decide on the suitability of existing comorbidity groups in light of initial exploratory analysis, devise any necessary modifications and consider options for changing current groupings of specific procedure and diagnosis categories, with expert input from clinicians and data managers from multiple centres (Month 4)

Comorbidities are likely to have a complex impact on risk of death, depending on number of comorbidities present, particular combinations of comorbidity, age and other covariates. It is not feasible to include all potential groupings of comorbidity information within the risk model and it is unlikely that further comorbidity information can be included without some trade-offs in the detail included for procedure. The options for dealing with comorbidity and any resultant trade-offs with specific procedure should not be decided only by the analysts (CP, MU, SC and a grade 7 research associate) but also need input from the clinical community.

The case mix of units is different not only in terms of primary cardiac diagnosis but also by pattern of comorbid conditions. It is also possible that an intensive care consultant will see the risk of comorbidity differently from a surgeon who might see it differently from a cardiologist. Additionally, each procedure can have several comorbidities entered (typically up to 8) and there may be variations in coding practice between centres. Prematurity and/or extremely low weight babies are important comorbidities and there may be scope for inferring their presence from age and weight information in the absence of relevant comorbidity codes. Thus it is crucial to have input from a range of centres, a range of clinical expertise and experienced data managers who have an excellent understanding of how comorbidities are actually coded within the data. To this end we have assembled an expert advisory panel of nine people from five centres comprising three surgeons (Victor Tsang, David Anderson and David Barron), two cardiologists (Kate English and Rodney Franklin), two intensivists (Kate Brown and Shane Tibby) and two data management experts (Thomas Witter and John Stickley).

The initial analyses performed as part of objective 1.1 will be shared in digested form with the advisory panel with potential options for grouping comorbidity highlighted. Potential updated treatment of diagnosis groups and specific procedures will also be given. The panel will then meet to discuss suggested options and potentially design new groupings. The panel will also discuss any variations in coding between centres, how these might impact on use of comorbidity as a risk factor and whether to recommend a common protocol for comorbidity coding in the future, as part of national audit. We note that although this project is independent

of the national audit body NICOR, two of the co-applicants (RF and KB) and a number of the named collaborators (KE, TW, DB) are on the steering and research committee (RF is chair) of the congenital audit.

While there is little to be done regarding data already entered if there is significant variation between units in how comorbidities are coded, it is nonetheless important to understand this variation when considering options for grouping comorbidities. For instance, some groupings might be more robust to differences in reporting than others (for instance numbers of comorbidities recorded compared to specific combinations of comorbid conditions). The opportunity for the advisory panel to meet and agree on ways forward for more uniform coding practices (if required) also facilitates future updates to PRAiS.

The result of this process will be defined strategies for:

- revisiting the assignment of individual comorbidity codes to broader comorbidity groups, updating and potentially refining the assignment developed by Kate Brown in the original NIHR project;
- a number of different options for assigning comorbidity categories to a 30-day episode, including options for taking account of numbers of comorbidities, combinations of comorbidities and other covariates such as age, weight and diagnosis;
- different options for combining some specific procedure categories;
- (potentially) different options for using more diagnostic information than the current high, medium, low risk categorisation;
- Ensuring risk adjustment is robust to any variation in coding practice between centres.
-

Objective 1.3 Modify the existing assignment of individual comorbidity codes to broader comorbidity categories and to a single 30-day patient episode with expert clinical input (Months 5 to 6)

After the initial advisory panel meeting, we anticipate that at the very least the assignment of individual comorbidity codes to comorbidity groups will have to be revisited and a scheme devised for how to assign an overall comorbidity group to a 30-day surgical episode (as in Brown et al, 2012 (5)). It is also possible that there may be further refinement of the original groups, leading to a substantially different scheme. Co-applicants Kate Brown and Rodney Franklin, who led the categorisation of diagnosis codes in the original risk model development, will undertake this task. As with diagnosis, we anticipate that this will be an iterative process working together with the analyst to identify inconsistencies in coding and refine the assignment algorithm. There are currently 86 specific EPCC comorbidity codes and a further 52 EPCC diagnosis codes that are recognised as comorbidities so a total of 138 codes to be revisited.

Objective 1.4 Explore options for modifying other risk factors to incorporate new comorbidity categories within the PRAiS risk model while maintaining a robust calibration (Months 5 to 10)

By this point we expect that the updated national dataset, including anonymised unit ID, will be with the Clinical Operational Research Unit. We anticipate that the national dataset will comprise approximately 23,000 surgical episodes and between 600 and 650 30-day deaths and all of this data will be used to develop the model. Using the rule of thumb that 10 ‘events’ are needed for each explanatory variable included (currently 39 degrees of freedom), this dataset should be sufficient for model development. However, we will check the performance of each parameterisation carefully and consideration of parsimony in number of parameters chosen (explicitly considered by the advisory panel in terms of trade-offs between detail in comorbidity, diagnostic and procedure information) will be key in the final determination of which risk factors to include in the parameterisation.

The CORU analyst will explore the performance of different parameterisations of PRAiS using all combinations of existing risk factors and newly identified options for categorising comorbidity, diagnosis and specific procedures as detailed in objective 1.1 above. Models will be fitted using multivariate logistic regression and 5x5 fold cross-validation. The performance of each fitted model will be assessed in a number of ways including:

- Hosmer-Lemeshow goodness-of-fit test

- MADCAP charts (as described in the original risk model development (1,35))
- Area under receiver operating characteristic (ROC) curves
- Consideration of deviance, Akaike's and Bayes' information criteria
- Examination of deviance residuals, Pearson residuals, Pregibon leverage (36) and influence measures (37)
- Stability of parameterisation within the 5x5 cross-validation test sets.

Models with markedly poor performance, those that perform worse than any other model on all indicators, or those that perform worse than the model calibrated with current PRAiS risk factors will be discarded at this stage. The different performance indicators for each of the remaining candidate models will be summarised and shared with the expert advisory panel.

A note on cross-validation:
Cross-validation involves repeated data splitting. For a 5-fold cross-validation the process is:
1. The model is developed and calibrated on the entire data set.
2. The data is randomly split into 5 equally sized subsets, the model is developed on 4 subsets (80% of the data) and tested on the subset that was excluded (20% of the data). This is repeated so that all 5 subsets are treated as the test set once.
3. Step two can be repeated on different partitions of the data to increase the reliability performance estimates. We will do this 5 times (5x5 fold cross-validation).
4. The results for the predictive accuracy are averaged over all of the cross-validations to obtain a measure of the predictive accuracy of the final model.

