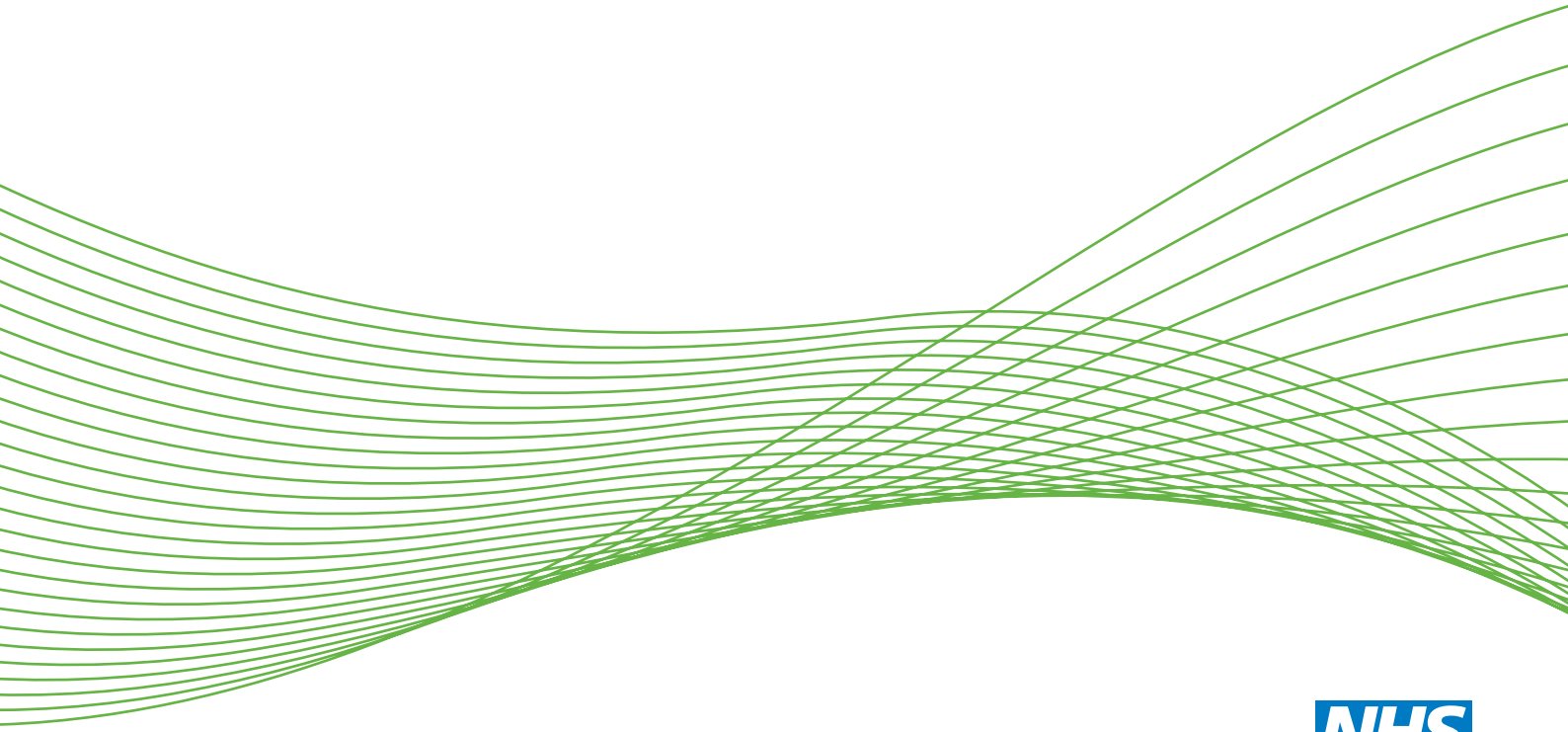
HEALTH SERVICES AND DELIVERY RESEARCH

VOLUME 2 ISSUE 43 NOVEMBER 2014
ISSN 2050-4349

What evidence is there for a relationship between organisational features and patient outcomes in congenital heart disease services? A rapid review

Janette Turner, Louise Preston, Andrew Booth, Colin O'Keeffe, Fiona Campbell, Amrita Jesurasa, Katy Cooper and Elizabeth Goyder



National Institute for Health Research

DOI 10.3310/hsdr02430

What evidence is there for a relationship between organisational features and patient outcomes in congenital heart disease services? A rapid review

Janette Turner, Louise Preston, Andrew Booth, Colin O'Keeffe, Fiona Campbell, Amrita Jesurasa, Katy Cooper and Elizabeth Goyder*

School for Health and Related Research (ScHARR), University of Sheffield, Sheffield, UK

*Corresponding author

Declared competing interests of authors: none

Published November 2014
DOI: 10.3310/hsdr02430

This report should be referenced as follows:

Turner J, Preston L, Booth A, O'Keeffe C, Campbell F, Jesurasa A, *et al*. What evidence is there for a relationship between organisational features and patient outcomes in congenital heart disease services? A rapid review. *Health Serv Deliv Res* 2014;**2**(43).

Health Services and Delivery Research

ISSN 2050-4349 (Print)

ISSN 2050-4357 (Online)

This journal is a member of and subscribes to the principles of the Committee on Publication Ethics (COPE) (www.publicationethics.org/).

Editorial contact: nihredit@southampton.ac.uk

The full HS&DR archive is freely available to view online at www.journalslibrary.nihr.ac.uk/hsdr. Print-on-demand copies can be purchased from the report pages of the NIHR Journals Library website: www.journalslibrary.nihr.ac.uk

Criteria for inclusion in the *Health Services and Delivery Research* journal

Reports are published in *Health Services and Delivery Research* (HS&DR) if (1) they have resulted from work for the HS&DR programme or programmes which preceded the HS&DR programme, and (2) they are of a sufficiently high scientific quality as assessed by the reviewers and editors.

HS&DR programme

The Health Services and Delivery Research (HS&DR) programme, part of the National Institute for Health Research (NIHR), was established to fund a broad range of research. It combines the strengths and contributions of two previous NIHR research programmes: the Health Services Research (HSR) programme and the Service Delivery and Organisation (SDO) programme, which were merged in January 2012.

The HS&DR programme aims to produce rigorous and relevant evidence on the quality, access and organisation of health services including costs and outcomes, as well as research on implementation. The programme will enhance the strategic focus on research that matters to the NHS and is keen to support ambitious evaluative research to improve health services.

For more information about the HS&DR programme please visit the website: http://www.nets.nihr.ac.uk/programmes/hsdr

This report

The research reported in this issue of the journal was funded by the HS&DR programme or one of its proceeding programmes as project number 13/05/12. The contractual start date was in March 2014. The final report began editorial review in April 2014 and was accepted for publication in May 2014. The authors have been wholly responsible for all data collection, analysis and interpretation, and for writing up their work. The HS&DR editors and production house have tried to ensure the accuracy of the authors' report and would like to thank the reviewers for their constructive comments on the final report document. However, they do not accept liability for damages or losses arising from material published in this report.

This report presents independent research funded by the National Institute for Health Research (NIHR). The views and opinions expressed by authors in this publication are those of the authors and do not necessarily reflect those of the NHS, the NIHR, NETSCC, the HS&DR programme or the Department of Health. If there are verbatim quotations included in this publication the views and opinions expressed by the interviewees are those of the interviewees and do not necessarily reflect those of the authors, those of the NHS, the NIHR, NETSCC, the HS&DR programme or the Department of Health.

Published by the NIHR Journals Library (www.journalslibrary.nihr.ac.uk), produced by Prepress Projects Ltd, Perth, Scotland (www.prepress-projects.co.uk).

Abstract

What evidence is there for a relationship between organisational features and patient outcomes in congenital heart disease services? A rapid review

Janette Turner, Louise Preston, Andrew Booth, Colin O'Keeffe, Fiona Campbell, Amrita Jesurasa, Katy Cooper and Elizabeth Goyder*

School for Health and Related Research (ScHARR), University of Sheffield, Sheffield, UK

*Corresponding author

Background: The purpose of this rapid evidence synthesis is to support the current NHS England service review on organisation of services for congenital heart disease (CHD). The evidence synthesis team was asked to examine the evidence on relationships between organisational features and patient outcomes in CHD services and, specifically, any relationship between (1) volume of cases and patient outcomes and (2) proximity of colocated services and patient outcomes. A systematic review published in 2009 had confirmed the existence of this relationship, but cautioned this was not sufficient to make recommendations on the size of units needed.

Objectives: To identify and synthesise the evidence on the relationship between organisational features and patient outcomes for adults and children with CHD.

Data sources: A systematic search of medical- and health-related databases [MEDLINE, EMBASE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), The Cochrane Library and Web of Science] was undertaken for 2009–14 together with citation searching, reference list checking and stakeholder recommendations of evidence from 2003 to 2014.

Review methods: This was a rapid review and, therefore, the application of the inclusion and exclusion criteria to retrieved records was undertaken by one reviewer, with 10% checked by a second reviewer. Five reviewers extracted data from included studies using a bespoke data extraction form which was subsequently used for evidence synthesis. No formal quality assessment was undertaken, but the usefulness of the evidence was assessed together with limitations identified by study authors.

Results: Thirty-nine papers were included in the review. No UK-based studies were identified and 36 out of 39 (92%) studies included only outcomes for paediatric patients. Thirty-two (82%) studies investigated the relationship between volume and mortality and seven (18%) investigated other service factors or outcomes. Ninety per cent were from the USA, 92% were multicentre studies and all were retrospective observational studies. Twenty-five studies (64%) included all CHD conditions and 14 (36%) included single conditions or procedures. Although the evidence does demonstrate a relationship between volume and outcome in the majority of studies, this relationship is not consistent. The relationship was stronger for single-complex conditions or procedures. A mixed picture emerged revealing a range of factors as well as volume that influence outcome, including condition severity, individual centre and surgeon effects and clinical advances over time. We found limited (seven studies) evidence about the impact of proximity and colocation of services on outcomes, and about volume on non-mortality outcomes.

Limitations: This was a rapid review that followed standard methods to ensure transparency and reproducibility. The main limitations of the included studies were the retrospective nature, reliance on routine data sets, completeness, selection bias and lack of data on key clinical and service-related processes.

Conclusions: This review identified a substantial number of studies reporting a positive relationship between volume and outcome, but the complexity of the evidence requires careful interpretation. The heterogeneity of findings from observational studies suggests that, while a relationship between volume and outcome exists, this is unlikely to be a simple, independent and directly causal relationship. The effect of volume on outcome relative to the effect of other as yet undetermined health system factors remains a complex and unresolved research question.

Funding: The National Institute for Health Research Health Services and Delivery Research programme.

Contents

List of tables

List of figures

List of boxes

List of abbreviations

ASO	arterial switch operation
BTSP	Blalock–Taussig shunt procedure
CHD	congenital heart disease
CINAHL	Cumulative Index to Nursing and Allied Health Literature
cPICU	cardiac paediatric intensive care unit
EACTS	European Association for Cardio-Thoracic Surgery
ECMO	extracorporeal membrane oxygenation
HLHS	hypoplastic left heart syndrome
HS&DR	Health Services and Delivery Research
ICD-9-CM	*International Classification of Diseases*, Ninth Revision, Clinical Modification
ICU	intensive care unit
IRP	independent reconfiguration panel
JR	judicial review
LOS	length of stay
MeSH	medical subject heading
NIHR	National Institute for Health Research
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RACHS-1	Risk Adjusted classification for Congenital Heart Surgery
ScHARR	School of Health and Related Research
STS-EACTS	Society of Thoracic Surgeons–European Association for Cardio-Thoracic Surgery
TGA	transposition of great arteries
VAD	ventricular assist device
VSD	ventricular septal defect

Plain English summary

Some people have problems with the structure of their heart when they are born (congenital heart disease). These problems need treatment during childhood and sometimes later when the patients become adults, and it is important that these people are cared for in a hospital where they will get the best possible specialist treatment for their condition.

For our review, we were asked to look at whether or not the treatment that patients receive and what happens to them as a result of this treatment (outcomes) are influenced by features of the hospital treating them. It is often thought that in hospitals where a lot of operations are done (both in the hospital and by individual surgeons), care for patients is better. It is also often thought that hospitals where key services are located together have better outcomes. We looked at published academic articles to provide this information.

We found 39 scientific studies that had investigated these features and analysed them to identify the key messages they contained. The main outcome studied was whether or not patients survived their surgery.

Our review found that while many of the studies show better patient outcomes when larger volumes of surgery are performed, this was not consistent and not all of the studies showed this. Where studies showed that there was a relationship between better patient outcomes and larger volumes of surgery, it was not clear why larger volumes led to better outcomes. More research is needed to try to better understand what other aspects of service affect outcome.

Scientific summary

Background

This rapid evidence synthesis has been written in response to a request by NHS England to further examine the evidence around the delivery of congenital heart disease (CHD) services. The purpose of the evidence synthesis is to support the ongoing service review about how these services should be best organised. Prior work for the service review referred to a 2009 literature review which confirmed a relationship between volume and patient outcomes in CHD and highlighted the contributory effects of other system and process factors to this relationship. This rapid evidence synthesis has reassessed and updated the evidence base to examine what evidence there is for a relationship between organisational features and patient outcomes in CHD services.

Objectives

This rapid review focuses on two key organisational features: volume and proximity. The rationale for this is based on the hypothesis that there may be a relationship between the volume of CHD procedures (both by institution and by surgeon) and patient outcomes and the clinical conjecture that reconfiguration which includes the colocation (or increased proximity) of specialist services may be related to better patient outcomes. The research questions also reflect the view that mediating factors influence the relationship between patient outcomes and volume and proximity.

The research questions are as follows:

- What is the current evidence for the relationship between institutional and surgeon volume and patient outcomes and how is that relationship influenced by complexity of procedure and by patient case mix?
- How are patient outcomes influenced by proximity to/colocation with other specialist clinical services (e.g. colocation of services such as specialist cardiac paediatric intensive care)?

Methods

The rapid review was undertaken in 12 weeks. Our review aimed to identify key evidence of relevance to the review question and to extract and synthesise this evidence in a transparent and reproducible manner. A range of search methods was used to identify English-language, peer-reviewed evidence from 2003 to 2014 to address the research questions. Search methods included database searches, citation searches, evidence from topic experts and scrutiny of reference lists from key reviews and included evidence. Assessment of the search results according to the inclusion and exclusion criteria was undertaken by one reviewer and a 10% random sample checked by a second reviewer according to a predefined set of inclusion and exclusion criteria. Data extraction was undertaken in Microsoft Excel (2010, Microsoft Corporation, Redmond, WA, USA) using a purpose-specific data extraction form developed iteratively and tested extensively for this rapid review. Formal quality assessment was not undertaken; instead the usefulness of included studies to answering the review question and the generic and study-specific limitations reported by study authors were critically assessed. Data were extracted and then tabulated in Microsoft Word (2010, Microsoft Corporation, Redmond, WA, USA). Owing to both the clinical and methodological heterogeneity of the included studies, a meta-analysis was not undertaken.

Results

A total of 39 studies were included in the review. Our database searches identified 2256 references, from which 19 papers were included in the review. Supplementary search methods were used extensively. An additional 20 papers included in the review were identified via citation searching (two papers), reference lists of published reviews (15 papers) and reference lists of included papers (three papers).

No UK-based studies were identified and 36 out of the 39 studies (92%) included outcomes only for paediatric patients. Of the 39 included studies, 32 (82%) investigated the relationship between volume and mortality and seven (18%) the relationships between other service factors and outcome or between volume and non-mortality outcomes. Eighteen of the 32 studies investigating the volume–mortality relationship included all CHD conditions and 14 focused on specific single or complex conditions and procedures. Thirty-one of the 37 studies (84%) that used mortality as the primary outcome measured in-hospital mortality. Only 10 (27%) of the included studies measured mortality after discharge from hospital. Thirty-five studies (90%) were from the USA, 92% were multicentre studies and all were retrospective observational studies.