The advantages of cross-validation over maintaining a single quarantined test set are:
- As each entry in the data are used an equal amount to test the model, there is less variability in the performance estimate
- The final model is validated and uses all available data
- Repeating the 5-fold partition leads to a more accurate performance estimate (54)

For PRAiS2 we have chosen a 5 fold split to ensure that there are sufficient events in each 20% test set for meaningful validation.

Objective 1.5 Calibrate a new PRAiS risk model, after deciding on the final risk factors by consideration of statistical goodness of fit and clinical face validity (Months 11 to 13)

The expert advisory panel will meet one more time, together with the analytical team, to discuss options for the final choice of risk factors. The final choice will be made based on candidate model performance over a range of indicators (specified in objective 1.4), clinical face validity and model parsimony (i.e. given two equally preferred candidate models, we will choose the one with fewer parameters). It is possible that the final choice for comorbidity information may also reflect hopes for future coding of comorbid conditions – for instance, it is possible that particular combinations of comorbidity groups will be included in the hope that perceived particularly important comorbidities will be more fully recorded in the future.

The analytical team will then double check the performance and stability of the final candidate model in the development dataset using 5x5 cross-validation, with any concerns being shared with the advisory panel electronically. The final model will then be calibrated on the entire dataset. The performance in the validation set will be assessed by Hosmer-Lemeshow goodness-of fit, MADCAP and ROC charts. As a final check on the performance of the new model, we will also calibrate the current PRAiS risk model on the full dataset. It is reasonable to demand that the new model is at least as good as the current version of PRAiS in terms of all three of Hosmer-Lemeshow goodness-of-fit, MADCAP and ROC curves.

Objective 1.6 Update the software that implements PRAiS with the new parameterisation (Months 13 to 15)

The final step will be to update the software used to implement PRAiS with the new final model. This will (likely) involve updating the way comorbidity risk factors are assigned to an episode, updating the groupings of diagnosis and specific procedure and updating the model parameterisation. We will work with current users of the software (TW and JS on the advisory panel) to co-design any required changes to the user interface. Additionally, the user manual, the list of explicit mappings from individual codes to risk factors (freely available to anyone from the CORU website) and the model specification (also freely available) will all need to be updated.

All current owners of a licenced copy of the PRAiS software will receive this update free of charge (this includes all English hospitals, NICOR and 2 other UK hospitals). The explicit mappings and model specification will be available to anyone. These months will also be used to write up of the development of the new risk model for open-access publication in a peer-reviewed journal and for the final NIHR report.

AIM 2

This part of the project will be a multi-disciplinary effort with interwoven strands led by Professor David Spiegelhalter, Winton Professor for the Public Understanding of Risk, Dr Tim Rakow, an experimental psychologist and Ms Emily Jesper of the charity Sense about Science. Professor Spiegelhalter and his team specialise in developing resources for the public understanding of science, with a focus on risk and probability. Dr Rakow specialises in using innovative methods from experimental psychology to investigate how people interpret risk and surgical outcomes when communicated using different graphical methods. In particular Dr Rakow has worked productively with Professor Spiegelhalter on the public interpretation of funnel plots (38) – the same form of plot used by NICOR to communicate paediatric surgery outcomes – and survival curves (39). Sense about Science is a leading advocate for effective science communication.

Objective 2.1 - Confirm our understanding of the current and planned presentations of mortality outcome data by the NICOR congenital audit (Months 1 to 2)

To produce meaningful resources for the public about the interpretation of mortality outcomes, we first need to be sure that we are working with the up to date format of output from the national audit body. It is essential that the developed material will reflect the content of the results published by NICOR, in the format that NICOR uses.

Dr Pagel and Professor Spiegelhalter will work with co-applicants Dr Franklin and Dr Brown to ensure that NICOR's current process for producing existing public output used by the congenital audit is fully understood by the project team. This will include horizon scanning for any intended changes to the output or additional material that NICOR might publish in the future. This collaborative effort will be facilitated by the fact that Professor Spiegelhalter is an existing adviser to NICOR on the presentation of its results and Dr Pagel has previously worked productively with NICOR staff on data presentation.

Objective 2.2 - Co-produce a web-tool with patient groups and interested users that includes an explanatory website, an interactive animation and a short video to facilitate the interpretation of mortality outcomes. (Months 3 to 12)

The intended public output is:

1. An explanatory website with multiple levels of explanation, targeted at audiences with differing information needs and preferences.
2. An interactive animation that would change illustrative outcome plots in response to changes in input from users. For instance, the impact of more surgical cases or one more death of a high risk patient for a centre to show the potentially large impact on smaller centres.

3. A final 'YouTube'-like animation, envisaged as approximately 2 minutes of audio plus a summary walk-through of the information on the site.

The presentation of the complex ideas behind using risk adjustment for audit is not straightforward and Professor David Spiegelhalter's expertise in communicating complex ideas about risk will be immensely valuable (for instance (40–44)). He and Mike Pearson have a track record of working together to produce useful tools and animations around interpreting risk (for instance (45,46)). However the input of potential users is also recognised as being extremely valuable and thus we plan to co-produce the material with a series of focus groups of potential users.

Patient and public input prior to any development

NICOR held a patient and public open day on 8 May 2014 for all of the national audits it currently manages, including the congenital heart audit. Dr Pagel, Professor Spiegelhalter and Mr Pearson will aim to understand any issues or concerns raised by patients from NICOR's patient day and any subsequent engagement around the output of the congenital audit (including informal feedback from members of the expert panel assembled for aim 1). This feedback would then directly inform the structure of the initial focus groups (described below).

Co-production of the web-tool with families and other interested users

The output is aimed at two reasonably distinct audiences:

1. Older patients, parents and families of children who have had/will have heart surgery. This group are likely to have a more emotional involvement with published results and are more likely to be focused on specific questions concerning individual hospitals.

2. Other interested users including press officers for medical charities or professional bodies, members of the media, NHS England, family liaison services of paediatric hospitals, interested members of the public.

We will thus convene two sets of groups in parallel throughout the process – one comprising parents and families and one of other interested users. Family members will be recruited via the Children's Heart Federation and through the local charities of the five specialist hospitals represented by members of the expert panel. Participants will be offered compensation for their time at the Involve rate of pay and travel expenses. We note that we will be recruiting parents/carers and not children since the large majority of children who undergo heart surgery are under the age of five. Interested users will be recruited by Sense about Science which already has between 500 and 1000 relevant contacts on its database including clinicians, journalists, science communicators, press officers, policy advisors and several patient groups.

We plan to hold four workshops for each group of users at 3, 6, 9 and 11 months, organised and facilitated by Sense about Science and held at their offices in London (i.e. 4 x 2 focus groups in total). All workshops will last for 1.5 hours after a sandwich lunch (provided). To ensure a fresh perspective at each time point, at least some members in each focus group will be new members. We envisage about 6 people per group at each meeting, i.e. a total of up to 24 family members and 24 interested users.

The purpose of each of the four sets of two workshops is given below. Before the first workshop, Emily Jesper and Victoria Murphy from Sense about Science will work with David Spiegelhalter, Mike Pearson, Christina Pagel and Tim Rakow to distil key insights about the funnel lots and possible areas of difficulty in interpretation to discuss with the focus groups. After each set of 2 meetings, Sense about Science will produce a short report to inform the development of the web material. Each focus group meeting will be

attended by at least one of the project team (Christina Pagel, Mike Pearson, Martin Utley, David Spiegelhalter).

Meeting 1 (x2) (May 2015, Month 3):
The project team will introduce the current graphical output from NICOR that the material is intended to support. Key features of the graphs will be explained and limitations of the analysis discussed. This will include discussion of the perceived need for risk adjustment of outcomes, the inherent limitations of any risk model, the impact of one or two deaths when dealing with small numbers of cases and the impact of multiple hypothesis testing. Initial reactions to the graphs will be sought from focus group members. Key messages to convey in the web-tool to be developed will then be discussed as a group, with prioritisation of the messages and some initial ideas for emphasis and presentation.

Meeting 2 (x2) (July 2015, Month 5):
Initial drafts of the website will be shared with focus groups as well as example output from NICOR (to test how useful the material is in interpreting the published output). All participants will have access to a computer for their exclusive use during the meeting. Focus group members new to the material will be encouraged to use the website and interactive animation without support (while MP or CP are in the room) to highlight any stumbling blocks to usability or understanding. Through interactive use, discussion and probing, insights will be gained to improve accessibility, understanding and to inform navigation throughout the website including use of drop downs, boxes, hover detail and animation.

Meeting 3 (x2) (October 2015, Month 8):
In this meeting, we aim to explore how people use the interactive animation and how easy it is to access and use. Again all participants will have access to a computer. Through use, discussion and probing, insights will be gained to improve accessibility, understanding and to develop layout, language and usability.

Meeting 4 (x2) (January 2015, Month 11):
Almost final versions of all the web-material - the static website, interactive animation and the short video - will be shared with focus groups, again initially focusing on reactions from members new to the material. This is a near-final opportunity to spot any potential problems in communication and also to work on last adjustments to the wording of the website, flow of the interactive animation or content of the video.

Throughout year 1 we will share developing material with anyone who has attended a focus group meeting, the expert panel assembled for Aim 1 and the project team using the online NIHR hub (47). This provides the opportunity to elicit additional feedback throughout but also allows participants to follow the progress of the web-tool and to track how its development has incorporated user comments.

Objective 2.3 Undertake a formative mixed-methods evaluation of the web-tool to strengthen the final outputs (Months 7 to 12)

Concurrent with the co-development of the material with the focus groups, Dr Rakow will lead research to evaluate the material by examining people's ability to understand, extract and use the information presented by the national audit output with the help of the web-tool. Since reasonably advanced drafts of the web material must exist for these formal experiments, this strand of the work will not start until autumn 2015 (to coincide with meeting 3 of Objective 2.2). Following the methods of Dr Rakow's previous research on the public understanding of graphics for risk communication in the medical domain (38,39), these experiments will examine: (a) comprehension of the presented information, and (b) the opinions that people form and the decisions that they make on the basis of that information. In particular, the experiments will examine how different versions of the web material change the level of comprehension and/or people's opinions/decisions. Some studies will use established "process tracing" methods from the cognitive and decision sciences (e.g., "think aloud" , eye-tracking and web-navigation metrics) to assess how people extract information from the explanatory website.

The primary aim of this strand of the project is to further improve the content, features and design of the web-tool to encourage appropriate interpretation and use of the audit data by the families of children with heart disease and other interested users. The learning from this evaluation will be fed back to David Spiegelhalter's team and incorporated into the learning from the focus groups to further improve the material.

The evaluation led by Dr Rakow during the development of the tool will be a series of three studies falling into one of two categories:

(1) An evaluation of a single element of the explanatory website, aimed at optimising that particular element. For example, there may be alternative ways to explain a message identified as key in focus group meeting 1, but some alternatives may be more effective than others. Alternative explanations (that represent feasible options for the tool) would be evaluated via formal experiments. Evaluations would focus of which alternatives foster appropriate interpretation the plots.

(2) An evaluation of a possible optional or additional feature of the tool. For example: one could include two ways of explaining what risk adjustment achieves, or only one. Experiments would examine whether adding/changing this feature improves interpretation. Such experiments will be directly complementary to the work exploring user preferences for the inclusion of such features in the focus groups.

We plan thee "waves" of data collection during the web-tool development, commencing bi-monthly from October 2015. The first two will examine individual elements of the draft website (i.e., category (1) above), the third will examine optional/additional features (i.e., category (2) above).

Participants for these studies will be recruited by Dr Rakow's team at King's College London (KCL, where he will be moving from the University of Essex in early 2015). The research volunteers for these studies need not be drawn for the same populations as the focus group participants, because the purpose of these studies is to explore how best to communicate the audit data to *anyone* without prior knowledge or technical appreciation of those data. Therefore, we will seek to recruit adult participants who vary on those characteristics that are particularly pertinent to one's ability to comprehend and use data (e.g., numeracy level, educational background). We plan for 80 participants per round to allow adequate statistical power to identify meaningful improvements to the tool. In some rounds, volunteers may participate in more than one experiment (e.g., each evaluating a different feature) in a 40-minute session. Volunteers will be reimbursed for their time (£7.50 for a 40-minute session; a rate a little above the "London living wage").

Objective 2.4 Disseminate the developed material via the Children's Heart Federation and Sense about Science and evaluate the usability and efficacy of the final web-tool as an aid to the public understanding of outcome data. Share with other charities and with the NICOR Congenital Audit (Months 13 to 15)

Dissemination

The final developed material will be launched by Sense about Science in March 2016. The web-tool will be shared with the project team and expert panel, NICOR, all focus group members, Sense about Science and the Children's Heart Federation. The content will be hosted on Professor Spiegelhalter's "Understanding Uncertainty" website (40) (co-sponsored by the Winton Fund for the Public Understanding of Risk and the University of Cambridge) which is widely used and freely accessible. If the NICOR congenital audit steering committee agrees, the content could also be linked to from the NICOR congenital audit public portal. The existence of the content and the link to it will also be disseminated by the Children's Heart Federation and Sense about Science through their existing networks. We will also share the content with other interested charities and user groups such as the British Heart Foundation and individual hospital charities (e.g. the Great Ormond Street charity). It is anticipated that individual hospitals that perform children's heart surgery may also wish to add a link to the material on their own websites.