Overall, we have found that although the evidence does demonstrate a relationship between volume and outcome in the majority of studies, this relationship is not consistent. Studies on single conditions or procedures were more likely to identify an effect of volume on mortality but these were focused on high-risk conditions, such as hypoplastic left heart syndrome, and procedures, for example the Norwood procedure. Even within these highly selected groups there was considerable variation in effect depending on procedure type and individual centre performance. It is possible that, for example, surgeon volume may be as important as centre volume for these complex cases. This updated and extended review confirms a pattern of studies supporting the existence of a volume and outcome relationship.

The findings from studies that did consider broader CHD populations were more equivocal. In some studies in which an effect was identified, the effect was weak or demonstrable for only specific subgroups of patients. Overall, there was no clear indication that the evidence for the volume and mortality relationship was substantially stronger than the evidence for a no effect relationship in this group. The findings further highlight the complex relationship between volume and outcome and the range of other factors, which also have an effect. Some of these, such as condition severity, are well established but the effect of association of processes, systems and individual clinical effects on outcome remain unknown.

We also included evidence from three studies on adult CHD, of which one, which included patients receiving a transplant for a range of conditions in addition to CHD, was of limited value. The other two studies explored the effect of surgeon type in relation to outcome. Both studies found that adult CHD patients had better outcomes when operated on by paediatric surgeons in specialist children's centres.

We found limited evidence on the effects of proximity of other services on mortality or the impact of volume on non-mortality outcomes. There appears to be relatively little evidence from studies that attempt to measure the effect of related processes on outcome and this is an area for future development.

Some key themes emerged from our analysis.

1. There are a range of factors which influence mortality in CHD, and centre volume is only one of them. Our data extraction identified 67 different variables used to adjust for risk in the included studies and the most influential risk factor for mortality is the severity of the condition.
2. Medicine moves forward, and clinical advances, training, increasing expertise and changes in service provision mean outcomes for CHD have also changed over time. Five studies that analysed data over long time periods (approximately 10 years) measured changes in mortality over time and found that, irrespective of other factors including volume, mortality decreased over this time period.

This occurred despite increasing complexity, thus attesting to ongoing clinical improvement. This means the relevance of findings from historical data to contemporary services needs to be carefully considered.

3. Although aggregated data may show a difference in mortality rates between low- and high-volume centres, such aggregation may mask between-centre variation. Several included studies identified variation between centres, with some low- or medium-volume centres performing equally as well as those with high volume. Such variation indicates that individual centre effects relating to training, management protocols, expertise and availability of services are also likely to influence outcomes.
4. The evidence base available to guide UK decisions on service design and configuration for CHD is dominated by retrospective studies conducted within the USA, and many of the studies have analysed centres with very small case numbers. The extent to which the reported findings are generalisable and relevant to the UK setting is, therefore, limited. The organisation of services in the USA is very different to the UK and other countries where there has already been a degree of centralisation of CHD services. With centralisation comes a corresponding increase in volume, as more cases are concentrated in fewer centres. It remains unclear whether the impact of volume on outcome is largely a consequence of higher-volume units organising and providing a complex service with all the 'right' components, or whether it remains an independent factor directly related to the advantages of dealing with a larger number of cases. The lack of any UK studies to contribute to the review indicates a serious gap in evidence relevant to service provision in the NHS.
5. Despite the growing number of studies, few have suggested what the optimum size of a CHD centre in terms of volume should be. Fewer than half of the included studies analysed volume as a continuous variable which would provide the most robust evidence from which to consider volume thresholds.

Limitations

This was a rapid review with limited second sifting and a modified quality appraisal that followed standard methods to ensure that it was transparent and reproducible.

Many authors of studies included in the review take great care to point out the methodological limitations of their studies and caution against overinterpretation of their findings. Included studies are predominantly retrospective and observational in nature. Such design features make it very problematic when trying to establish a direct inverse relationship of cause (volume) to effect (mortality). All but five of the included studies used routine data sets as the source data including administrative, registry and voluntary data sets. With this comes consequent risks to data quality such as completeness, accuracy and selection bias. These sources also lack the data on key clinical and service-related processes needed to explain the associated effects of factors other than volume on outcome. The insights gained from study reports of a single condition or surgical procedure are important for an understanding of those conditions. Typically such reports bear little relation to overall surgical volume and, therefore, provide a limited contribution to the evidence that relates to optimal volumes for entire CHD services.

It is increasingly recognised that certain methods of investigation and analysis are unsuited to investigation of the volume/outcome question. Even though considerable advances in methodological approaches (e.g. complexity stratification) continue to be made, questions about the optimal configuration for volume/outcome debate remain unlikely to be resolved within the foreseeable future. This seems particularly the case given the absence of a comprehensive and accurate national database that provides sufficient information to account for risk, complexity and the effects of clinical care and service-related processes.

Conclusions

We have conducted a rapid review of the evidence on the relationship between volume and outcome and between other service factors and outcome for CHD. Overall, we found a substantial number of studies reporting a positive relationship between volume and outcome, particularly for highly complex cases. However, the complexity of the evidence requires careful interpretation. A mixed picture emerged from the 39 included studies, which increases our understanding of the complexity of this relationship and highlights variation in both methods and findings across individual studies, the potential effects of a range of other factors that may interact with volume and influence outcome and the methodological limitations imposed by the research approaches taken. Interpreting the evidence is particularly challenging because of a lack of information on clinical and service-related processes in the literature. This lack of information means that the volume–outcome relationship is difficult to disentangle from other clinical and service-related processes and outcomes.

A clear evidence gap remains to be addressed with regard to better understanding of the relationships between the wide range of organisational factors in CHD services, how these can potentially predict a number of outcomes of relevance to patients and families, and the causal pathways between organisational factors and outcomes. It is these questions that need to be answered and this requires the development of comprehensive, high-quality clinical and administrative databases which collect information on a range of organisational factors and outcomes related to quality of care. There is scope to expand the existing National Institute for Cardiovascular Outcomes Research (NICOR) database to capture more of this information. There is a clear need to conduct robust UK-based studies; an enhanced database could then be used to conduct observational studies of the relationship between organisational factors, including volume, and outcomes that would have direct relevance to the NHS. Future research efforts directed to these tasks would be of considerable benefit to improving patient care for CHD.

Funding

The National Institute for Health Research Health Services and Delivery Research programme.

Chapter 1 Background

This rapid evidence synthesis has been written in response to a request by NHS England to further examine the evidence around the delivery of congenital heart disease (CHD) services. The purpose of the evidence synthesis is to support the ongoing NHS England service review about how CHD services should be best organised.

Services for children with CHD have been the subject of scrutiny for a number of years. In 2012, following an extensive review as part of the Safe and Sustainable work programme, a series of recommendations were made for the reconfiguration of cardiac services for this patient group.[1] The rationale for change was based on the view that clinical expertise was spread too thinly and that providing CHD surgery in a smaller number of units would ensure a critical mass of cases, access to associated specialist staff and the ability to provide a safe 24/7 emergency service. At the time of the review CHD surgery for children was carried out in 11 centres.

The Safe and Sustainable CHD review (*Review of Children's Congenital Cardiac Services in England*)[1] recommended that CHD services be provided by seven managed clinical networks centred on seven units. However, these recommendations were challenged and subsequently became the subject of a judicial review (JR) and an independent reconfiguration panel (IRP) inquiry, which concluded that processes of the review were flawed. Consequently, service reconfiguration was not implemented and these services are subject to a new review which will consider the whole lifetime pathway for CHD.

The JR and IRP identified a number of issues of concern with the Safe and Sustainable review process including the use and interpretation of the existing evidence base on surgical services for CHD and patient outcomes. In particular, they questioned the reliance on evidence around the relationship between volume of cases and outcomes. A literature review undertaken in 2009 by Ewart[2] had examined this evidence in detail and, although confirming the existence of a relationship between volume and outcome, cautioned that this relationship alone was not sufficient to make recommendations on the size of units needed. The review was not able to identify any reliable evidence on the cut-off points in terms of the minimum annual numbers of cases needed for a centre. Ewart[2] also highlighted that probable contributory effects of other system and process factors on the relationship between volume and outcome in the published literature were unclear.

As it is now almost 5 years since the publication of the Ewart review, it is timely to reassess the evidence base for CHD services to support the current service review. The purpose of this evidence synthesis, in the form of a rapid review, is to examine what evidence there is for a relationship between organisational features and patient outcomes in CHD services.

This rapid review of published research on the relationship between volume, proximity and patient outcomes is just one of the sources of evidence which has been commissioned to inform the NHS England CHD service review. The overall aim of this service review was to ensure that services for people with CHD are provided in a way that achieves the highest possible quality within the available resources. This will involve consideration of a very wide range of types of evidence including published research, but also audit and other service quality-related data from CHD services and information based on the experiences of clinicians, patients and families.

Chapter 2 Hypotheses tested in the review (research questions)

Because this is a rapid review, it focuses on two key organisational features: volume and proximity. The rationale for this is based on the existing, evidence-based consensus that there may be a relationship between the volume of CHD procedures (both by institution and by surgeon) and patient outcomes and the clinical consensus that reconfiguration which includes the colocation (or increased proximity) of specialist services may be related to better patient outcomes. The research questions also reflect the view that there are mediating factors that influence the relationship between patient outcomes and volume and proximity.

The research questions are as follows:

- What is the current evidence for the relationship between institutional and surgeon volume and patient outcomes and how is that relationship influenced by complexity of procedure and by patient case mix?
- How are patient outcomes influenced by proximity to/colocation with other specialist clinical services (e.g. colocation of services such as specialist cardiac paediatric intensive care)?

Chapter 3 Review methods

Rapid review methods

Owing to the need to complete this review within a very short timeframe (12 weeks including a 3-week protocol development stage) rapid review methods were used to ensure the efficient identification and synthesis of the most relevant evidence.

Rapid review methods are still in their relative infancy, in comparison with the more established systematic review. Harker and Kleijnen[3] examined a number of rapid reviews in order to develop understanding and definition of what a rapid review was. Rapid reviews are undertaken over a short time frame with a streamlined methodology. This streamlined methodology is a necessary compromise from a standard systematic review. Although Harker and Kleijnen[3] found considerable variation in the methodologies adopted by rapid reviews, acknowledging that there is not a 'one size fits all' methodology, they advise 'clear and transparent description and discussion of methodology utilised and acknowledge any limitations'. This advice has informed our choice of methods and report writing.

Our review did not attempt to identify *all* relevant evidence or to search *exhaustively* for all evidence that meets the inclusion criteria; the search approach aimed to identify the key evidence of most relevance to the review question.

The scope to both search for and review related evidence, reflecting the multiple dimensions of the topic, was considerable and, thus, was considered prohibitive within the given time frame. The rapid review therefore focused on the most relevant evidence from CHD services for children and adults. The rapid review was based on a proposed conceptual framework included in the study protocol. This allowed us to:

- define the scope of the search strategy
- define inclusion and exclusion criteria to specify what types of studies were to be included in the final report
- construct summary tables of all included studies to present key information and findings
- synthesise the evidence from the included studies.

Protocol development

The protocol for the review was developed iteratively between the School of Health and Related Research (ScHARR), NHS England and the National Institute for Health Research (NIHR) Health Services and Delivery Research (HS&DR) programme. In addition, comments were sought from key stakeholders, who were part of the NHS England Clinical Advisory Panel for the CHD review. The protocol development started on 7 January 2014 and was published on the NHS England website on 10 February 2014.[4]

Use of the conceptual framework

There is an extensive health services research evidence base documenting associations between a range of organisational factors, particularly factors related to location, nature and size of specialist facilities and outcomes, in both elective and emergency service provision. There is also a major field of research that has explored, both quantitatively and qualitatively, the impact of different aspects of service organisation and delivery which influence patient safety and may reduce the risk of adverse outcomes for patients. In order to make the relationship between this wider evidence base and the, relatively limited,

scope of this commissioned rapid review more explicit, a logic model (or conceptual framework) was developed for the study protocol and this is included in *Appendix 1*. This figure shows the relationship between the specific inclusion criteria for this review and the much wider context of factors of known relevance which were considered for inclusion in the review if there were relevant data within the included studies. This approach was chosen based on the need to both limit the scope of the review to the most relevant evidence, while not ignoring the very wide range of organisational, cultural and patient-related factors already known to be important predictors of outcome. The conceptual model was used to inform (1) the literature search, (2) development of inclusion and exclusion criteria, (3) data extraction and (4) evidence synthesis.

Literature searching

A range of search methods, as outlined below, were used in order to identify evidence to answer the rapid review research questions in a timely fashion:

- Stage 1 – search of health and medical databases.
- Stage 2 – citation searching.
- Stage 3 – call for evidence from topic experts.
- Stage 4 – scrutiny of reference lists of published reviews/key evidence.
- Stage 5 – scrutiny of reference lists of included papers.

The search process was undertaken with reference to the protocol, in particular to the conceptualisation of the different subareas within which to identify relevant evidence (*Figure 1*).

A systematic search of medical and health-related databases [MEDLINE, EMBASE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), The Cochrane Library and Web of Science] was undertaken for the years 2009–14 together with citation searching, reference list checking and recommendations from stakeholders to identify evidence for 2003–14. The rationale for limiting the review to 2003–14 was that this was in line with the dates used by Ewart[2] and would limit the body of evidence to a manageable but meaningful number of studies.

Stage 1: search of health and medical databases

The starting point of our search strategy was Ewart.[2] We modified search terms from the previous review to capture a wider evidence base around the population (adults and children), interventions (surgical and interventional) and outcomes (mortality, complications and related outcomes).

The search strategy used a combination of free text and medical subject headings (MeSH) and can be found in *Appendix 2*. The search was around key terms for the population (CHD), the intervening variables (volume and proximity) and outcomes (mortality, death, survival).

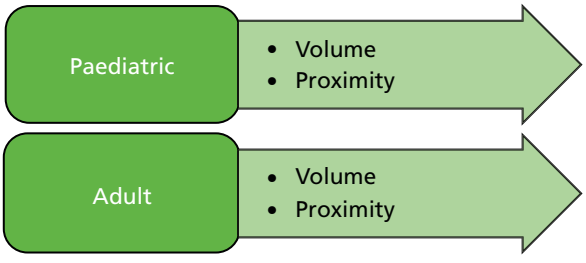


FIGURE 1 Conceptualisation of the evidence base.

We searched MEDLINE and EMBASE via OvidSP, The Cochrane Library via Wiley Online Library, Web of Science via Web of Knowledge and CINAHL via EBSCO*host*. MEDLINE, EMBASE, CINAHL and The Cochrane Library are commonly considered the core databases for identifying evidence relating to clinical topics.[5]

The search strategy was limited to 2009–14 with the rationale that relevant evidence from 2003–8 would be cited in later papers or in later reviews retrieved by the database search and, therefore, identified via stages 2–5.

The searches were undertaken in January 2014 and an updated search was undertaken in March 2014. The search results were downloaded into Reference Manager (version 12; Thomson Reuters, New York City, NY, USA) where they were assessed for inclusion in the review. Additional detail on this process is available later in *Chapter 3, Assessment according to inclusion and exclusion criteria*.

Stage 2: citation searching

A search was undertaken to identify any published articles that have cited any of the articles included in the Ewart review.[2] This search was undertaken via Google Scholar, using the Publish or Perish software [Harzing AW (2007); available from www.harzing.com/pop.htm] to manage the references identified. These references were then imported into Reference Manager.

We also undertook citation searching using included papers in areas not included within the scope of the original Ewart review[2] (i.e. adult and paediatric proximity and adult volume).

Stage 3: call for evidence from topic experts

A call for evidence for potential inclusion in the review was made via the NHS England CHD blog,[4] directly at the NHS England patient and public group and via e-mail to the NHS England Clinical Advisory panel. Evidence was forwarded to ScHARR via NHS England. Papers suggested by topic experts and the wider group of interested parties are listed in *Appendix 2*.

Stage 4: scrutiny of reference lists of published reviews/key evidence

In order to identify additional published evidence that was not retrieved by the database searches, the team undertook scrutiny of reference lists of published reviews of services, guideline documents and reports as identified through stages 1, 2, 3 and 5. Reviews that informed this stage of the search are listed in *Appendix 2*.