In particular, Sense about Science will ask the following groups of organisations to promote the web-tool to their networks via social media, newsletters, physical mail-outs, on their website, in articles and in talks:

- Health information organisations and websites including: *Healthy Evidence (a new collaboration between NHS 'Behind the Headlines', Health Unlocked and Sense About Science); the UK Cochrane Centre, Patient Voices, NHS trusts and NHS Choices, the Association of Medical Research Charities and its members, Cancer Research UK, Public Health England*
- Scientific and medical organisations who work closely with Sense About Science including: *the Medical Royal College of Surgeons, Royal College of Midwives, Royal College of Nursing, Royal College of Paediatrics and Child Health and other royal colleges, British Heart Foundation and other medical charities, the Wellcome Library, British Science Association, British Library (Science), other professional and learned societies including the Royal Statistical Society*
- Over 100 UK university departments who are involved in their Voice of Young Science programme will be asked to promote it to undergraduates and postgraduates.
- Civil organisations not traditionally involved in discussions about statistical interpretations of mortality rates who work with Sense About Science including: *Mumsnet, Which?, University of the Third Age, Office for Fair Trading, Citizen's Advice Bureau, Skeptics in the Pub*
- Sense about Science will also promote the resources to their contacts within policy including local authorities.

Sense about Science will also work alongside the UCL Press Office to announce the launch of the web-tool, including sending a press release to the lifestyle press (e.g. parenting magazines) and specialist press (e.g. New Scientist, Research Fortnight) and run a social media campaign via Facebook and Twitter to direct people towards the web-tool.

Evaluation
In April 2016, Dr Rakow's team will perform a final study, focusing on evaluating the effectiveness of the whole web-tool in aiding appropriate interpretation of NICOR's published output. This will be a global evaluation of the complete material, examining whether the different elements of the tool work together to provide an effective platform for communicating the key messages identified in interpreting the published audit output. Key components to be examined are:

(a) Usability and effectiveness – which elements people respond to, make use of, and benefit from: as determined by (i) user self-reports or think-aloud protocols, (ii) observable process-tracing data such as mouse clicks or eye-tracking data, (iii) tests of comprehension and interpretation.
(b) What works for whom? – Whether and how people make use of the different elements of the tool, and how they select which elements to make use of.

At this stage, users can use as much or as little of the functionality as they wish. The level of comprehension afforded by the explanatory website can be evaluated either by comparing it against what can be understood without the benefit of the website, and/or by comparison against a desired minimum standard (e.g., aiming to exceed the 90% accuracy for extracting basic information from simpler funnel plots as reported by Rakow et al. (38)).

Additionally, on the launched website users will have the opportunity to provide feedback in a comments section. Online use of the launched material will be monitored and textual analysis of any comments will be performed with help from the UCL Public Engagement Unit (Gemma Moore). Sense about Science will also monitor take-up of the material as part of their dissemination strategy.

Project facilitation to make the most out of the engagement activity
The input of the two parallel focus group strands and the experimental work by Dr Rakow's team to the development of the web-tool is an innovative approach to public engagement and has the potential to significantly enhance communication of mortality outcomes after heart surgery in children. However, it is also a complex process and the combination of these elements is new to all project members. To support our work in this new approach, we will work with Dr Laura Meagher who is an experienced facilitator of multi-

dimensional initiatives. She illuminates effective practices through her evaluations of knowledge exchange, public engagement, impact and interdisciplinarity.

She will play the role of a critical friend throughout the project: her role will be to ask questions, stimulate discussion and reflection, bring perspectives from a range of other projects, and serve as a sounding board. She will meet with the project team at these key stages of the project:

1. **Start of the project (Month 1)** – she will help in the initial framing of goals and objectives with correlated fine-tuning of plans/questions/optimisation of user perspectives, early identification of mid-process indicators to watch for that would suggest the project's public engagement is working well or not and definition of stated and un-stated assumptions on the part of the team.
2. **Midway in the project (Month 8)**– she will help to ensure the fit of focus group agendas with agreed objectives, identification of any issues arising, team reflection on how integrated understanding (e.g. from user focus groups or Dr Rakow's experimental work) is growing as to how the project's public engagement efforts can be most effective - and any related evolution of project objectives/plans;
3. **At/near the end of the project (Month 14)** - assessment of the process through which the public engagement efforts have developed and led toward impacts and capture of 'lessons learned' that could be useful for other arenas of communication about medical risk, when co-production with users can help (in particular with families where the engagement is potentially emotionally fraught).

In particular, such facilitated reflection throughout will help any transferable lessons learned to become a valuable additional output of our project (as well as benefitting the project directly).

DISSEMINATION AND PROJECTED OUTPUTS

Knowledge Output:

Outputs will include:

- Updated PRAiS risk model for 30-day mortality following paediatric cardiac surgery (Aim 1)
- Updated software to implement new risk model (Aim 1)
- New algorithms for characterising comorbidities associated with a patient record (Aim 1)
- Online material for the public/family members/media (Aim 2)
- New learning on how formal experiments and co-production with users can be integrated to improve public engagement efforts (Aim 2).

Dissemination:

In addition to the dissemination strategy for the web-tool outlined for objective 2.4 above, we will publish the research for both aims in peer-reviewed journals and presentations at academic conferences. We anticipate three main papers: one on the updated PRAiS risk model including discussion of the contribution of the expert panel; one on the experimental psychology research led by Dr Rakow and a third paper on our experience of using this innovative approach to developing web material for families and other interested users. In addition, the research output will be shared with other centres conducting children's heart surgery and with the national audit for children's heart surgery (NICOR Congenital). NICOR and all UK units will receive the updated software at no additional cost.

Knowledge generalisability opportunities:

This research project has been designed with effective knowledge mobilisation at the front of our minds. The better understanding of comorbidities and their impact on mortality may be relevant to other paediatric outcomes and the methods developed here for incorporating this information into risk models could be used for general paediatric intensive care and/or adult congenital heart outcomes.

This project will also generate experience about working closely with patients and the public around the communication of mortality data in sensitive areas such as children's heart surgery and how this can be combined with formal experiments to improve communication. Given that the current trend is towards greater transparency and increased publication of outcomes across many more clinical specialties, this project's learning could be very important to others in the coming years.

PLAN OF INVESTIGATION AND TIMETABLE

The project timetable is set out below.

Activity	Month number														
	Before start of project	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		03/15	04/15	05/15	06/15	07/15	08/15	09/15	10/15	11/15	12/15	01/16	02/16	03/16	04/16	05/16
AIM 1																
Apply for access to April 2009 to December 2013 NICOR dataset	X															
Objective 1.1 initial exploration of options for incorporating comorbidity		X	X	X												
Objective 1.2 expert advisory group initial selection of options					X											
Objective 1.3 modifying existing allocation of comorbidity codes						X	X									
Objective 1.4 comparing different updated risk models with otions decided as part of 1.2						X	X	X	X	X	X					
Objective 1.5 Calibrate and test final version of risk model												X	X	X		
Objective 1.6 Update software for PRAiS and write up model														X	X	X
AIM 2																
Laura Meagher meets with the project team		X							X						X	
Objective 2.1 establish current NICOR reporting output		X	X													
Objective 2.3 Apply for ethics approval for Dr Rakow's formal experiments		X	X	X	X	X	X									
Objective 2.2 Co-production of web-tool with patients and other interested users				X	X	X	X	X	X	X	X	X	X			
Objective 2.2 Focus group meetings facilitated by Sense about Science (4 sets of 2 groups).				X		X			X			X				
Objective 2.3 & 2.4 Formal experiments evaluating web-tool									X		X		X		X	
Objective 2.4 Launch & disseminate web-tool via Children's Heart Federation, Sense about Science and NICOR. Write up work for publication.														X	X	X

PROJECT MANAGEMENT

Management and coordination of work streams

The project will be led and managed by Dr Christina Pagel. In particular, Dr Pagel will manage the Grade 7 CORU postdoctoral analyst in the refinement of the PRAiS risk model and manage the public engagement activity of aim 2.

Dr Andrew Wilshere, CORU's research manager, working with CP, will organise project team meetings, the expert panel meetings for AIM1, will be in charge of subcontracts and finances and the data sharing agreements with NICOR and other centres (as needed).

Dr Brown will lead the reassignment of individual European Paediatric Short Codes to comorbidity groups.

Dr Pagel will be responsible for producing the online material, although it will be developed by Professor David Spiegelhalter and Mr Mike Pearson at the University of Cambridge. Emily Jesper will be responsible for running the focus groups to co-produce the material and Dr Rakow will be responsible for the experiments evaluating the developing material: designing the studies, overseeing the data collection, and reporting the outcomes, plus supervising the part-time research assistant to be based at KCL.

ETHICAL ISSUES AND APPROVALS

The National Information Governance Board for Health and Social Care for England and has granted NICOR Section 251 exemption of the NHS Act 2006 for all the cardiac audits that it manages. Section 251 permits the common law duty of confidentiality to be lifted for activities that fall within defined medical purposes where anonymised information will not suffice and consent is not practicable. Any data shared with the UCL Clinical Operational Research Unit will be pseudonymised and subject to a data sharing agreement. The data will be stored within UCL's Identifiable Data Handling Solution system which meets the requirements of the NHS Information Governance Toolkit and ISO 27001.

Thus the proposed research for Aim 1 only involves the analysis of routinely collected anonymised data which does not contain personal information, after consent has been given by the data owner (NICOR or the individual centres). After examination of guidelines issued by the National Research Ethics Service, we do not believe that ethical approval is required. (Used document: Does my project require review by a Research Ethics Committee? downloaded from www.nres.nhs.uk 7 March 2014).

The proposed engagement of families, carers and the public for the focus groups in Aim 2 constitutes active involvement in the research. The focus groups will be acting as specialist advisors and not as research participants, hence ethical approval is not required as defined by INVOLVE for this aspect. However, ethics approval will be required and sought from the appropriate body for Dr Rakow's strand of activity.

Data protection

All data used for **Aim 1** will be pseudonymised and not patient identifiable. The data will be held in the UCL Identifiable Data Handling Solution (IDHS) system. The IDHS system meets the requirements of the NHS Information Governance Toolkit and ISO 27001 in keeping data secure. Only researchers named on the data agreement with the data owner (whether NICOR or individual units) will have access to the data.

The data collected as part of Dr Rakow's work for **Aim 2** will be stored in electronic format in accordance with the Data Protection Act 1998. Therefore, when consent to participate in the research is obtained, participants will be informed that the data they provide will be stored on a secure computer. There will be no need to record the participant's identity alongside their demographic data, or the responses that they provide

in the study; and participants will be assured that they will not be personally identifiable in any reporting of the data.

PATIENT AND PUBLIC INVOLVEMENT

Patient and public involvement is central to achieving **Aim 2** – the co-production of material to help people interpret the mortality outcomes as they are published by NICOR.

We have the support and input of the Children's Heart Federation, a user group for families and children living with congenital heart disease; Sense about Science, a charity promoting the public understanding of reported evidence and the national audit body NICOR (Professor John Deanfield, Research Lead for NICOR, Dr Rodney Franklin, Clinical lead for the Congenital Heart Audit & co-applicant).

We hope that feedback from NICOR's patient and public open day held in May 2014 will inform the content of the material. Focus groups of patient representatives and the public, recruited by the Children's Heart Federation and Sense about Science, will provide crucial input throughout the project.

EXPERTISE AND JUSTIFICATION OF SUPPORT REQUIRED

Applicants

Chief Investigator
Dr Christina Pagel (25% FTE) is Lecturer in Operational Research at the UCL Clinical Operational Research Unit (CORU) and the UCL Department of Applied Health Research. A named co-investigator on the HSDR funded project and part of the analytical team that developed the PRAiS risk model, she has since led the development and roll-out of software to implement PRAiS, visiting all but one of the UK centres in the process. She combines excellent organisational, analytical, statistical and modelling skills with an appreciation of the clinical and regulatory context of her work and a genuine commitment to the co-design and co-production of analytical tools for health care. Christina will lead the proposed study, supervise the work of the Research Associate analyst, work with David Spiegelhalter's group, Sense about Science and Tim Rakow to develop material for the public. She will also update the PRAiS software with the updated risk model.

Co-applicant
Dr Sonya Crowe (5% FTE) is a Health Foundation Improvement Science Fellow at the UCL Clinical Operational Research Unit. A key member of the team that developed the PRAiS model and the software to implement it, she brings to this study considerable and valuable experience of working with the NICOR congenital dataset. She will advise on model development and support the work of the Research Associate in their work on data cleaning and processing.

Co-applicant
Martin Utley (5% FTE) is Director of the UCL Clinical Operational Research Unit. He has worked on collaborative research projects in the area of paediatric cardiac surgery for over ten years and was a co-investigator on the original PRAiS study. He joined Dr Pagel on their 2013 visits to surgical units in the UK, discussing with clinical teams the benefits, limitations and appropriate use of risk-adjusted monitoring of outcomes. In addition to advising on model development and animation content, he will provide mentorship support to Dr Pagel.

Co-applicant
Dr Kate Brown (20 days (6% FTE)) is a consultant intensivist at Great Ormond Street Hospital. As a co-investigator on the original PRAiS study, she provided clinical expertise to the choice, analysis and interpretation of risk factors and led engagement with the NICOR congenital stakeholder group, a role she will revive in the proposed study with respect to comorbidities. Kate was involved in piloting the PRAiS

software and joined Christina and Martin on some of their trips to other UK surgical units. An experienced PI with NIHR HSDR, she will provide mentorship support to Dr Pagel.