Stage 5: scrutiny of reference lists of included papers

Reference lists of all papers identified for inclusion were examined. Any titles considered to be relevant were then scrutinised at an abstract level via PubMed. Any relevant full papers were considered for inclusion by a reviewer. Where papers were identified for inclusion, their reference lists were subsequently checked.

Inclusion/exclusion criteria

The inclusion or exclusion of studies in the review was according to the criteria in *Table 1*.

TABLE 1 Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Population	Adults and children undergoing treatment (surgical or interventional) for CHD	
Intervention	Measurement of outcomes based on at least one of the following: volume of activity or colocation with other related services	
Outcome	Patient outcomes	Process/service outcomes (these will be included only if studies report at least one patient outcome)
Study type	Quantitative studies (observational evidence and evidence from trials). Publication date 2003–14. Published, peer-reviewed evidence	Qualitative evidence, evidence from surveys of views/experiences, editorials, opinions, non-English-language papers, non-OECD countries

OECD, Organisation for Economic Co-operation and Development.

Assessment according to inclusion and exclusion criteria

References identified from stages 1 and 2 were downloaded into Reference Manager, version 12, to be sifted for inclusion in the review. All potential titles were examined for inclusion by one reviewer. Any titles that did not meet the inclusion criteria were excluded. Following the examination at the title level, any remaining references were scrutinised at the abstract level. For any references where possible inclusion was unclear, a second reviewer independently examined the corresponding full text.

Ten per cent of the titles and abstracts of these citations identified by the searches were checked by a second reviewer (and a check for consistency undertaken).

For stages 3, 4 and 5 references were checked following the same three-stage process as for stages 1 and 2 (title, abstract and full text).

Assessment for inclusion of conference abstracts identified from all stages of the search was undertaken by one reviewer and checked by a second. Both reviewers assessed each conference abstract based on three criteria, namely whether or not:

- the abstract fulfilled the inclusion criteria, in terms of the explanatory variables and outcomes
- the evidence in the abstract was included within an already included paper
- there were sufficient data in the abstract to be able to use the data in a meaningful manner to address the aims of the review.

Data extraction, including development of the data extraction tool

The aim of the data extraction process was to focus on the most critical information for evidence synthesis rather than exhaustively extracting and critiquing all available information within individual papers. Owing to the rapid nature of the review, data extraction was undertaken by five reviewers.

A standardised data extraction form was developed using the following process. The initial draft of the data extraction tool was designed as a comprehensive way to capture all relevant information from the studies on a broad range of factors related to CHD services that may affect patient outcomes following interventions. Four members of the ScHARR review team tested this initial draft on three studies.[6–8]

It became apparent that these studies, which focused on the relationship between volume and mortality, considered complexity of the underlying cardiac condition and other patient-level factors in their analysis, but did not include details of relevant organisational factors such as staffing and proximity of related services. Similarly, mortality was the only outcome considered in these studies and other relevant outcomes such as morbidity, complications, length of stay (LOS) and readmissions were not included.

The data extraction tool was therefore revised in the light of this initial data extraction. The revision also included reference to data tables included in other reviews in this area: Ewart[2] and Bazzani and Marcin.[8] The final layout was determined to explicitly include the following key details, in addition to the information included as standard on a data extraction form:

- where data were obtained from a database, whether contribution to the database was voluntary (to indicate potential bias in reporting) and whether the purpose of the database was administrative or clinical (to highlight the potential limitations of the details available)
- whether volume was considered as a continuous or categorical variable and, if categorical, what were the thresholds determined by the study for the different categories
- the covariates used in the analysis
- in the quantitative assessment of the relationship between volume/proximity and mortality, a breakdown of the crude association and the adjusted association (for case mix ± other covariates).
- where an association was identified, what was the nature of this relationship (linear or non-linear)?

A sample data extraction form is available in *Appendix 3*.

Quality assessment

Rather than using a standard checklist approach, the focus was on an assessment of the overall usefulness of the included evidence in answering the research questions. The assessment of usefulness was based on a number of factors which included:

- whether the study adjusted for severity of condition
- whether the study adjusted for age
- whether the study was multicentre
- whether the study included more than one intervention/condition
- whether the contribution to the database used to collect the data was voluntary and whether data were collected comprehensively or collectively.

Assessment of the limitations of included studies was also undertaken using the limitations reported by study authors in the included studies.

Synthesis

Data were extracted and tabulated. This tabulation was used to inform the narrative synthesis in the results section. A meta-analysis was not considered given that the review was a rapid review and there was considerable heterogeneity in the design, methods and setting of the included studies making the clinical value of such a formal statistical analysis open to debate.

Chapter 4 Studies included in the review

Results of the literature search

The full papers and conference abstracts identified as a result of the literature search are described in the modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram in *Figure 2*.

To summarise *Figure 2*, 39 full journal articles and four conference abstracts met the inclusion criteria. Four additional abstracts met the inclusion criteria; however, the evidence included in them was already included in a full paper. Upon scrutiny, the information included in the abstracts was insufficient for full data extraction and could not be used in a meaningful manner to address the aims of the review. Therefore, a decision was made to extract as much data as possible from these abstracts and include this information for reference in the report appendix but to not include this evidence in the analysis. The tables can be found in *Appendix 3*.

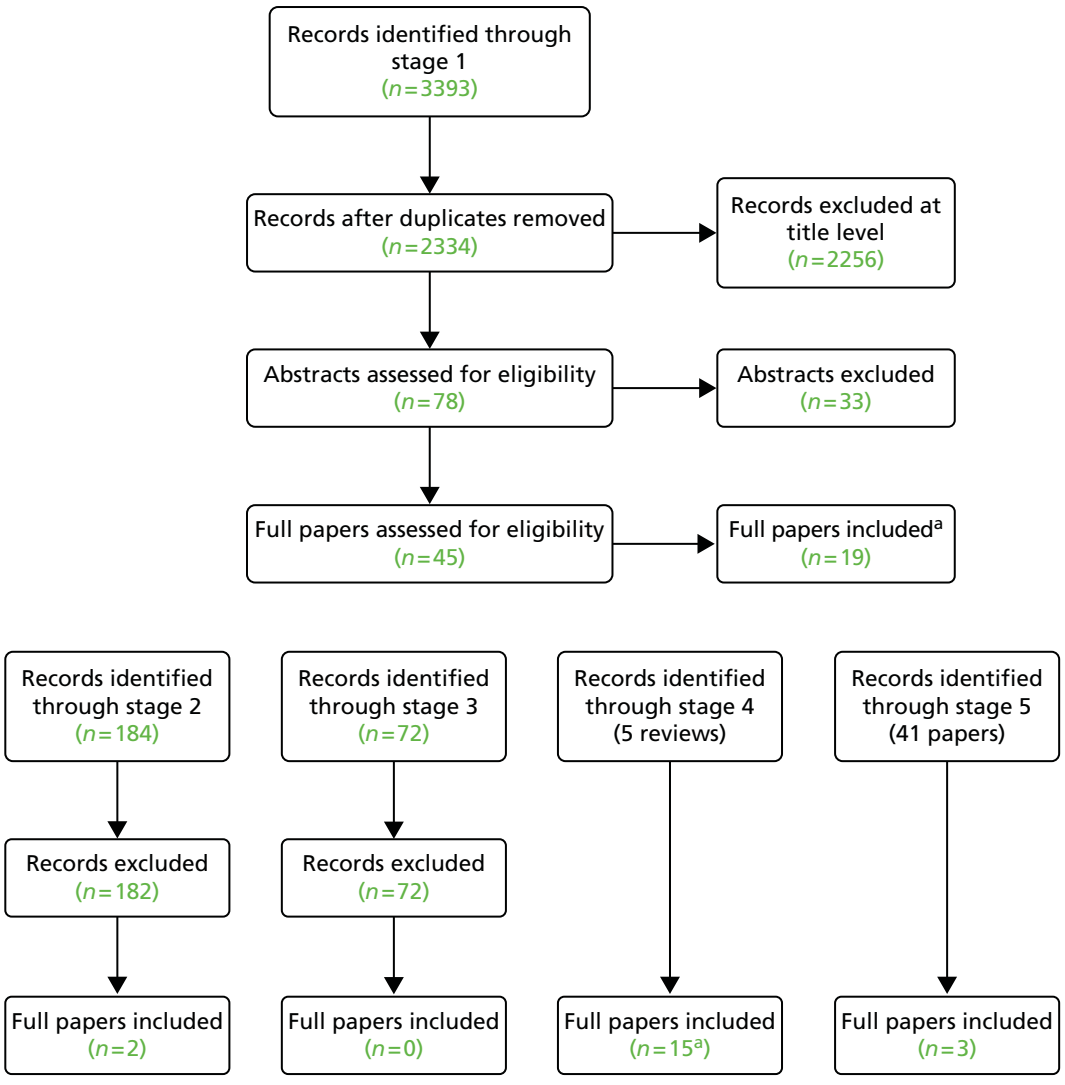


FIGURE 2 Modified PRISMA diagram. a, This includes seven papers originally included in Ewart.[2]

Second screening of retrieved references

In order to check the screening consistency of the single reviewer a second reviewer screened approximately 10% of the references ($n = 300$). Reviewer 2 tagged 5 out of 292 (1%) references excluded by reviewer 1 as potential includes and tagged 1 out of 8 (12.5%) references included by reviewer 1 as probable excludes. This gave a kappa statistic of 0.77, generally acknowledged as good agreement. The three additional potential includes identified by reviewer 2 were tenuous includes (two review articles potentially relevant as background, and an article for which only a title was available), whereas the one article tagged as 'include' by reviewer 1 and 'exclude' by reviewer 2 was subsequently checked for inclusion at the full-text stage. Therefore, it was unlikely that any relevant primary studies were overlooked in the 10% sample checked and this result can be extrapolated to the remainder of the screening process.

List of studies included in the review

Box 1 lists the studies that met the criteria for inclusion for review.

List of conference abstracts included in the review

Table 2 lists the conference abstracts that met the criteria for inclusion in the review.

BOX 1 List of studies included in the review

Author and year

- Arenz *et al.*, 2011.[9]
- Arnaoutakis *et al.*, 2012.[10]
- Bazzani and Marcin, 2007.[8]
- Benavidez *et al.*, 2007.[11]
- Berry *et al.*, 2007.[12]
- Berry *et al.*, 2006.[13]
- Burstein *et al.*, 2011.[14]
- Chang *et al.*, 2006.[7]
- Checcia *et al.*, 2005.[15]
- Davies *et al.*, 2011.[16]
- Dean, 2013.[17]
- Dinh and Maroulas, 2010.[18]
- Eldadah *et al.*, 2011.[19]
- Fixler, 2012.[20]
- Gray *et al.*, 2003.[21]
- Hickey *et al.*, 2010.[22]
- Hirsch *et al.*, 2008.[23]
- Hornik *et al.*, 2012.[24]
- Karamlou *et al.*, 2013.[25]
- Karamlou *et al.*, 2008.[26]
- Karamlou *et al.*, 2010.[27]
- Kazui *et al.*, 2007.[28]
- Kim *et al.*, 2011.[29]
- McHugh *et al.*, 2010.[30]
- Mery, 2014.[31]
- Morales *et al.*, 2010.[32]
- Oster *et al.*, 2011.[33]
- Pasquali *et al.*, 2012a.[34]
- Pasquali *et al.*, 2012b.[35]
- Petrucci *et al.*, 2011.[36]
- Pinto *et al.*, 2012.[37]
- Sakata *et al.*, 2012.[38]
- Seifert *et al.*, 2007.[39]
- Tabbutt *et al.*, 2012.[40]
- Vinocur, 2013.[41]
- Welke *et al.*, 2010.[42]
- Welke *et al.*, 2009.[43]
- Welke *et al.*, 2008.[6]
- Welke *et al.*, 2006.[44]

TABLE 2 List of conference abstracts included in the review

Author	Related to study
Karamlou *et al.* 2014[45]	Karamlou *et al.* 2010[27]
Kochilas *et al.* 2009[46]	Vinocur 2013[41]
Scheurer *et al.* 2011[47]	Burstein *et al.* 2011[14]
Welke *et al.* 2012[48]	Hornik *et al.* 2012[24]

Chapter 5 Studies excluded from the review

A full list of the full-text studies and conference abstracts excluded from the review is available in *Appendix 2*. In addition, the evidence suggested by topic experts and assessed for inclusion by the review team is also available in *Appendix 2*.

Chapter 6 Results of the review

Detailed summary tables of included papers are provided in *Appendix 3*. We also identified four relevant published conference abstracts and a summary of these is provided in *Appendix 2* for reference. However, we have not considered these in our analysis.

Characteristics of included studies

Thirty-nine full-text papers were included in the review. The characteristics of these papers are summarised in *Table 3*.

No UK studies were identified and 36 out of 39 studies (92%) included only paediatric patients. The majority of studies (90%) were conducted in the USA and most were multicentre (92%). We have classified included studies in to three broad groups: those where the primary objective was to explore the relationship between volume of service and mortality outcome for a range of CHD conditions (18/39); those where the focus was on the relationship between volume and mortality outcome for specific single conditions or procedures (14/39); and those where the focus was on the impact of a variable other than volume or where non-mortality outcomes only were reported (7/39). For studies involving specific conditions or procedures these were mainly complex conditions, such as hypoplastic left heart syndrome (HLHS), pulmonary atresia and/or procedures including the Norwood procedure, arterial switch operation (ASO), transposition of great arteries (TGA) and Blalock–Taussig shunt procedure (BTSP) (10/14); heart transplant (2/14); ventricular septal defect (VSD) repair cases only (1/14); and ventricular assist devices (VADs) only (1/14).

Two studies included a paediatric CHD population as a subgroup in studies that examined a range of cardiothoracic procedures[38,28] and one a range of common paediatric operations.[12] For these studies only the findings related to the CHD population are reported here. Three procedure-based studies for heart transplant[10,16] and VAD[32] included patients with conditions other than CHD.

The majority of studies used routine data sets (35/39) and, among these, voluntary clinical or mixed clinical and administrative data sources predominated (21/39), with 13 studies utilising involuntary administrative data. Descriptions of these data sets are provided in *Appendix 4*. Five studies used study-specific data including one using data from a clinical trial.[40]

Half of the studies included children of all ages (age range 0–20 years), 14 out of 39 included only newborns and infants and three studies included adults.

Mortality was the primary outcome measure used, with two studies reporting only morbidity outcomes. The use of routine data is reflected in the types of study design used. There were no primary clinical trials with retrospective observational designs being the predominant feature. There was one before-and-after study assessing the impact of a cardiac paediatric intensive care unit (cPICU).[19]

Study populations and settings

Table 4 provides a summary of the dates, inclusion dates, study settings and sample sizes. Where reported, numbers of centres and centre volumes are included. In-hospital mortality is death during the admission for the procedure.

TABLE 3 Summary of characteristics of included full papers

Study characteristics	Number (%)
Total number of full-text papers included	39 (100)
Variables	
Paediatric volume and mortality relationship (all conditions)	18 (46)
Paediatric volume and outcome relationship (specific conditions/procedures)	14 (36)
Variables other than volume or non-mortality outcomes	7 (18)
Country	
USA/Canada	35 (90)
Japan	2 (5)
Germany	1 (2.5)
Sweden	1 (2.5)
Centre type	
Multicentre	36 (92.4)
Single centre	3 (7.6)
CHD condition/procedure type	
All CHD conditions/procedures	25 (64)
Single CHD condition/procedure	14 (36)
Data sources	
Voluntary (STS-CHD, HCUP-KIDS, PCCC and UHC databases)	21 (53)
Involuntary/registry (PHIS, NIS, OSHPD, UNOS, Texas birth defects registry)	13 (33)
Study specific	5 (13)
Patient population	
All children (0–20 years)	22 (56.4)
Newborns and infants only	14 (36.9)
Adults	3 (7.6)
Outcomes measured	
Survival/mortality only	29 (74.5)
Survival/mortality and other outcomes	8 (20.5)
Other outcomes only (e.g. morbidity, complications)	2 (5)
Design	
Retrospective cohort	33 (82)
Cross-sectional analysis	5 (13)
Before and after	1 (2.5)

HCUP-KIDS, Healthcare Cost and Utilization Project – Kids Inpatient Database; NIS, Nationwide Inpatient Sample; OSHPD, Office of State-wide Health Planning and Development (California); PCCC, Paediatric Cardiac Care Consortium; PHIS, Paediatric Health Information Service; STS-CHD, Society of Thoracic Surgeons – Congenital Heart Disease; UHC, University Health System Consortium; UNOS, United Network for Organ Sharing.