Co-applicant
Dr Rodney Franklin (25 days (8% FTE)) is a consultant paediatric cardiologist at the Royal Brompton Hospital and chair of the NICOR congenital steering committee. He has led the development of international coding frameworks in congenital heart disease and will contribute this expertise to the proposed study along with his clinical knowledge on comorbidity and surgical risk. As Chair fo the NICOR steering committee he will also provide input into the development of the web-tool for Aim 2. He was a collaborator on the original PRAiS study.

Co-applicant
Dr Tim Rakow (10% FTE for 9 months) is a Reader in Psychology at the University of Essex (moving to KCL, in January 2015). He researches judgment and decision under risk, and has published studies on the public understanding of survival curves (39) and funnel plots (38), and how paediatric cardiologists and heart surgeons' risk assessments compare to, and are informed by, risk models (48).

Named Collaborators

Aim 1

The following collaborators will sit on the expert panel along with Drs Brown and Franklin. We have included costs for 10 days each of their time (2 days for face-to-face meetings and 8 days outside of meetings).

Mr Victor Tsang was PI on the original PRAiS study. A consultant surgeon at Great Ormond Street Hospital, he will provide a surgical perspective on the role of comorbidity in influencing risk of death in the peri-operative period.

Dr Kate English is a consultant adult congenital cardiologist at Leeds General Infirmary and a member of the NICOR congenital steering committee. She will contribute clinical expertise to the identification and interpretation of risk factors.

Mr David Anderson is a consultant surgeon at Evelina London Children's hospital. He will contribute a surgical perspective to the identification and interpretation of risk factors.

Dr Shane Tibby is a consultant intensivist at Evelina London Children's Hospital with an interest in monitoring outcomes after paediatric cardiac surgery. He will contribute an intensive care perspective to the identification and interpretation of risk factors.

Mr David Barron is a consultant surgeon at Birmingham Children's hospital and a member of the NICOR congenital steering committee. He will contribute a surgical perspective to the identification and interpretation of risk factors.

Mr John Stickley and Mr Thomas Witter are experienced data managers working at Birmingham Children's Hospital and Evelina London Children's Hospital respectively. Mr Witter collaborated with Kate Brown and CORU in piloting the PRAiS software and both have considerable understanding of the congenital dataset. Thomas currently represents the database managers on the NCHDA steering group.

Aim 2

Professor David Spiegelhalter is Professor of Public Understanding of Risk at the University of Cambridge. A highly respected statistician, he has a longstanding interest in the analysis, interpretation and communication of outcomes following paediatric cardiac surgery. He will contribute to the development of resources designed to meet the overlapping but distinct information needs of patients and families and the

wider public. Professor Spiegelhalter will contribute his expertise at no cost to the project. Mr Michael Pearson works with Professor Spiegelhalter at the University of Cambridge and will develop the web animation (20 days). Professor Spiegelhalter and Mike Pearson have recently launched a cardiovascular risk calculator for use by clinicians with their patients (45), a project chaired by Professor John Deanfield, research lead for NICOR. An example of their work producing animations on the public communication of risk is a web animation on the risks of diabetes made for the 2011 Big Bang Science Fair (46).

Ms Emily Jesper has been assistant director at the charity Sense about Science since November 2011 and is responsible for developing and leading patient and public health projects. She runs user testing workshops and roundtables and works with researchers and the public to address recurring themes, improve the communication of evidence and draw out underlying assumptions on difficult issues. She will run and facilitate the focus group activity to co-develop the material and launch the final material together with Victoria Murphy, programme manager at Sense about Science. Victoria has experience of facilitating workshops to test out concepts, materials, understanding and usability and runs the Sense About Science workshop programmes, including peer review and communicating evidence. (64 days between EJ and VM).

Dr Samana Schwank is the Information and Research Coordinator from the Children's Heart Federation. The Children's Heart Federation has extensive experience in disseminating information to parents and will recruit up to 24 parents for the four family member focus group meetings. (10 days)

Dr Laura Meagher is senior partner of the Technology Development Group, specialising in both facilitating and evaluating complex research and knowledge exchange/public engagement initiatives (49,50). She is currently serving as a critical friend evaluator and member of the steering committee in the six year EPSRC CHI+MED initiative (computer human interface in medical devices) (51) and served as a critical friend and evaluator on Queen Mary College London's "Computer science for fun" project (52). As a critical friend to this project, she will facilitate team reflection on and improvement of dynamic processes during the project (formative evaluation) and toward the end will capture team learning about co-production and integration of approaches that can benefit others undertaking similar challenges in public engagement. She will meet with the team three times during the project. (11 days)

Ms Gemma Moore works with the UCL Public Engagement Unit and will support the final evaluation of the material. She will undertake this work as part of her current role at UCL and is thus not costed as part of this grant.

Other costs

Grade 7 Postdoctoral Research Associate – UCL Clinical Operational Research Unit (50% FTE). The research associate, based within CORU, will perform the analysis required for objectives 1.1 to 1.5, under Dr Pagel's supervision and with additional support from Professor Utley and Dr Crowe.

Research Manager – UCL Clinical Operational Research Unit (15% FTE). CORU's research manager, Dr Wilshere, will assist Dr Pagel in project management by helping in budget management, sub-contract set up for external co-applicants, set up of data sharing agreements, payment of costs to named collaborators and organisation of face-to-face meetings.

Grade 5 Research Assistant – Department of Psychology, King's College London (60% FTE for 9 months). The research assistant will work on objectives 2.3 & 2.4 under the supervision of Dr Rakow: assisting him with the preparation, implementation and analysis of the studies; and having primary responsibility for recruiting participants and collecting the data.

Data collection and dissemination (objectives 2.3 & 2.4) – A further £4,650 is budgeted for the experimental evaluation of the explanatory website to cover: participant payments, research assistant travel and computer, and attendance at one research conference (e.g., Annual Meeting of the European Group for Process Tracing Studies).

We have additionally budgeted for the expanded role of the focus groups run by Sense about Science (£6,775) which includes costs for participant honoraria, travel costs for participants, refreshments, room & laptop hire and printing costs.

UCL Business manages the licensing of the PRAiS software through its licensing transaction webportal E-lucid. In order to distribute the new version of PRAiS to the registered licensees, UCLB will: i) update the PRAiS product page with the relevant version change information; ii) replace the 'old' PRAiS software code which is stored on the server with the new version to allow licensees to download through their E-lucid account; iii) notify each licensee of the availability of the new software and provide download support as required. Licence and software distribution management costs are typically covered by the licence fee. However as this upgrade to the PRAiS software will be provided to licensees free of charge, UCLB will charge a one-off fee equivalent to 1 person-day of Marina Santilli (£710) for this activity (which includes any subsequent support for the distribution of bug-fix versions of the code if this is necessary). This ensures that the updated software is made available free of charge to all licence holders.