TABLE 4 Summary of the dates, inclusion dates and study settings of included studies

Study	All (A) or specific (S) cases[a]	Study period	Sample size,[b] number of centres	Lowest and highest reported centre volumes per year[c]	Mortality/survival end point
Arenz *et al.* 2011[9]	A	2006–9	1828	Single centre mean 457 cases per year	In hospital within 30 days
Arnaoutakis *et al.* 2012[10]	S	2000–10	18,226,141 centres	≤ 7 to > 15 transplant cases	30 days and 1 year
Bazzani and Marcin 2007[8]	A	1998–2003	(a) 12,801 cases, four analyses (b) 13,917 cases, one analysis	Lowest 20 < 75, > 75 cardiac surgery cases	Within 30 days
Benavidez *et al.* 2007[11]	A	2000	10,032, 100 centres	< 150 to > 450 CHD surgery admissions	Morbidity only
Berry *et al.* 2007[12]	S	2003	2301, 113 centres	≤ 4 to ≥ 10 VSD repair cases	In hospital
Berry *et al.* 2006[13]	S	1997 and 2000	754 in 1997, 880 in 2000	1 to 10 HLHS cases	In hospital
Burstein *et al.* 2011[14]	A	2007–9	20,922, 47 centres	< 150 to ≥ 350 CHD surgery cases	In hospital
Chang *et al.* 2006[7]	A	1989–99	25,402, 500 centres	≤ 100 cases to > 100 cases CHD surgery cases	In hospital, 30, 90 and 365 days
Checcia *et al.* 2005[15]	S	1998–2001	801, 29 centres	< 16 to > 30 Norwood procedure cases	In hospital
Davies *et al.* 2011[16]	S	1992–2007	4647, 136 centres	< 19 to ≥ 63 transplants in preceding 5 years	In hospital, 1 year
Dean 2013[17]	S	1998–2007	1949, 48 centres	Not specified	In-hospital mortality
Dinh 2010[18]	A	1985–2004	80,000, 47 centres	Not specified	In hospital
Eldadah *et al.* 2011[19]	A	2004–8	199 before, 244 after	Single centre	In hospital
Fixler 2012[20]	A	1996–2003	1213	Distance not volume	1 year
Grey *et al.* 2003[21]	A	1992	284 admissions, 261 patients, four centres	47 to 85 complex CHD surgery cases	30 days post operation
Hickey *et al.* 2010[22]	A	2005–6	19,736, 38 centres	47 to 764 CHD surgery cases	In hospital
Hirsch *et al.* 2008[23]	S	2003	547, 74 centres	1 to 31 Norwood procedure 1 to 24 ASO	In hospital
Hornik *et al.* 2012[24]	S	2000–9	2555 patients, 53 centres	≤ 10 to > 20 Norwood procedure cases	In hospital
Karamlou *et al.* 2013[25]	A (ECMO only)	2000–9	3867, 207 centres	Annual ECMO cases < 15 to > 30	In hospital
Karamlou *et al.* 2008[26]	A	1988–2003	30,250	Not specified Continuous variable	In hospital
Karamlou *et al.* 2010[27]	S	1987–2000	2421, 33 centres	1 to 47 (per surgeon) of four complex groups	In hospital

continued

TABLE 4 Summary of the dates, inclusion dates and study settings of included studies (*continued*)

Study	All (A) or specific (S) cases[a]	Study period	Sample size,[b] number of centres	Lowest and highest reported centre volumes per year[c]	Mortality/survival end point
Kazui *et al.* 2007[28]	A	2000–4	11,197, 135	≤ 1–4 to > 20 cases of open heart surgery of newborns and infants	In hospital
Kim *et al.* 2011[29]	A	2000–8	97,563 all CHD, 3061 adults, 42 centres	< 10 to > 20 adults admitted for CHD surgery < 200 to > 400 all cases including children	In hospital
McHugh *et al.* 2010[30]	S	1998–2007	9187, 118 centres	10-year study period: HLHS palliation procedures < 20 to > 64 procedures	In hospital
Mery 2014[31,49]	A	2004–11	77,777, 43 centres	Not volume	Complication only
Morales *et al.* 2010[32]	S	2006	187, 67 centres	1 to > 5 VAD placements	In hospital
Oster *et al.* 2011[33]	A	July 2006–8	49,792, 24, 112 subgroups, 39 centres	Not specified Continuous variable	In hospital
Pasquali *et al.* 2012a[34]	S	2000–9	2557, 53 centres	≤ 10 to > 20 Norwood procedure cases	In hospital
Pasquali *et al.* 2012b[35]	A	2006–9	35,776 patients, 68 centres	< 150 to > 350 CHD surgery cases	In hospital
Petrucci *et al.* 2011[36]	S	2002–9	1273, 70 centres	Not specified	In hospital
Pinto *et al.* 2012[37]	A	2005–June 2006	271	Distance not volume. Single centre	Post discharge
Sakata *et al.* 2012[38]	A	2005–9	13,074, 220 centres	Not specified – CHD subgroup of eight cardiothoracic procedures	30 days
Seifert *et al.* 2007[39]	A	2000	10,282	Not specified Continuous variable	In hospital
Tabbutt *et al.* 2012[40]	S	2005–8	549 cases, 15 centres	≤ 15 to > 30 Norwood procedure cases	In hospital, 30 days
Vinocur 2013[41]	A	1982–2007	10,945, 85,023 subgroups, 49 centres	≤ 10 to 500 CHD surgery cases	In hospital
Welke *et al.* 2010[42]	A	2000–5	21,709, 161 centres	Modelling	In hospital
Welke *et al.* 2009[43]	A	2002–6	32,413, 48 programmes	< 150 to ≥ 350 CHD surgery cases	In hospital
Welke *et al.* 2008[6]	A	1988–2005	55,164, 307 centres	< 200 to < 300 CHD surgery cases	In hospital
Welke *et al.* 2006[44]	A	2001–4	12,672 procedures, 11 centres	103–801 CHD surgery cases	In hospital

ECMO, extracorporeal membrane oxygenation.
a All is where all conditions were included; specific is where selected conditions or procedures were included.
b Some papers report by operations or cases and others report by number of patients.
c Illustrates categories in included centres at lowest volume and highest volume where reported.

Most of the included studies were conducted after 2009 (29/39, 74%), with 14 studies conducted before 2009. The latter comprised the seven studies included in the Ewart review[2] and an additional seven studies identified as a consequence of our broader search strategy and inclusion criteria to include adult studies and those concerned with non-mortality outcomes or the impact of factors other than volume. Fifteen studies (38%) covered time periods of greater than 5 years. Just over half (8/14) of the studies for specific conditions or procedures, in which case numbers will be smaller, utilised data from more than 5 years compared with 28% of studies where all conditions were included. Unsurprisingly, there is a marked difference in sample sizes between studies including all CHD conditions compared with those including highly selected populations based on single conditions or procedures and single-centre studies. Where reported, there are also differences in the centre volumes with studies on specific conditions or procedures having lower-volume thresholds. Among these 14 studies, nine included centres with 20 or fewer cases per year. For studies including all CHD cases, 10 out of 25 had centres with ≤ 200 cases per year and five of these had < 100 cases per year, including two studies with very low-volume centres with < 10 cases per year.[41,28]

The primary end point for measuring mortality outcome was within the post-operative period, with 31 out of 37 (84%) studies reporting in-hospital mortality. Seven studies measured mortality at 30 days and four studies measured mortality up to 1 year.

Study analyses: adjustment for confounders and risk

The CHD population is highly complex and varied in terms of both the range of conditions it encompasses and the associated severity and risk of mortality for different conditions. Three CHD risk scores that take account of surgical complexity and associated risk of mortality have been developed for risk adjustment in CHD: Society of Thoracic Surgeons–European Association for Cardio Thoracic Surgery (STS-EACTS), Risk Adjusted classification for Congenital Heart Surgery (RACHS-1) and the Aristotle Complexity score. A detailed description of each score is provided in *Appendix 4*. Other risk scores do exist for CHD, but have not been used in the studies that have been included in the review. Outcome is also dependent on a range of patient, demographic and service factors that need to be taken into account in study analyses. We extracted details of all covariates used in the analyses of each included study and identified 67 different types of covariate (excluding subgroups within types). Thirty-one (79%) of the studies included a covariate that accounted in some way for the patient's condition. Of these, 18 used a risk score for surgical complexity, eight a condition descriptor, three a procedure descriptor and two an *International Classification of Diseases*, Ninth Revision, Clinical Modification (ICD-9-CM) diagnostic code. Of other covariates, the most commonly used were age (18/39), comorbidity (14/39), sex (13/39) and ethnicity (9/39). Some studies of highly selected groups of patients did not always adjust for common covariates such as complexity (where a single condition was the subject) or age (where the study population was all neonates).

A detailed summary of the 32 covariate types reported in at least 2 of the 39 included studies is provided in *Appendix 4*.

Overview of main findings

We have summarised the main findings of each included study in terms of whether or not a measurable effect of volume on mortality outcome was reported. Effect is defined as an inverse relationship between volume and mortality, that is increasing volume results in decreasing mortality (or, conversely, low volume is associated with higher mortality). Where survival is reported, the effect relationship is increasing survival with increasing volume and vice versa. Kazui *et al.*[28] reported an inverse relationship between volume and mortality with higher mortality in low-volume centres, and Sakata *et al.*[38] found no relationship between volume and morbidity for the CHD subgroup. Both reported wide variation in mortality rates across all

volumes and both concluded that risk-adjusted measures are needed to explore this relationship more robustly.

Relationship between volume and mortality for all coronary heart disease conditions

We identified 19 studies that examined the relationship between centre volume and mortality. A single-centre study by Arenz *et al.*[9] examined unit performance over 4 years using a composite measure including mortality, but did not directly test the relationship between volume and mortality. Thirteen studies examined this relationship as the primary objective of the study, two examined the effect of adult CHD operative management by paediatric services or surgeon and two examined the relationship as part of a more general study to identify risk factors for mortality or surgical performance. One study examined the relationship between volume and mortality and the impact of specialist nursing skills. A summary of the findings is given in *Table 5*. Note that the estimates of effect size are not comparable between studies because of the different inclusion criteria (procedures, time periods, institutions), different definitions for volume categories, different definitions for mortality outcomes and adjustment for different confounding factors. Detailed analysis for each included study is available in *Appendix 3*.

A number of studies detected no effect of volume on mortality. Oster *et al.*[33] calculated standardised mortality rates from previous performance and found no strong effect with borderline significance for all cases and high-risk cases and no effect for low-risk cases and concluded that it is whole-hospital performance, rather than volume, that produces impact on outcome. Welke *et al.* has conducted a series of studies examining the relationship between volume and mortality. The earliest study[44] found no effect of volume on mortality although complexity increased and mortality decreased over the study period. The 2008 study[6] found high-volume hospitals performed better than other groups, but complexity (RACHS-1) and age were better discriminators for mortality than volume, which was only just significant (receiver operating curve area 0.5). This general relationship was repeated in the 2009 study,[43] which found an inverse relationship between volume and mortality, but this was only significant for high-risk groups with no effect in low-risk groups. The most recent study[42] examined the threshold needed to detect changes in mortality as a consequence of differences in volume and found that mortality was too low or individual procedures too rare to detect the true relationship between volume and performance.

Two studies included volume as a variable in broader studies designed to identify predictors of mortality in CHD, but were not designed to explore this relationship as a primary objective. Chang *et al.*[7] analysed the effect of a range of variables and found no association between volume and mortality for post-discharge deaths, but an association when in-hospital deaths are included, and that age and procedure type were better predictors of mortality risk. The objective of the study by Seifert *et al.*[39] was to examine the influence of sex on outcome. Volume was used as a covariate in the analyses and an association between volume and outcome was detected, but this was one of a number of variables that were also associated with increased risk of mortality. Both of these studies highlight that volume is just one factor influencing outcome.

Of studies reporting an effect of volume on outcome, Bazzani and Marcin[8] conducted a comprehensive set of analyses replicating four previous studies and developing a new model using a larger, more contemporary data set. A significant effect was found when volume was analysed as both a categorical and continuous variable, with mortality decreasing for every 100 additional cases per year. However, the effect detected was weaker than that reported in the previous studies and after sensitivity analysis, in which the single highest-volume hospital was removed, the effect was reduced for the continuous analysis and disappeared for the categorical analysis. Dinh and Maroulas[18] conducted a modelling study and found an inverse relationship between volume and mortality that held for both low- and high-risk patients in low- and medium-volume units and suggested this relationship was strong enough that it should be possible to identify a threshold for unit size. The study by Gray *et al.*,[21] published in 2003, used data from a single year 10 years previously (1992). The study found no consistent relationship between volume and outcome in four centres with variable rates in the three lower-volume centres compared with the highest, suggesting there is also a centre effect but the relevance to current services is questionable.

TABLE 5 Effect of volume on mortality for all conditions: adjusted analyses

Study	Adjusted analysis of volume and mortality/survival outcome		Notes and headline message
	No effect detected (estimate of effect size and/or *p*-value)	Effect detected (estimate of effect size and/or *p*-value)	
Arenz *et al.* 2011[9]	N/A	Basic and comprehensive performance score increased from 100% at baseline to 124.9% and 132.9% respectively. Volume increased from 407% to 487% over the same time period	Composite measure of performance including mortality showed **performance over 3 years maintained despite increasing complexity and volume**
Bazzani and Marcin 2007[8]		Continuous • Volume/mortality: OR 0.86/increase of 100 cases, 95% CI 0.81 to 0.92 Categorical • Volume/mortality: OR 0.75, 95% CI 0.55 to 1.02 in hospitals, with > 75 cases per year compared with hospitals with < 75 cases	Effect weaker using new expanded data set than replicated analysis of four previous studies. Effect lost by removing single highest-volume centre. Scatterplot of volume vs. outcome showed no clear cut-off **For each 100-patient increase in annual volume, there was a 13.9% decrease in the odds of dying**
Dinh and Maroulas 2010[18]		Mortality • Linear decreasing dependency (mortality and volume) 1985–9: $p = 0.005$ 1990–4: $p = 0.016$ 1995–9: $p = 0.043$ 2000–4: $p = 0.045$	Modelling study. Inverse relationship between volume and mortality. Small and medium-sized centres had higher mortality than high-volume centres **In small and medium-sized centres, the smaller the volume, the higher the risk of dying**
Gray *et al.* 2003[21]	All patients Volume/mortality: ORs = 0.24,[a] 0.12,[b] 0.32[c] ($p = 0.0001$)		Comparison between four centres in 1 year **Differences in mortality in centres was not consistent with smaller-volume centres, having lower mortality than the highest-volume centre**
Hickey *et al.* 2010[22]		Volume/mortality: OR 0.93/increase of 100 cases, 95% CI 0.90 to 0.96	Also looked at effect of specialist nursing staff **For each 100-patient increase in annual volume, there was a 7% decrease in the odds of dying**
Kazui *et al.* 2007[28]		Newborns: OR 2.20, 95% CI 0.95 to 5.09 Infants: OR 3.69, 95% CI 2.02 to 6.73	**Higher mortality in lowest-volume centres than in highest-volume centres** for subgroup of cardiothoracic procedures **No adjustment for risk**

continued

TABLE 5 Effect of volume on mortality for all conditions: adjusted analyses (*continued*)