Finally we have included costs for travel for various project team members to meet each other, in particular trips to Cambridge to work with David Spiegelhalter and Mike Pearson on the web-tool, travel for the expert panel assembled for Aim 1 and travel for Laura Meagher (£2,759).

REFERENCES

1. Pagel C, Brown KL, Crowe S, Utley M, Cunningham D, Tsang V. A mortality risk model to adjust for case mix in UK paediatric cardiac surgery. Health Serv Deliv Res. 2013 May;1(1).

2. Crowe S, Brown KL, Pagel C, Muthialu N, Cunningham D, Gibbs J, et al. Development of a diagnosis- and procedure-based risk model for 30-day outcome after pediatric cardiac surgery. J Thorac Cardiovasc Surg. 2012 Jul 17;

3. Pagel C, Utley M, Crowe S, Witter T, Anderson D, Samson R, et al. Real time monitoring of risk-adjusted paediatric cardiac surgery outcomes using variable life-adjusted display: implementation in three UK centres. Heart Br Card Soc. 2013 Apr 5;

4. Cunningham D, Franklin R, Bridgewater B, Deanfield JE. NICOR Investigation of mortallity from paediatric cardiac surgery in England 2009-12 [Internet]. NHS England; 2013 [cited 2013 Apr 20]. Available from: http://www.england.nhs.uk/2013/04/12/reports-chs-leeds/

5. Brown KL, Crowe S, Pagel C, Bull C, Muthialu N, Gibbs J, et al. Use of diagnostic information submitted to the United Kingdom Central Cardiac Audit Database: development of categorisation and allocation algorithms. Cardiol Young. 2012 In Press;

6. NICOR. NICOR, specific procedures national data [Internet]. 2013 [cited 2014 Mar 18]. Available from: https://nicor4.nicor.org.uk/CHD/an_paeds.nsf/WBenchmarksYears?openview&RestrictToCategory=2012&start=1&count=500

7. NIHR Evaluation, Trials and Studies | 12/5005/06 [Internet]. [cited 2014 Apr 3]. Available from: http://www.nets.nihr.ac.uk/projects/hsdr/12500506

8. Aylin P, Alves B, Best N, Cook A, Elliott P, Evans SJ, et al. Comparison of UK paediatric cardiac surgical performance by analysis of routinely collected data 1984–96: was Bristol an outlier? The Lancet. 2001 Jul;358(9277):181–7.

9. Moore A, Agnew T, Cole A. Bristol Royal Infirmary--the aftermath: six pages of analysis. Health Serv J. 2001 Jul 19;111(5764):11–7.

10. Murphy JF. The Bristol Royal Infirmary Inquiry 18th July 2001. Ir Med J. 2001 Sep;94(8):228.

11. NHS. Safe and Sustainable: Childrens Congenital Cardiac Services [Internet]. NHS Specialist Services; 2011 [cited 2013 Jan 3]. Available from: http://www.specialisedservices.nhs.uk/safe_sustainable/childrens-congenital-cardiac-services.

12. Jenkins KJ, Gauvreau K, Newburger JW, Spray TL, Moller JH, Iezzoni LI. Consensus-based method for risk adjustment for surgery for congenital heart disease. J Thorac Cardiovasc Surg. 2002 Jan;123(1):110–8.

13. Lacour-Gayet F, Clarke D, Jacobs J, Gaynor W, Hamilton L, Jacobs M, et al. The Aristotle score for congenital heart surgery. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu. 2004;7(1):185–91.

14. O'Brien SM, Clarke DR, Jacobs JP, Jacobs ML, Lacour-Gayet FG, Pizarro C, et al. An empirically based tool for analyzing mortality associated with congenital heart surgery. J Thorac Cardiovasc Surg. 2009 Nov;138(5):1139–53.

15. Lovegrove J, Valencia O, Treasure T, Sherlaw-Johnson C, Gallivan S. Monitoring the results of cardiac surgery by variable life-adjusted display. The Lancet. 1997 Oct 18;350(9085):1128–30.

16. Clinical Practice Improvement Centre, Queensland Government. VLADs for Dummies. Australia: Wiley; 2008.

17. Pagel C, Crowe S, Brown K, Utley M. The benefits and risks of risk-adjustment in paediatric cardiac surgery. Heart. 2013 Oct 3;heartjnl – 2013–304848.

18. Unit "should end child heart ops." BBC [Internet]. 2010 Oct 15 [cited 2014 Mar 20]; Available from: http://www.bbc.co.uk/news/health-11546509

19. Surgery halted after child deaths. BBC [Internet]. 2010 Mar 4 [cited 2014 Mar 20]; Available from: http://news.bbc.co.uk/1/hi/england/oxfordshire/8548568.stm

20. Smith R. Babies died after junior surgeon left to cope on his own. Telegraph.co.uk [Internet]. 22:26 [cited 2014 Mar 20]; Available from: http://www.telegraph.co.uk/health/healthnews/7914517/Babies-died-after-junior-surgeon-left-to-cope-on-his-own.html

21. Association P. John Radcliffe Hospital "must not resume heart surgery" [Internet]. The Independent. [cited 2014 Mar 20]. Available from: http://www.independent.co.uk/life-style/health-and-families/health-news/john-radcliffe-hospital-must-not-resume-heart-surgery-2038570.html

22. Alex, Topping ra. Leeds General Infirmary halts heart surgery on children. The Guardian [Internet]. 2013 Mar 29 [cited 2014 Mar 20]; Available from: http://www.theguardian.com/society/2013/mar/29/leeds-general-infirmary-halts-heart-operations-children

23. Boseley S, editor health. Leeds General Infirmary to resume children's heart surgery. The Guardian [Internet]. 2013 Apr 8 [cited 2014 Mar 20]; Available from: http://www.theguardian.com/society/2013/apr/08/leeds-general-childrens-heart-surgery

24. Children's heart surgery unit "safe." BBC [Internet]. 2014 Mar 14 [cited 2014 Mar 20]; Available from: http://www.bbc.co.uk/news/uk-england-leeds-26551617

25. Barrow M, Sellman M. MPs condemn NHS chief over Leeds child heart unit suspension. The Times (London) [Internet]. London; 2013 Mar 29 [cited 2014 Mar 20]; Available from: http://www.thetimes.co.uk/tto/news/uk/article3726399.ece

26. Heart surgery unit set to re-open [Internet]. ITV News. [cited 2014 Mar 20]. Available from: http://www.itv.com/news/calendar/2013-04-05/heart-surgery-unit-set-to-re-open/

27. Perry K. Bristol Children's Hospital "still in denial" about deaths, say parents. Telegraph.co.uk [Internet]. 20:03 [cited 2014 Mar 20]; Available from: http://www.telegraph.co.uk/health/children_shealth/10642511/Bristol-Childrens-Hospital-still-in-denial-about-deaths-say-parents.html

28. Cooper C. England's chief doctor would send his children for heart surgery at Bristol Royal Hospital - even though he has just ordered a review into deaths there [Internet]. The Independent. [cited 2014 Mar 20]. Available from: http://www.independent.co.uk/life-style/health-and-families/health-news/englands-chief-doctor-would-send-his-children-for-heart-surgery-at-bristol-royal-hospital--even-though-he-has-just-ordered-a-review-into-deaths-there-9139300.html

29. Spiegelhalter D. Are you 45% more likely to die in a UK hospital rather than a US hospital? BMJ. 2013;347:f5775.

30. Spiegelhalter D. Statistics behind the headlines. Have there been 13,000 needless deaths at 14 NHS trusts? BMJ. 2013;347:f4893.

31. UCL Clinical Operational Research Unit. PRAiS: Excel software to implement PRAiS risk model using routine audit data [Internet]. 2013. Available from: http://www.e-lucid.com/i/software/clinical_data_modelling/PRAiS.html

32. CCAD. Central Cardic Audit Database: Paediatric Analysis Home Page [Internet]. Congenital Heart Disease Website. 2011 [cited 2011 Jan 29]. Available from: http://www.ucl.ac.uk/nicor/

33. Winnett R. Patients will be able to see surgeons' survival rates, says Jeremy Hunt. Telegraph.co.uk [Internet]. 19:22 [cited 2014 Mar 20]; Available from: http://www.telegraph.co.uk/health/10096920/Patients-will-be-able-to-see-surgeons-survival-rates-says-Jeremy-Hunt.html

34. Campbell D, correspondent health. Jeremy Hunt suspends children's heart surgery unit closures. The Guardian [Internet]. 2013 Jun 12 [cited 2014 Mar 20]; Available from: http://www.theguardian.com/society/2013/jun/12/jeremy-hunt-suspends-heart-unit-closures

35. Gallivan S, Utley M, Pagano D, Treasure T. MADCAP: a graphical method for assessing risk scoring systems. Eur J Cardiothorac Surg. 2006 Apr 1;29(4):431–3.

36. Pregibon D. Logistic-Regression Diagnostics. Ann Stat. 1981;9(4):705–24.

37. Hosmer DW, Lemeshow S, Sturdivant RX. Applied Logistic Regression. 3 edition. Wiley; 2013. 528 p.

38. Rakow T, Wright RJ, Spiegelhalter DJ, Bull C. The pros and cons of funnel plots as an aid to risk communication and patient decision making. Br J Psychol Lond Engl 1953. 2014 Aug 14;

39. Rakow T, Wright RJ, Bull C, Spiegelhalter DJ. Simple and multistate survival curves: can people learn to use them? Med Decis Mak Int J Soc Med Decis Mak. 2012 Dec;32(6):792–804.

40. Understanding Uncertainty [Internet]. [cited 2014 Mar 31]. Available from: http://understandinguncertainty.org/

41. RiskDisplay [Internet]. [cited 2014 Mar 31]. Available from: http://understandinguncertainty.org/files/animations/RiskDisplay1/RiskDisplay.html

42. Micromorts [Internet]. [cited 2014 Mar 31]. Available from: http://understandinguncertainty.org/files/animations/Micromorts/Micromorts.html

43. Screening Tests [Internet]. [cited 2014 Mar 31]. Available from: http://understandinguncertainty.org/files/animations/BayesTheorem1/BayesTheorem.html

44. ▸ Cambridge Ideas - Professor Risk - YouTube [Internet]. [cited 2014 Mar 31]. Available from: https://www.youtube.com/watch?v=a1PtQ67urG4

45. JBS3 Risk Calculator [Internet]. [cited 2014 Mar 31]. Available from: http://www.jbs3risk.com/index.htm

46. ▸ Big Bang Diabetes Movie - YouTube [Internet]. [cited 2014 Mar 31]. Available from: https://www.youtube.com/watch?v=NJ-KvsUvSXM

47. NIHR Hub [Internet]. [cited 2014 Oct 31]. Available from: http://www.nihr.ac.uk/about/nihr-hub.htm

48. Rakow T, Vincent C, Bull K, Harvey N. Assessing the likelihood of an important clinical outcome: new insights from a comparison of clinical and actuarial judgment. Med Decis Mak Int J Soc Med Decis Mak. 2005 Jun;25(3):262–82.

49. Meagher L, Lyall C. The invisible made visible: using impact evaluations to illuminate and inform the role of knowledge intermediaries. Evid Policy J Res Debate Pract. 2013 Aug 1;9(3):409–18.

50. Halcro DK, Guerra L, Anderson M, Edgar PD, Devis JMR, Grant K. Innovation Support in Latin America and Europe: Theory, Practice and Policy in Innovation and Innovation Systems. Gower Publishing, Ltd.; 2014. 315 p.

51. CHI+MED - making medical devices safer [Internet]. [cited 2014 Oct 30]. Available from: http://www.chi-med.ac.uk/

52. Computer Science for Fun - cs4fn: The cs4fn Project: Evaluation [Internet]. [cited 2014 Oct 30]. Available from: http://www.cs4fn.org/project/evaluation/

53. Tutorial in biostatistics - Multivariable prognostic models: Issues in developing modles, evaluating assumptions and adequacy, and measuring and reducing errors. Harrell F, Kerry L, Mark D. 1996, Statistics in Medicine, Vol. 15, pp. 361-387.

54. Internal validation of predictive models: Efficiency of some procedures for logistic regression analysis. Steyerber E, Harrell F, Borsboom G, Eijkemans M, Vergouwe Y, Habberma D. 2001, Journal of Clinical Epidemiology, Vol. 54, pp. 774-781

55. Park MH, Shim HS, Kim WH, Kim H-J, Kim DJ, Lee S-H, et al. Clinical Risk Scoring Models for Prediction of Acute Kidney Injury after Living Donor Liver Transplantation: A Retrospective Observational Study. PloS One. 2015;10(8):e0136230.

56. Cao Y, Rosner BA, Ma J, Tamimi RM, Chan AT, Fuchs CS, et al. Assessing individual risk for high-risk colorectal adenoma at first-time screening colonoscopy. Int J Cancer J Int Cancer. 2015 Oct 1;137(7):1719–28.