Study	Adjusted analysis of volume and mortality/survival outcome: No effect detected (estimate of effect size and/or *p*-value)	Adjusted analysis of volume and mortality/survival outcome: Effect detected (estimate of effect size and/or *p*-value)	Notes and headline message
Oster *et al.* 2011[33]	$p = 0.41$ low risk; $p = 0.067$ high risk		SMR calculated from previous performance. Stratified cases no significance in low-risk cases, borderline for high risk **Previous hospital mortality was more significantly associated with future mortality than volume, indicating that factors other than volume have an effect**
Pasquali *et al.* 2012[35]		Continuous • OR 1.10, 95% CI 1.04 to 1.17; $p = 0.002$ Categorical • OR 1.60, 95% CI 1.23–2.08; $p = 0.004$	Complex analysis comparing cases with and without complications. Association highest in cases of highest surgical risk **Mortality greatest in low-volume centres for all cases and those with complications**
Sakata *et al.* 2012[38]	Pearson's correlation coefficient Newborns: –0.108 ($p = 0.273$) Infants: –0.151 ($p = 0.149$)		**No relationship between volume and mortality for subgroup of paediatric cardiothoracic procedures** **No adjustment for risk**
Vinocur 2013[41]		OR 0.84/increase of 100 cases, 95% CI 0.78 to 0.90; $p < 0.0001$	Inverse relationship for each 100 cases added to volume. 10-fold decrease in mortality in teaching hospitals over time **For each 100-patient increase in annual volume, there was a 16% decrease in the odds of dying**
Welke *et al.* 2010[42]	Only 8% of hospitals had minimum case load required to detect a 5% difference in mortality		Compared case volumes with thresholds needed to detect 5% and doubling a decrease in mortality **Paediatric cardiac surgery operations are performed too infrequently or have mortality rates that are very low. Mortality rates are a poor measure for comparing hospital performance**
Welke *et al.* 2009[43]	Low-difficulty operations: $p = 0.29$	Difficult operations (Aristotle score > 3) • OR 2.41; $p < 0.0001$	**There is no relationship between volume and mortality for low-difficulty operations but mortality decreases as volume increases for complex procedures**
Welke *et al.* 2008[6]		Small/medium hospital vs. large hospitals OR 1.85, 95% CI 1.56 to 2.20 vs. OR 1.48, 95% CI 1.24 to 1.77 respectively	Age and complexity better predictors of mortality than volume **Mortality rates significantly better for hospitals performing > 200 operations per year, but volume–mortality relationship was not linear with variability in different volume groups**

TABLE 5 Effect of volume on mortality for all conditions: adjusted analyses (*continued*)

Study	Adjusted analysis of volume and mortality/survival outcome: No effect detected (estimate of effect size and/or *p*-value)	Adjusted analysis of volume and mortality/survival outcome: Effect detected (estimate of effect size and/or *p*-value)	Notes and headline message
Welke *et al.* 2006[44]	Volume not predictor of mortality; *c*-statistic 0.55		**Mortality most associated with case-mix and not volume**
Karamlou *et al.* 2008[26]		Non-paediatric vs. paediatric surgeons • OR 4.5, 95% CI 2.1 to 9.5 More vs. less paediatric CHD experience • OR 0.92, 95% CI 0.89 to 0.95 More vs. less paediatric plus adult CHD experience • OR 0.65, 95%CI 0.43 to 0.99	Study looked at adult CHD surgery by paediatric surgeons **Adult patients operated on by paediatric surgeons have lower mortality and this decreases further as surgeon volume increases**
Kim *et al.* 2011[29]	Total CHD volume. High volume (≥ 400 cases) vs. low volume (< 200 cases): adjusted OR 1.6, 95% CI not reported	Adult volume high vs. low adult CHD surgery volume (< 10 cases annually) • OR 0.4, 95% CI 0.2 to 0.7	Study looked at adult CHD in paediatric hospitals **Adult CHD patients have lower mortality in the highest-volume group compared with two lower-volume groups**
Studies identifying predictors of mortality or other indirect measures			
Chang *et al.* 2006[7]	No difference for post-discharge mortality	Total mortality (in hospital and post discharge) • OR 1.23; $p < 0.01$	One risk factor for mortality examining a range of variables **Lower-volume hospitals had higher mortality for all cases combined (in hospital and post discharge), but no difference in post-discharge-only deaths**
Seifert *et al.* 2007[39]		Highest vs. lowest-volume quartile • OR 0.5, 95% CI 0.35 to 0.71; $p < 0.001$ Middle vs. lowest-volume quartile • OR 0.68, 95% CI 0.46 to 1.00; $p = 0.049$	Main objective was to assess effect of sex on mortality. Volume used as one of a number of covariates **Mortality lower in highest-volume centres and may be one factor influencing outcome**

CI, confidence interval; N/A, not applicable; OR, odds ratio; SMR, standardised mortality ratio.
a Second largest hospital vs. largest hospital.
b Third largest hospital vs. largest hospital.
c Smallest hospital vs. largest hospital.
Bold text denotes a summary of the study results.

Pasquali *et al.*[35] conducted a complex set of analyses examining the relationship between volume and mortality and mortality in patients with complications. An effect was found in the relationship between volume and mortality in all patients and was stronger in those with complications. There was no difference in complication rates between high- and low-volume centres but low-volume centres had higher mortality in patients with complications, suggesting high-volume hospitals may be better at managing complications. Vinocur[41] analysed data from a 25-year period (1982–2007) and found an inverse relationship between volume and mortality for every 100 extra cases per year. However, the study also found that mortality decreased 10-fold over this time period, indicating improving care and that individual centre effect contributed more than volume to the risk model. A number of studies used data over a time period of 10 years or more and, while these remain of value in contributing to the evidence base, it is also the case that over time there has been substantial change in the management of CHD so relevance to current service provision or performance needs to be considered when interpreting results.

Two studies examined the effect of managing adult CHD in paediatric services or by paediatric surgeons. The study by Karamlou *et al.*[26] found that adults operated on by paediatric heart surgeons had lower mortality rates than those operated on by non-paediatric heart surgeons and that mortality was also associated with surgeon volume. Kim *et al.*[29] examined the relationship between volume and mortality among adults undergoing operation in paediatric centres. They found no effect of total CHD volume on mortality, but did find that mortality was lower in centres that had higher volumes of adult cases.

Relationship between volume and mortality for all selected conditions or procedures

We identified 14 studies of the relationship between volume and mortality for selected conditions or procedures. The findings are summarised in *Table 6*.

Studies of the volume and mortality relationship were predominantly centred on complex and relatively rare conditions and associated procedures (9/14 studies). In general, these studies did demonstrate an effect of volume on mortality, but the relationship is not straightforward. In two studies of HLHS palliation, Dean[17,50] found an effect for stage 1 palliation but not for stage 2, and McHugh *et al.*[30] also found that the association between low volume and higher mortality was strongest for stage 1, with variable effects for stages 2 and 3. The study by Karamlou *et al.*[27] looked at volume and outcome for five conditions and procedures, and found that the volume and outcome effect was present for only one group (TGA). Four of the six studies on the Norwood procedure found an association between volume and mortality[15,23,24,34] and two found no association,[27,40] although Tabbutt *et al.*[40] did find that low volume was associated with higher morbidity and LOS in hospital. A single study identifying risk factors for mortality after BTSP found no relationship between volume and mortality, with condition severity and weight being the most significant predictors for mortality.

One of the advantages of using these highly selected and standardised patient groups is that the potential effects of other factors on outcome may also be identifiable. Indeed the findings of these studies highlight this complexity. Highly specialised and complex surgery requires clinical expertise. Four studies also measured the effect of individual surgeon volume. For the Norwood procedure, Hornik *et al.*[24] reported decreasing mortality with increasing surgeon volume, while Tabbutt *et al.*[40] and Checcia *et al.*[15] found no effect of surgeon volume, although in the latter study it was acknowledged that the number of cases per surgeon may have been too small to detect an effect. Karamlou *et al.*[27] found increasing surgeon volume improved outcome, but only for TGA and not for other groups within that study.

These studies also acknowledged the effect that individual institutions may have on mortality. The study by Karamlou *et al.*[27] on five different but complex patient groups found that there was wide between-centre variation in performance for the different conditions and that good performance for one condition was not necessarily translated to all conditions within a centre. McHugh *et al.*[30] also identified substantial between-centre variation and found that, although, overall, mortality was higher in low-volume centres, some low- and medium-volume centres were also achieving good outcomes.

TABLE 6 Effect of volume on mortality for specific conditions/procedures: adjusted analyses

Study	Adjusted analysis of volume and mortality/survival outcome		Notes and headline message
	No effect detected (estimate of effect size and/or *p*-value)	Effect detected (estimate of effect size and/or *p*-value)	
Arnaoutakis *et al.* 2012[10]		30-day mortality • Low vs. high volume: OR 1.9, 95% CI 1.5 to 2.4 • Medium vs. high volume: OR 1.3, 95% CI 1.1 to 1.5 1-year mortality • Low vs. high volume: OR 1.6, 95% CI 1.3 to 1.9 • Medium vs. high volume: OR 1.2, 95% CI 1.1 to 1.3	Heart transplants including non-CHD (CHD only 3% of cases) Mortality lower in high-volume centres at 30 days and 1 year. High-risk patients had higher mortality in low-volume centres, suggesting higher volume moderates the effect of risk
Berry *et al.* 2007[12]	Highest vs. lowest mortality rate (1.7% vs. 1.1%) OR 1.59, 95% CI 0.2 to 12.7		Surgery for VSD is a subgroup in a study of common paediatric operations. No relationship between volume and mortality, but VSD surgery concentrated in children's hospitals resulted in better outcome
Berry *et al.* 2006[13]		Low volume vs. high volume: OR 3.1, 95% CI 1.1 to 8.3	HLHS. Effect in low (one to three cases per annum) quartile. Operation at teaching hospital was also an effect Comparing mortality in four volume groups found mortality was worse in the lowest-volume group but no difference between the other three groups
Checcia *et al.* 2005[15]	Surgeon, $p = 0.312$	Volume $r^2 = 0.18$; $p = 0.02$ Survival increased 4% (95% CI 1% to 7%) per 10 additional procedures	The Norwood procedure. Number of cases per surgeon too small to detect an effect For each additional increase in volume of 10 cases per year there is a 4% improvement in survival
Davies *et al.* 2011[16]		Low- vs. high-volume centres: OR 1.60, 95% CI 1.13 to 2.24 Medium- vs. high-volume centres: OR 1.24, 95% CI 0.92 to 1.67	Heart transplants including non-CHD Measure is observed vs. expected mortality In low- and medium-volume centres mortality is worse than expected when compared with mortality in high-volume centres
Hirsch *et al.* 2008[23]		Significant inverse associations for institutional volume/ in-hospital mortality for the Norwood procedure ($p \leq 0.001$) and ASO ($p = 0.006$)	The Norwood procedure vs. ASO. Inverse relationship of volume to mortality As volume of cases per year increases mortality decreases

continued

TABLE 6 Effect of volume on mortality for specific conditions/procedures: adjusted analyses (*continued*)

Study	Adjusted analysis of volume and mortality/survival outcome		Notes and headline message
	No effect detected (estimate of effect size and/or *p*-value)	Effect detected (estimate of effect size and/or *p*-value)	
Hornik *et al.* 2012[24]		Continuous lower centre volume associated with higher inpatient mortality ($p = 0.03$). Surgeon volume associated with higher inpatient mortality ($p = 0.02$) Categorical lowest vs. highest category: OR 1.56, 95% CI 1.05 to 2.31; $p = 0.03$ Lowest vs. highest surgeon volume: OR 1.6, 95% CI 1.12 to 2.27; $p = 0.01$	The Norwood procedure. Analysed centre and surgeon volume. Effect held for both Both high-volume centres and high-volume individual surgeon case load have lower mortality than low-volume centres and low case load surgeons
Karamlou *et al.* 2010[27]	Centre volume on adjusted mortality: $p = 0.17$ for the Norwood procedure and $p = 0.07$ for PAIVS Surgeon total case volume: $p = 0.4$ for the Norwood procedure	Centre volume impact on adjusted mortality: $p < 0.001$ for TGA and IAA Surgeon total case volume: $p = 0.002$ for TGA	Complex CHD (four groups). Centre and surgeon volume. Variable performance – good outcomes for one group did not translate to all groups No relationship between centre or surgeon volume for the Norwood procedure and PAIVS. but higher-volume centres had lower mortality for TGA and IAA and higher surgeon volume had lower mortality for TGA only
McHugh *et al.* 2010[30]	Stage 2: medium volume vs. highest and stage 3: low volume vs. highest, not significant but no values given	Stage 1 • Low vs. high volume: OR 2.49, 95% CI 1.51 to 4.07 • Medium vs. highest volume: OR 1.75, 95% CI 1.23 to 2.49 • 1998–2002 vs. 2003–7: OR 1.62, 95% CI 1.16 to 2.27 Stage 2 • Low vs. highest volume: OR 2.09, 95% CI 1.06 to 4.11 Stage 3 • Medium vs. high volume: OR 1.70, 95% CI 1.13 to 2.57	HLHS. Longitudinal study, so it also looked at early vs. late-era surgery. Late era also had an effect A complex pattern emerges with higher mortality in both low- and medium-volume centres compared with high-volume centres for stage 1, but mixed results for stages 2 and 3. Mortality reduced over time independently of volume

TABLE 6 Effect of volume on mortality for specific conditions/procedures: adjusted analyses (*continued*)

Study	Adjusted analysis of volume and mortality/survival outcome: No effect detected (estimate of effect size and/or *p*-value)	Adjusted analysis of volume and mortality/survival outcome: Effect detected (estimate of effect size and/or *p*-value)	Notes and headline message
Morales *et al.* 2010[32]		OR 0.07, 95% CI 0.02 to 0.24	Use of VAD – patients other than CHD. Effect was in large-volume teaching hospitals vs. rest Placement of VAD at large-volume teaching hospitals reduces the risk of mortality when compared with lower-volume and non-teaching hospitals
Pasquali *et al.* 2012[34]		Volume as continuous variable $p = 0.04$; categorical lowest vs. highest category > 20; OR 1.54, 95% CI 1.02 to 2.32; $p = 0.04$	The Norwood procedure. Volume mortality effect, but when volume adjusted between-centres, variation remained Overall higher volumes are associated with lower mortality, but there is variation in individual centre mortality rates that do not reflect this relationship
Studies identifying predictors of mortality			
Dean 2013[17]	Stage 2 and 3 palliation	Stage 1 palliation • High vs. low volume: OR 0.57, 95% CI 0.45 to 0.71	HLHS. Volume split is top five vs. the rest (42) Volume is one variable examining a range of risk factors for mortality For stage 1 palliation mortality is lower in the highest-volume centres, but mortality in medium-volume centres is not investigated. No relationship between volume and mortality for stages 2 and 3
Petrucci *et al.* 2011[36]	OR per 10-unit increase in average volume = 0.98, 95% CI 0.85 to 1.13; $p = 0.78$		BTSP. Total case volume and BTSP volume included No relationship between volume and mortality was found
Tabbutt *et al.* 2012[40]	Mortality – no effect, but values not reported	Morbidity • Renal failure: centre volume, $p = 0.006$; surgeon volume, $p = 0.02$ • Sepsis: centre volume, $p = 0.003$ • Time to extubation: centre and surgeon volume, $p < 0.001$ • LOH: centre volume, $p < 0.001$	The Norwood procedure. Centre and surgeon volume No relationship between volume and mortality was found, but lower-volume centres and surgeon procedures were associated with higher rates of morbidity outcomes and LOS

CI, confidence interval; IAA, interrupted aortic arch; OR, odds ratio; PAIVS, pulmonary atresia with intact ventricular septum.

Similarly, the study by Pasquali *et al.*[34] identified an effect of volume on outcome, but volume accounted for only 14% of between-centre variation in risk of mortality, indicating that there is a range of other factors that are also having an impact.

Included studies also demonstrate the potential effects of changes in clinical advances and service provision. The study by McHugh *et al.*[30] used data over a 10-year period and a dichotomised analysis of early- and late-era surgery found that mortality improved over time. There has also been a move to centralisation or regionalisation of services, which is reflected in these studies. The primary objective of the study by Berry *et al.*[13] was to assess the impact of management at teaching compared with non-teaching centres and found over a 3-year period that stage 1 palliation surgery for HLHS in non-teaching hospitals reduced from 20% to 2%. In another study, Berry *et al.*[12] explored the relationship between volume and outcome for four common paediatric operations including repair of VSD. For this subgroup no effect was detected between volume and mortality but VSD surgery was much more centralised to specialist children's hospitals than the other three operations, which the author considered may have provided a protective effect. A study by Morales *et al.*[32] of patients receiving a VAD found an effect of volume on mortality where the comparator was not just high volume but high-volume teaching hospitals compared with other centres. We included two studies of cardiac transplant and both identified lower mortality rates in high-volume hospitals. However, one study included only adults,[10] the other[16] focused on children, and both included a range of conditions other than CHD. These studies add to the already substantial evidence on centralisation of transplant services but are of limited relevance to the evidence base on specialist paediatric CHD service provision.

Relationship between proximity and distance on mortality and volume on non-mortality outcomes

The provision of good CHD surgical care requires not just surgical expertise but also provision of the associated services that provide pre- and post-operative care. It has been suggested that the proximity of these services, for example by having them all available on one site rather than having to transfer patients at critical times for specialist care, may also be a factor that contributes to outcome in CHD. In addition, although the emphasis of volume on outcome is dominated by mortality, it can be argued that there may also be an effect on non-mortality patient outcomes such as morbidity and quality of life and service consequences such as LOS in hospital and associated costs. We identified seven studies that explored relationships other than volume and mortality for CHD. The findings of these studies are summarised in *Table 7*.

We identified two studies that specifically looked at proximity of associated specialist services and both examined the effect of a specialist cPICU. In a multicentre study, Burstein *et al.*[14] compared care in cPICU with other intensive care units (ICUs) and found no effect on mortality except for STS-EACTS level 3 cases and primarily in patients undergoing atrioventricular repair and ASOs, suggesting that potential benefits may only be applicable to specific patient groups. Eldadah *et al.*[19] conducted a single-centre before-and-after study evaluating the impact of introducing a cPICU and found a reduction in mortality and a bigger effect in reducing morbidity (wound infection and chest re-exploration).

One study by Karamlou *et al.*[25] explored the relationship between centre extracorporeal membrane oxygenation (ECMO) case volume and mortality in paediatric patients requiring ECMO and found a decreased mortality rate in the highest-volume ECMO centres, supporting the concept of regionalising highly specialist services.

In a related study discussed earlier, Hickey *et al.*[22] examined the effect of volume on not only mortality but also ICU nursing staffing and skill mix. They found no relationship between nursing staffing and skill mix and mortality but did find that high nursing workload was associated with volume. They concluded that it is possible that nursing staffing levels may already be above the threshold needed to detect an effect on mortality.

TABLE 7 Effect of proximity and distance on mortality and volume on non-mortality outcomes

Study	Impact on outcome: No effect detected (estimate of effect size and/or *p*-value)	Impact on outcome: Effect detected (estimate of effect size and/or *p*-value)	Notes and headline messages
Effect of proximity of associated services or distance from specialist centres			
Burstein *et al.* 2011[14]	No overall difference between CICU and PICU: OR 0.88, 95% CI 0.65 to 1.19	For STS-EACTS 3: OR 0.47, 95% CI 0.25 to 0.86 in favour of CICU	Paediatric cardiac intensive care unit vs. other ICUs Overall, there was no relationship between mortality rates and the type of ICU caring for patients but for one group of mid-complexity cases, where mortality was lower in paediatric ICU
Eldadah *et al.* 2011[19]		Mortality declined from 3.5% to 0.8%; $p < 0.05$	Paediatric cardiac intensive care unit before and after. Decrease in mortality and morbidity Outcomes following paediatric cardiac surgery improved after the introduction of a dedicated paediatric cardiac ICU
Karamlou *et al.* 2013[25]		Highest category of volume for ECMO: OR 0.51, 95% CI 0.30 to 0.87; $p < 0.01$	ECMO case volume. Lowest mortality in patients requiring ECMO associated with highest ECMO volume centres Patients requiring ECMO have a lower mortality rate if they are cared for in units that manage a high volume of ECMO cases
Fixler 2012[20]	Mortality not significantly related to distance 50–100 miles vs. < 50 miles: HR 0.83, 95% CI 0.57 to 1.22; for > 100 miles vs. < 50 miles: HR 1.08, 95% CI 0.86 to 1.36		Distance to cardiac centre not related to unadjusted first-year survival The distance to a specialist cardiac centre does not appear to have any impact on mortality following CHD surgery
Pinto *et al.* 2012[37]	Mortality for those living 90–300 minutes away vs. those < 90 minutes away: HR 2.1; 95% CI 0.7 to 5.7		Effect detected for adverse events in patients 90–300 minutes from centre, but not for patients < 90 minutes or > 300 minutes The distance to a specialist cardiac centre does not appear to have any impact on mortality following CHD surgery
Effect of volume on non-mortality outcomes only			
Benavidez *et al.* 2007[11]		Complications – increased risk of death if complications: OR 2.4; $p < 0.001$	High-volume hospitals had more complications, higher complexity but lower mortality Patients with complications after CHD surgery have a higher mortality rate, but this is reduced if they are cared for in high-volume centres
Mery 2014[31]		Complications – highest-volume quartile lower incidence of chylothorax: OR 0.49, 95% CI 0.42 to 0.58 vs. lowest volume	Chylothorax complication Patients cared for in lowest-volume centres are more likely to develop this specific complication when compared with the highest-volume centres

CI, confidence interval; CICU, children's intensive care unit; HR, hazard ratio; ICU, intensive care unit; OR, odds ratio; PICU, paediatric intensive care unit.

Two studies examined the relationship between distance from specialist cardiac centres and mortality[20,37] and both found no relationship between distance and mortality, although Fixler[20] found higher mortality in specific geographical areas where there was no identifiable cardiac centre. This effect may be as dependent on demographic factors as distance. Pinto *et al.*[37] did find a higher rate of adverse events in one group, although this was the mid-distance (and not nearest or furthest) and the paper raised the possibility that the effect may be a consequence of follow-up and monitoring policies related to proximity to a centre rather than distance itself.

We found two studies in which the primary outcomes in relation to volume were complication rates. The study by Benavidez *et al.*[11] primarily looked at complication rates, although mortality rates were also measured. The main findings were that higher-volume centres had higher complication rates but lowest-volume centres had higher mortality rates. They acknowledged that this may be a consequence of better reporting of complications in high-volume centres but also suggested that better mortality outcome, despite higher complication rates in high-volume centres, may be because high-volume centres are better at managing and rescuing patients with complications. The study by Mery[31,49] looked at risk factors for one specific complication – chylothorax – and found a relationship with a reduced rate of chylothorax in the highest-volume centres compared with other centres. Nevertheless, the same study also observed that some low-volume centres had comparable complication rates to high volume, again highlighting variability between centres.

A small number of the other studies we have included also examined non-mortality outcomes. In addition to the Eldadah *et al.*[19] and Pinto *et al.*[37] studies mentioned above, Tabbutt *et al.*[40] and Davies *et al.*[16] both found lower complication rates in high-volume centres following the Norwood procedure. Burstein *et al.*,[14] Berry *et al.*[12] and Pasquali *et al.*[35] all found no association between volume and complication rates. Karamlou *et al.*[26] and Davies *et al.*[16] both found that low-volume centres were associated with longer LOS. Two studies[26,32] also assessed costs, and both found a relationship of higher costs associated with low-volume centres. Mery[31] found that chylothorax complication increased both LOS and costs. Although these variables were not explicitly tested in conjunction with volume in this study, this does provide some indication, given the relationship of lower complication rates in high-volume units, that there is likely to be an association. There is a more substantial literature on costs and volume, but this was outside the scope of our review.

Chapter 7 Discussion

Summary of the evidence about the relationship between volume and outcomes

The evidence reviewed did not include any UK-based studies and is predominantly based on outcomes in paediatric patients. Overall, we have found that although the evidence does demonstrate a relationship between volume and outcome in the majority of studies this relationship is not consistent. Instead there is a mixed picture with both effect and no effect being reported. Studies on single conditions or procedures were more likely to identify an effect of volume on mortality but, given that the focus of these studies was populations of patients with complex conditions and associated surgical procedures that require highly specialised care and expertise, this in itself is unsurprising. The findings from these studies were not unequivocal as even within these highly selected groups there was considerable variation in effect depending on procedure type and individual centre performance. What these studies do indicate is the potential value of centralising or regionalising highly specialised services for very rare and complex cases. However, it cannot be assumed that comparable effects can be achieved for a much broader range of conditions and, therefore, used to define CHD centre volume. It is possible that surgeon volume may be as important as centre volume for these complex cases.

The findings from studies that did consider broader CHD populations were more equivocal. In some studies where an effect was identified, the effect was weak or only demonstrable for specific subgroups of patients. There was no clear indication that the evidence for the volume and mortality relationship was substantially stronger than the evidence for a no effect relationship in these broader groups. The findings further highlight the complex relationship between volume and outcome and the range of other factors which also have an effect. Some of these, such as condition severity, are well established but the effect of association of processes, systems and individual clinical effects on outcome remain unknown.

We also searched for evidence from studies on adult CHD, but this yielded only three papers. One of these studies was concerned exclusively with cardiac transplantation for a range of conditions, not just CHD, so is of limited value other than to provide more general evidence of the potential value of centralising specialist services. The main focus of the other two studies was the effect of surgeon type and both found that adult CHD patients had better outcomes when operated on by paediatric surgeons in specialist children's centres. Karamlou[26] found that outcome was associated with surgeon volume and Kim *et al.*[29] found a similar association with adult procedure volume indicating the influence of expertise on outcome.

The previous systematic review conducted by Ewart[2] included studies published up until 2009. We have included studies considered by that review in this rapid review together with related studies published from 2009 to March 2014. The review by Ewart[2] included seven studies and concluded that, while the evidence did suggest there is a relationship between volume and outcome, it is likely that volume is a surrogate marker that encompasses other processes and system factors, the effects of which are unknown. The additional evidence included in this review primarily adds further to our understanding of the complexity of the relationship between volume and outcome. While there is now a larger number of studies reporting a relationship between volume and outcome, these studies also increase the evidence that this is unlikely to be a simple, independent and purely directly causal relationship. The effect of volume on outcome relative to the effect of other, as yet undetermined, health system factors remains a complex and unresolved research question.

Summary of the evidence about the relationship between proximity and outcomes and volume and non-mortality outcomes

We also attempted to identify studies that explored factors related to influencing outcomes in CHD other than the relationship between volume and mortality. This yielded only a small number of relevant papers. Two studies found a benefit in terms of reducing mortality and morbidity in patients cared for in specialist ICUs. One study identified lower mortality for patients requiring ECMO who were cared for in high-volume ECMO units. Two studies on distance to specialist cardiac care found no relationship to mortality. Similarly, we found only two studies in which the primary objective considered the effect of volume on complications. However, a small number of the studies that examined the volume–mortality relationship also measured morbidity as a secondary outcome. Such a small number of relevant studies does not provide a robust evidence base on related factors but collectively they do highlight that the overriding emphasis of research studies on CHD services has been dominated by measurement of the relationship between volume and mortality and mainly short-term, in-hospital mortality. Care is the product of a complex set of processes, of which volume of activity in any given centre or unit is only one contributor. There appears to be relatively little evidence from studies that attempt to measure the effect of related processes on outcome. The consequences of care, and hence outcomes, are also greater than may be captured by data on short-term mortality. Long-term mortality is also important, as are a range of other important short- and long-term outcomes for survivors including morbidity (for example, complications) physical and neurological functioning and quality of life, and service consequences such as LOS and costs, that seem to have received scant attention. As a consequence, the available evidence base that can inform CHD service design is seriously limited and does not reflect the complex features and relationships that contribute to service provision.

What are the issues that have emerged from the evidence?

We have not conducted a systematic review but in assessing a broader topic range and more current literature we have identified some key themes.

1. *There are a range of factors which influence mortality in CHD, and centre volume is only one of them.* In our data extraction we recorded variables within studies that were also identified as associated with mortality. This process revealed a wide range of patient, demographic and service factors that also have an impact on outcome. The most influential risk factor for mortality by far is the severity of the condition and the associated surgical complexity needed to treat that condition. Where an effect of volume on mortality was measured, in general, this tended to be greater in high-risk patients, as illustrated by the studies on complex single conditions. This is further supported by some of the studies that included broader CHD populations. It is reasonable to assume that complex high-risk surgery requires high-level surgical expertise. A small number of studies have attempted to try to disentangle the effects of individual surgeon performance on outcome but with mixed results. This requires further exploration as this complex relationship of what has an effect – a high volume of complex procedures in a centre or a high volume of complex procedures by an individual surgeon – is still unclear. Furthermore, there is some evidence[27] that it cannot be assumed that a high level of technical competence in one complex procedure translates across a range of conditions.
2. *Medicine moves forward and clinical advances, training, increasing expertise and changes in service provision mean outcomes for CHD have also changed over time*. Five studies that analysed data over long time periods (≈ 10 years) measured changes in mortality over time and found that, irrespective of other factors including volume, mortality decreased despite increasing complexity[8,18,30,41,44] illustrating ongoing clinical improvement. What this also means is that the relevance of findings from historical studies or more recent studies that have used historical data will not reflect current care and clinical improvements, so relevance to contemporary services needs to be considered. This observation also has implications for future research. The most recent study by Welke *et al.*[42] attempted to establish the case

volume thresholds needed to detect changes in mortality and concluded that some individual procedures occurred too infrequently or mortality rates were too low to reliably use mortality as a measure of between-centre performance. If clinical advances continue to improve survival, this principle will need to be borne in mind.

3. *Although aggregated data may show a difference in mortality rates between low- and high-volume centres, such aggregation may mask between-centre variation.* The studies by Gray *et al.*,[21] Pasquali *et al.*,[34] Karamlou *et al.*[27] and McHugh *et al.*[30] all identified variation between centres, with some low- or medium-volume centres performing equally as well as those with high volume. These studies acknowledged that there are likely to be other centre effects such as training, management protocols, expertise, teaching hospitals, availability of services, composition of care teams and quality programmes that influence outcome. As a result it is unclear whether it is volume or these other effects that are influencing outcome.
4. *The evidence base available to guide UK decisions on service design and configuration for CHD is dominated by retrospective and uncontrolled studies conducted within the USA*. A noteworthy absence is the lack of any relevant large, well-designed UK multicentre studies. The extent to which the reported findings are generalisable and relevant to the UK setting is therefore limited. In the USA, services are organised very differently to the UK. Key differences include geography and, therefore, distances to specialist care; multiple providers of health care, which means variation in organisation of services, for example numbers of units within different counties and states; and complex health service financing models. *Many of the studies have analysed centres with very low volumes of cases* – for very rare complex cases the volume of cases may be less than five a year and for broader CHD services some studies have included centres treating fewer than 20 cases a year.
5. Elsewhere and in line with other specialist services there has been a move to centralisation or regionalisation of CHD services, particularly in Europe.[51,52] In the UK, CHD services for children are already regionalised, so evidence on the relationship of very low-volume centres on mortality has little relevance to decision-making about services which are already highly centralised. However, CHD services for adults are less centralised, so decision-making relating to service provision may be informed by evidence relating volume and outcomes.
6. It is axiomatic that, with this centralisation, there is also a corresponding increase in volume as more cases are concentrated in fewer centres but centres will also be characterised by the range of factors associated with service provision discussed previously. It remains unclear whether the impact of volume on outcome is largely a consequence of higher-volume units organising and providing a complex service and high-quality service with all the right components that would be expected to reduce risk, or an independent factor directly related to the advantages of dealing with a larger number of cases. For example, staff may have more experience of specific procedures and potential complications. It is the individual and combined effects of these complex factors on clinical outcomes for patients that remain to be unpicked. Without this better understanding the appropriate interpretation of the observed volume–outcome relationship remains unclear. There is also a lack of evidence about the effects of service factors such as proximity to specialist services and the impact of care on outcomes other than mortality.
7. *Despite the growing number of studies on the relationship between volume and outcome, few studies have suggested what the optimum size of a CHD centre in terms of volume should be*. Fewer than half of the included studies analysed volume as a continuous variable (14/35 relevant studies), which would provide the most robust evidence from which to consider volume thresholds. Analyses conducted with volume as a categorical variable carry several limitations in informing decisions about volume thresholds in terms of both decisions about within study thresholds and the questionable robustness of the findings. This is particularly the case when comparisons have been made between very high- and very low-volume centres only. Dinh and Maroulas[18] suggested that the inverse relationship between volume and outcome detected in their modelling study on 10 years of data was sufficiently robust to allow calculation of volume thresholds. However, these authors did not go as far as identifying what this should be. Hirsch *et al.*[23] suggested that a reasonable threshold for referral of children requiring the Norwood procedure is centres doing at least 20 procedures a year and 10 procedures a year for ASO. Bazzani and Marcin[8] constructed scatterplots of volume against mortality and found no obvious

threshold for centre volume. The review by Ewart[2] considered the data presented by Welke *et al.*[6] and suggested a possible threshold of 200–250 cases per year. Welke *et al.*[6] clearly expressed the view that volume is likely to be a surrogate for the processes and characteristics of care systems that produce outcomes and that centre-specific quality measures would be more informative than volume thresholds. Pasquali *et al.*[34] and Vinocur[41] concurred with this view and suggested that service design decisions should be guided by a range of individual centre performance measures and not volume. There are consistent and clear messages within the literature we have reviewed about the danger of viewing volume in isolation. Furthermore, included studies also caution concerning the likely, but as yet poorly understood, interaction of volume with the numerous other clinical and structural dimensions that contribute to delivering high-quality services and, hence, good outcomes. Finally, questions still remain concerning what volume should be the item of consideration: is it whole-service volume, complex procedure volume or individual surgeon volume that should direct decisions?

Methodological limitations of the included studies

Quality assessment and methodological limitations

As this is a rapid review we have not conducted a quality appraisal of individual included studies. However, we have considered the collective methodological limitations of these studies in order to provide an overview of study quality and have assessed the usefulness of these studies in answering the research questions. *Appendix 4* provides a simple summary of key items for each paper that relate to the usefulness of studies on CHD services. Items relate to whether or not studies have conducted analyses that have adjusted for the two key risk factors for mortality, severity/complexity and age, whether they are single-centre or multicentre studies and whether they included at least two CHD conditions or procedures. In summary, 37 out of 39 studies adjusted for severity, 28 out of 39 adjusted for age, although some studies on specific groups of patients were confined to specific age groups or, for example, neonates; 35 out of 39 were multicentre studies, with just three single-centre studies; and 25 out of 39 studies included a population with more than one condition or procedure.

Author assessments of study limitations

Many authors of included studies take great care to point out the methodological limitations of their studies and caution against overinterpretation of their findings. Included studies are predominantly retrospective and observational in nature. There were no prospective studies. Such design features make it very problematic when trying to establish a direct inverse relationship of cause (volume) to effect (mortality). Many of the source databases are limited in being primarily created for administrative purposes, for example claims data collection and billing.[6,17,23,26,29,42,50] As a consequence, we can have little confidence in the clinical coding,[42] although several studies seek to ascertain accuracy by comparing the coding for diagnosis with the coding for the surgical procedure[42] in order to establish internal coherence and consistency.

Information bias might be introduced through 'miscoding of information provided, missing data, or misinterpretation of data'.[23] Incompleteness of data is considered problematic, for example even where records are available, large numbers of surgeon identifiers may be missing.[12] Other data sources were voluntary, which introduces problems of selection bias as they may be selective in their coverage[27,36,41,43] or according to predefined membership or explicit criteria.[40] Changes or indeed inconsistency in institutional characteristics, such as coding for teaching status, may result in one hospital being coded differently across different points of an interrupted time series.[13] Welke[6] considered that in large data sets errors in quality are likely to be random rather than systematic, although it could also be argued that for data on rare conditions errors may then be systematic.

A key concern of this report relates not simply to the surgical performance of different sized units but also to the personnel and structural characteristics of the observed surgical units. On these latter matters, administrative source databases have few contextual data to offer.[14] Important contextual details are

thought to include institutional factors such as team composition, individual surgeon training and experience, type of facility (e.g. freestanding children's hospital, general hospital), transfusion practices, infection control, and care pathways.[41] Indeed several commentators also bemoan the lack of even basic clinical contextual details such as certain anatomical features[13] or accompanying non-surgical procedures. Critical details such as non-intervention, transfer to another institution and pre-operative mortality are frequently unavailable.[15] Furthermore, some clinical data features rely on subjective judgement, while perioperative details are frequently missing.[36] It is essential to recognise that not all in-hospital mortality will have an underlying surgical cause.[39]

A further consideration occurs where the research question is deliberately prescribed, i.e. where data relate to a single institution, a single year or, as with a substantial proportion of studies, a single procedure. Data relating to a single institution are unlikely to be generalisable, particularly in the absence of details of the pattern of referrals to that location.[37] While analysing data from a single year circumvents concerns relating to structural changes or improvements in procedures over time,[39] it carries the attendant danger of placing inordinate and inappropriate emphasis on an isolated time point. Finally, in the case of study reports of a single surgical procedure, the insights to be gained by a more extended examination of a discrete area of surgical practice involving typically more rare and complex conditions are outweighed, at least for the question that is the focus of this report, by neglecting overall surgical volume. Such studies thus provide a negligible contribution to the 'evidence' that relates to optimal volumes for entire CHD services.

The well-reported characteristic of paediatric cardiac surgery as covering a wide range of conditions and associated procedures poses a further threat to accurate interpretation. While it is helpful to consider an overall portfolio of procedures, the data for rare conditions necessarily involve small numbers of procedures.[14] Combining this statistical characteristic with the decreasing numbers of events of interest (i.e. mortality), particularly as cardiac surgical procedures improve, further limits the value of the reported results.[33,42] Numbers of procedures and numbers of deaths are particularly limited in low-volume units meaning that low-volume units are particularly vulnerable to even very small errors in the data.

With the ongoing development of methods for analysing the volume/outcome conundrum comes increasing recognition of the unsuitability of certain methods of investigation and analysis. For example, recent papers carry almost universal acknowledgement of the inappropriateness of any analysis that does not take into account any adjustments for risk[38] and complexity. Handling data on number of procedures as a continuous, rather than a categorical, variable is now considered essential while approaches that seek to establish a threshold that represents a stepwise change in outcome are frequently criticised for being unsophisticated and misleading.[26]

It would be negligent to overlook the considerable advances in methodology that have occurred during the time period charted by these included studies. The increasing sophistication of the tools that seek to score for complexity are just one such example, as documented in *Appendix 4*. However, while evolution and improvement of such tools and scores is to be welcomed such ongoing modification adds further to the complexity of a research area already characterised by considerable clinical heterogeneity. It is arguable whether or not the ongoing debates regarding the optimal configuration for volume/outcome are likely to be resolved in the absence of a comprehensive and accurate national database that provides sufficient information for risk stratification, complexity scoring and adequate contextual detail on clinical context as well as on structural and personnel-related factors.

Chapter 8 Conclusions

We have conducted a rapid review of the evidence on the relationship between volume and outcome, and other service factors and outcomes, for CHD. We found a large proportion of papers which analysed the relationship between volume and mortality for paediatric CHD surgery, but very limited evidence in relation to the other factors of interest or for adult populations. It is noteworthy that so much evidence is available in what is a relatively small clinical specialty. No UK-based studies or cross-country comparisons were identified. *This review identified a substantial number of studies reporting a positive relationship between volume and outcome, but the complexity of the relationship and of the evidence underpinning it requires careful interpretation.* The mixed picture emerging from the 39 included studies increases our understanding of the complexity of this relationship and highlights variation in both methods and findings across individual studies, the potential effects of a range of other factors that may interact with volume and influence outcome, and the methodological limitations imposed by the research approaches taken.

Even though our systematic, yet time-limited, searches have revealed a substantial number of studies on CHD outcomes, the existing data sources carry major limitations, particularly given the absence of information on clinical and service-related processes and outcomes, which are consistently recognised as important to patient care and safety. As a consequence, it is problematic to interpret the current evidence for the relationship between volume and outcome, as the impact this relationship may be having cannot be disentangled from the effects of other factors. The limitations of the rapid review approach mean that we could not consider conducting a meta-analysis of the evidence on volume and outcome, but this is an option that could be considered and which may further enhance the evidence available. Further evidence review of the broader fields of cardiac surgery (rather than just CHD) may also contribute to identifying some of the clinical and service-related processes and outcomes that may be relevant to CHD and provide a framework for future data collection and new studies.

The design, development and delivery of consistently good-quality and safe services require an understanding of the complex components and interactions that constitute a service and how these influence patient outcome. There is a clear evidence gap that needs to be addressed with regard to better understanding of the relationships between the wide range of organisational factors in CHD services; how these relationships can potentially predict a number of outcomes of relevance to patients and families; and the causal pathways between organisational factors and outcomes. The development and validation of clinical and administrative databases which can be used for observational studies of the relationship between organisational factors and outcomes would clearly be a valuable resource. There is scope to expand the National Institute for Cardiovascular Outcomes Research (NICOR) database to consistently collect information on a wider range of processes, organisational factors and outcomes related to quality of care that are not captured at present. It is our considered opinion that this should be the target at which future research efforts should be directed. This would support the design and conduct of UK studies and help address the clear lack of evidence relevant to service provision in the NHS.

Acknowledgements

We would like to thank the NIHR HSDR team for their support and the stakeholders and clinical experts who suggested evidence for the inclusion in the review.

Contributions of authors

Ms Janette Turner (Senior Research Fellow) contributed to proposal writing, undertook data extraction and led on the evidence synthesis.

Dr Louise Preston (Research Associate) contributed to the proposal writing, designed and ran the literature search, contributed to report writing and managed the project.

Dr Andrew Booth (Reader) undertook citation searches, contributed to the proposal writing, assessed evidence for inclusion in the review, proofread the final report, constructed summary tables, assessed the methodological limitations of the included studies and was the chief methodologist on the review.

Mr Colin O'Keeffe (Research Fellow) undertook data extraction and contributed to evidence synthesis through the production of summary tables and other key tables.

Mrs Fiona Campbell (Research Fellow) undertook data extraction and contributed to the construction of summary tables.

Dr Amrita Jesurasa (Honorary Clinical Lecturer in Public Health) undertook data extraction and report writing.

Dr Katy Cooper (Research Fellow) undertook the double-sifting and contributed to the proposal writing and construction of summary tables.

Professor Elizabeth Goyder (Professor of Public Health) was the senior lead on the project, contributed to the proposal writing and undertook the sifting of conference abstracts and construction of summary tables.

Publications

There are currently no publications associated with this rapid review.

References

1. NHS Specialised Services. *Review of Children's Congenital Cardiac Services in England*. London: NHS Specialised Services; 2012.
2. Ewart H. *The Relation Between Volume and Outcome in Paediatric Cardiac Surgery*. Oxford: Public Health Resource Unit; 2009.
3. Harker J, Kleijnen J. What is a rapid review? A methodological exploration of rapid reviews in health technology assessments. *Int J Evid Based Healthc* 2012;**10**:397–410. http://dx.doi.org/10.1111/j.1744-1609.2012.00290.x
4. Holden J. *The New Congenital Heart Disease Review: 17th update – John Holden*. NHS England, 2014. URL: www.england.nhs.uk/2014/02/10/john-holden-17 (last accessed 26 August 2014).
5. Sampson M, Barrowman NJ, Moher D, Klassen TP, Pham B, Platt R, *et al.* Should meta-analysts search EMBASE in addition to MEDLINE? *J Clin Epidemiol* 2003;**56**:943–55. http://dx.doi.org/10.1016/S0895-4356(03)00110-0
6. Welke KF, Diggs BS, Karamlou T, Ungerleider RM, Welke KF, Diggs BS, *et al.* The relationship between hospital surgical case volumes and mortality rates in pediatric cardiac surgery: a national sample, 1988–2005. *Ann Thorac Surg* 2008;**86**:889–96. http://dx.doi.org/10.1016/j.athoracsur.2008.04.077
7. Chang RK, Rodriguez S, Lee M, Klitzner TS, Chang RK, Rodriguez S, *et al.* Risk factors for deaths occurring within 30 days and 1 year after hospital discharge for cardiac surgery among pediatric patients. *Am Heart J* 2006;**152**:386–93. http://dx.doi.org/10.1016/j.ahj.2005.12.016
8. Bazzani LG, Marcin JP. Case volume and mortality in pediatric cardiac surgery patients in California, 1998–2003. *Circulation* 2007;**115**:2652–9. http://dx.doi.org/10.1161/CIRCULATIONAHA.106.678904
9. Arenz C, Asfour B, Hraska V, Photiadis J, Haun C, Schindler E, *et al.* Congenital heart surgery: surgical performance according to the Aristotle complexity score. *Eur J Cardiothorac Surg* 2011;**39**:e33–7. http://dx.doi.org/10.1016/j.ejcts.2010.11.062
10. Arnaoutakis GJ, George TJ, Allen JG, Russell SD, Shah AS, Conte JV, *et al.* Institutional volume and the effect of recipient risk on short-term mortality after orthotopic heart transplant. *J Thorac Cardiovasc Surg* 2012;**143**:157–67. http://dx.doi.org/10.1016/j.jtcvs.2011.09.040
11. Benavidez OJ, Gauvreau K, Del NP, Bacha E, Jenkins KJ, Benavidez OJ, *et al.* Complications and risk factors for mortality during congenital heart surgery admissions. *Ann Thorac Surg* 2007;**84**:147–55. http://dx.doi.org/10.1016/j.athoracsur.2007.02.048
12. Berry JG, Lieu TA, Forbes PW, Goldmann DA, Berry JG, Lieu TA, *et al.* Hospital volumes for common pediatric specialty operations. *Arch Pediatr Adolesc Med* 2007;**161**:38–43. http://dx.doi.org/10.1001/archpedi.161.1.38
13. Berry JG, Cowley CG, Hoff CJ, Srivastava R, Berry JG, Cowley CG, *et al.* In-hospital mortality for children with hypoplastic left heart syndrome after stage I surgical palliation: teaching versus nonteaching hospitals. *Pediatrics* 2006;**117**:1307–13. http://dx.doi.org/10.1542/peds.2005-1544
14. Burstein DS, Jacobs JP, Li JS, Sheng S, O'Brien SM, Rossi AF, *et al.* Care models and associated outcomes in congenital heart surgery. *Pediatrics* 2011;**127**:e1482–9. http://dx.doi.org/10.1542/peds.2010-2796

15. Checchia PA, McCollegan J, Daher N, Kolovos N, Levy F, Markovitz B, *et al.* The effect of surgical case volume on outcome after the Norwood procedure. *J Thorac Cardiovasc Surg* 2005;**129**:754–9. http://dx.doi.org/10.1016/j.jtcvs.2004.07.056

16. Davies RR, Russo MJ, Hong KN, Mital S, Mosca RS, Quaegebeur JM, *et al.* Increased short- and long-term mortality at low-volume pediatric heart transplant centers: should minimum standards be set? Retrospective data analysis. *Ann Surg* 2011;**253**:393–401. http://dx.doi.org/10.1097/SLA.0b013e31820700cc

17. Dean PNM. Effects of race, ethnicity, and sex on surgical mortality in hypoplastic left heart syndrome. *Pediatr Cardiol* 2013;**34**:1829–36. http://dx.doi.org/10.1007/s00246-013-0723-3

18. Dinh K, Maroulas V. Statistical modelling of mortality risk for congenital heart defects. *J Appl Quantit Methods* 2010;**5**:670–8.

19. Eldadah M, Leo S, Kovach K, Ivan, Pepe J, Fakioglu H, *et al.* Influence of a dedicated paediatric cardiac intensive care unit on patient outcomes. *Nurs Crit Care* 2011;**16**:281–6. http://dx.doi.org/10.1111/j.1478-5153.2011.00455.x

20. Fixler DEN. Effect of acculturation and distance from cardiac center on congenital heart disease mortality. *Pediatrics* 2012;**129**:1118–24. http://dx.doi.org/10.1542/peds.2011-3114

21. Gray DT, Louhimo I, Ahonen J, Emanuelsson Br. Inter-institutional variation in risk-adjusted paediatric cardiac surgical outcomes. *Prog Pediatr Cardiol* 2003;**18**:33–42. http://dx.doi.org/10.1016/S1058-9813(03)00074-2

22. Hickey P, Gauvreau K, Connor J, Sporing E, Jenkins K, Hickey P, *et al.* The relationship of nurse staffing, skill mix, and Magnet recognition to institutional volume and mortality for congenital heart surgery. *J Nurs Admin* 2010;**40**:226–32. http://dx.doi.org/10.1097/NNA.0b013e3181da3f71

23. Hirsch JC, Gurney JG, Donohue JE, Gebremariam A, Bove EL, Ohye RG, *et al.* Hospital mortality for Norwood and arterial switch operations as a function of institutional volume. *Pediatr Cardiol* 2008;**29**:713–17. http://dx.doi.org/10.1007/s00246-007-9171-2

24. Hornik CP, He X, Jacobs JP, Li JS, Jaquiss RD, Jacobs ML, *et al.* Relative impact of surgeon and center volume on early mortality after the Norwood operation. *Ann Thorac Surg* 2012;**93**:1992–7. http://dx.doi.org/10.1016/j.athoracsur.2012.01.107

25. Karamlou T, Vafaeezadeh M, Parrish AM, Cohen GA, Welke KF, Permut L, *et al.* Increased extracorporeal membrane oxygenation center case volume is associated with improved extracorporeal membrane oxygenation survival among pediatric patients. *J Thorac Cardiovasc Surg* 2013;**145**:470–5. http://dx.doi.org/10.1016/j.jtcvs.2012.11.037

26. Karamlou T, Diggs BS, Person T, Ungerleider RM, Welke KF, Karamlou T, *et al.* National practice patterns for management of adult congenital heart disease: operation by pediatric heart surgeons decreases in-hospital death. *Circulation* 2008;**118**:2345–52. http://dx.doi.org/10.1161/CIRCULATIONAHA.108.776963

27. Karamlou T, McCrindle BW, Blackstone EH, Cai S, Jonas R, Bradley SM, *et al.* Lesion-specific outcomes in neonates undergoing congenital heart surgery are related predominantly to patient and management factors rather than institution or surgeon experience: a Congenital Heart Surgeons Society Study. *J Thorac Cardiovasc Surg* 2010;**139**:569–77. http://dx.doi.org/10.1016/j.jtcvs.2008.11.073

28. Kazui T, Osada H, Fujita H, Committee for Scientific Affairs. An attempt to analyze the relation between hospital surgical volume and clinical outcome. *Gen Thorac Cardiovasc Surg* 2007;**55**:483–92. http://dx.doi.org/10.1007/s11748-007-0172-0

29. Kim YY, Gauvreau K, Bacha EA, Landzberg MJ, Benavidez OJ, Kim YY, *et al.* Risk factors for death after adult congenital heart surgery in pediatric hospitals. *Circulation* 2011;**4**:433–9. http://dx.doi.org/10.1161/CIRCOUTCOMES.110.958256

30. McHugh KE, Hillman DG, Gurka MJ, Gutgesell HP, McHugh KE, Hillman DG, *et al.* Three-stage palliation of hypoplastic left heart syndrome in the University HealthSystem Consortium. *Congenital Heart Dis* 2010;**5**:8–15. http://dx.doi.org/10.1111/j.1747-0803.2009.00367.x

31. Mery CMM. Incidence and treatment of chylothorax after cardiac surgery in children: analysis of a large multi-institution database. *J Thorac Cardiovasc Surg* 2014;**147**:678–86. http://dx.doi.org/10.1016/j.jtcvs.2013.09.068

32. Morales DL, Zafar F, Rossano JW, Salazar JD, Jefferies JL, Graves DE, *et al.* Use of ventricular assist devices in children across the United States: analysis of 7.5 million pediatric hospitalizations. *Ann Thorac Surg* 2010;**90**:1313–18. http://dx.doi.org/10.1016/j.athoracsur.2010.04.107

33. Oster ME, Strickland MJ, Mahle WT, Oster ME, Strickland MJ, Mahle WT. Impact of prior hospital mortality versus surgical volume on mortality following surgery for congenital heart disease. *J Thorac Cardiovasc Surg* 2011;**142**:882–6. http://dx.doi.org/10.1016/j.jtcvs.2011.04.011

34. Pasquali SK, Jacobs JP, He X, Hornik CP, Jaquiss RD, Jacobs ML, *et al.* The complex relationship between center volume and outcome in patients undergoing the Norwood operation. *Ann Thorac Surg* 2012;**93**:1556–62. http://dx.doi.org/10.1016/j.athoracsur.2011.07.081

35. Pasquali SK, Li JS, Burstein DS, Sheng S, O'Brien SM, Jacobs ML, *et al.* Association of center volume with mortality and complications in pediatric heart surgery. *Pediatrics* 2012;**129**:e370–6. http://dx.doi.org/10.1542/peds.2011-1188

36. Petrucci O, O'Brien SM, Jacobs ML, Jacobs JP, Manning PB, Eghtesady P, *et al.* Risk factors for mortality and morbidity after the neonatal Blalock–Taussig shunt procedure. *Ann Thorac Surg* 2011;**92**:642–51. http://dx.doi.org/10.1016/j.athoracsur.2011.02.030

37. Pinto NM, Lasa J, Dominguez TE, Wernovsky G, Tabbutt S, Cohen MS, *et al.* Regionalization in neonatal congenital heart surgery: the impact of distance on outcome after discharge. *Pediatr Cardiol* 2012;**33**:229–38. http://dx.doi.org/10.1007/s00246-011-0116-4

38. Sakata R, Kuwano H, Yokomise H, Sakata R, Kuwano H, Yokomise H. Hospital volume and outcomes of cardiothoracic surgery in Japan: 2005–9 national survey. *Gen Thorac Cardiovasc Surg* 2012;**60**:625–38. http://dx.doi.org/10.1007/s11748-012-0128-x

39. Seifert HA, Howard DL, Silber JH, Jobes DR, Seifert HA, Howard DL, *et al.* Female sex increases the risk of death during hospitalization for pediatric cardiac surgery. [Erratum appears in *J Thorac Cardiovasc Surg.* 2007;**134**:333–4.] *J Thorac Cardiovasc Surg* 2007;**133**:668–75. http://dx.doi.org/10.1016/j.jtcvs.2006.11.014

40. Tabbutt S, Ghanayem N, Ravishankar C, Sleeper LA, Cooper DS, Frank DU, *et al.* Risk factors for hospital morbidity and mortality after the Norwood procedure: a report from the Pediatric Heart Network Single Ventricle Reconstruction trial. *J Thorac Cardiovasc Surg* 2012;**144**:882–95. http://dx.doi.org/10.1016/j.jtcvs.2012.05.019

41. Vinocur JMM. Surgical volume and center effects on early mortality after pediatric cardiac surgery: 25-year North American experience from a multi-institutional registry. *Pediatr Cardiol* 2013;**34**:1226–36. http://dx.doi.org/10.1007/s00246-013-0633-4

42. Welke KF, Karamlou T, Ungerleider RM, Diggs BS, Welke KF, Karamlou T, *et al.* Mortality rate is not a valid indicator of quality differences between pediatric cardiac surgical programs. *Ann Thorac Surg* 2010;**89**:139–44. http://dx.doi.org/10.1016/j.athoracsur.2009.08.058

43. Welke KF, O'Brien SM, Peterson ED, Ungerleider RM, Jacobs ML, Jacobs JP, *et al.* The complex relationship between pediatric cardiac surgical case volumes and mortality rates in a national clinical database. *J Thorac Cardiovasc Surg* 2009;**137**:1133–40. http://dx.doi.org/10.1016/j.jtcvs.2008.12.012

44. Welke KF, Shen I, Ungerleider RM, Welke KF, Shen I, Ungerleider RM. Current assessment of mortality rates in congenital cardiac surgery. *Ann Thorac Surg* 2006;**82**:164–70. http://dx.doi.org/10.1016/j.athoracsur.2006.03.004

45. Karamlou T, Jacobs M, Pasquali S, He X, Hill K, O'Brien S, *et al. Influence of Surgeon and Center Volume on Early Morbidity and Mortality Following Arterial Switch Operation for Transposition of the Great Arteries: An Analysis of the STS Congenital Heart Surgery Database*. Proceedings of the Fiftieth Annual Meeting of The Society of Thoracic Surgeons, Orlando, FL, USA. 25–29 January 2014.

46. Kochilas L, Maroulas V, Rood K, Larson V, Moller J. In-hospital mortality for surgical repair of congenital heart defects is inversely related to hospital surgical volume. *Circulation* 2009;**120**:S568–9.

47. Scheurer M, Gauvreau K, Laussen PC, Mayer J, Atz AM, Newburger JW. The impact of a designated cardiac intensive care unit on outcomes after the Norwood procedure. *J Am Coll Cardiol* 2011;**57**:E405. http://dx.doi.org/10.1016/S0735-1097(11)60405-1

48. Welke KFK, Karamlou T, He X, Jacobs M, Jacobs J, Pasquali S. Surgeon volume is associated with operative mortality after congenital cardiac surgery. *Circulation* 2012;**126**:A10802.

49. Mery CMM. Incidence and treatment of chylothorax after cardiac surgery in children: analysis of a large multi-institution database. *J Thorac Cardiovasc Surg* 2014;**147**:678–86. http://dx.doi.org/10.1016/j.jtcvs.2013.09.068

50. Dean PNM. Effects of race, ethnicity, and sex on surgical mortality in hypoplastic left heart syndrome. *Pediatr Cardiol* 2013;**34**:1829–36. http://dx.doi.org/10.1007/s00246-013-0723-3

51. Daenen W, Lacour-Gayet F, Aberg T, Comas JV, Daebritz SH, Di DR, *et al.* Optimal structure of a congenital heart surgery department in Europe. *Eur J Cardiothorac Surg* 2003;**24**:343–51. http://dx.doi.org/10.1016/S1010-7940(03)00444-5

52. Lundström NR, Berggren H, Björkhem G, Jögi P, Sunnegårdh J. Centralization of pediatric heart surgery in Sweden. *Pediatr Cardiol* 2014;**21**:353–7. http://dx.doi.org/10.1007/s002460010079

53. Tsang VT, de LM, Utley M, Tsang VT, de Leval M, Utley M. Paediatric cardiac surgery. *Scand Cardiovasc J* 2009;**43**:4–6. http://dx.doi.org/10.1080/14017430802422387

54. Caldarone CA, Al-Radi O. The limits of confidence: at what price a baby's life? *Pediatr Cardiol* 2008;**29**:704–5. http://dx.doi.org/10.1007/s00246-008-9218-z

55. Hilton CJ, Hamilton JRL, Vitale N, Haaverstad R. Effects of Bristol on surgical practice in the United Kingdom. *Interact Cardiovasc Thorac Surg* 2005;**4**:197–9. http://dx.doi.org/10.1510/icvts.2004.102137

56. Hudsmith LE, Thorne SA. Transition of care from paediatric to adult services in cardiology. *Arch Dis Child* 2007;**92**:927–30. http://dx.doi.org/10.1136/adc.2006.103812

57. 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**:185–91. http://dx.doi.org/10.1053/j.pcsu.2004.02.011

58. Queensland Government. *Report of the Taskforce on Paediatric Cardiac Services*. Brisbane, QLD: Queensland Government; 2006.

59. Mellis C, Cartmill T, Dobson A, Gentles T, Shann F. *Review of Paediatric Cardiac Services in Queensland*. Brisbane, QLD: The State of Queensland (Queensland Health); 2006.

60. Bristol Royal Infirmary Inquiry. *The Report of the Public Inquiry into Children's Heart Surgery at the Bristol Royal Infirmary 1984–1995: Learning from Bristol*. London: The Stationery Office; 2001.

61. Reid GJ, Irvine MJ, McCrindle BW, Sananes R, Ritvo PG, Siu SC, *et al.* Prevalence and correlates of successful transfer from pediatric to adult health care among a cohort of young adults with complex congenital heart defects. *Pediatrics* 2004;**113**:e197–205. http://dx.doi.org/10.1542/peds.113.3.e197

62. Welke KF, Peterson ED, Vaughan-Sarrazin MS, O'Brien SM, Rosenthal GE, Shook GJ, *et al.* Comparison of cardiac surgery volumes and mortality rates between the Society of Thoracic Surgeons and Medicare databases from 1993 through 2001. *Annals Thorac Surg* 2007;**84**:1538–46. http://dx.doi.org/10.1016/j.athoracsur.2007.06.022

63. Commission for Paediatric Heart Interventions. *Concentration of Congenital Heart Surgery and Catheter Interventions*. Leiden: Commission for Paediatric Heart Interventions; 2009.

64. O'Brien SM, Jacobs JP, Clarke DR, Maruszewski B, Jacobs ML, Walters HL, 3rd, *et al.* Accuracy of the Aristotle basic complexity score for classifying the mortality and morbidity potential of congenital heart surgery operations. *Ann Thorac Surg* 2007;**84**:2027–37. http://dx.doi.org/10.1016/j.athoracsur.2007.06.031

65. Moons P, Meijboom FJ, Baumgartner H, Trindade PT, Huyghe E, Kaemmerer H. Structure and activities of adult congenital heart disease programmes in Europe. *Eur Heart J* 2010;**31**:1305–10. http://dx.doi.org/10.1093/eurheartj/ehp551

66. Federal Ministry of Justice. *Proclamation of a Resolution of the Federal Joint Committee Regarding a Guideline Over Quality Assurance Measures Over Cardiac Surgery Care for Children and Teenagers in Accordance with 137 Paragraph 1 Number 2 of the Fifth Book Of Social Security Statute Book (Sgb V), Guidelines for Paediatric Cardiac Surgery*. 1st edition. Berlin: Federal Ministry of Justice; 2010.

67. The Royal College of Surgeons of England. *Surgery for Children: Delivering a First Class Service*. London: The Royal College of Surgeons of England; 2007. URL: www.rcseng.ac.uk/publications/docs/CSF.html (accessed 2 September 2014).

68. Ontario Ministry of Health and Long Term Care. *Specialized Paediatric Services Review – Report of the Minister's Advisory Committee*. Toronto, ON: Ministry of Health and Long Term Care; 2002.

69. Giamberti A, Chessa M, Abella R, Butera G, Carlucci C, Nuri H, *et al.* Morbidity and mortality risk factors in adults with congenital heart disease undergoing cardiac reoperations. *Ann Thorac Surg* 2009;**88**:1284–9. http://dx.doi.org/10.1016/j.athoracsur.2009.05.060

70. Centre for Maternal and Child Health. Saving Mothers' Lives: Reviewing maternal deaths to make motherhood safer: 2006–8. *BJOG* 2011;**118**:1–203. http://dx.doi.org/10.1111/j.1471-0528.2010.02847.x

71. Hickey PA, Gauvreau K, Curley MA, Connor JA, Hickey PA, Gauvreau K, *et al.* The effect of critical care nursing and organizational characteristics on pediatric cardiac surgery mortality in the United States. *J Nurs Admin* 2013;**43**:637–44. http://dx.doi.org/10.1097/NNA.0000000000000005

72. Hickey PA, Gauvreau K, Jenkins K, Fawcett J, Hayman L, Hickey PA, *et al.* Statewide and national impact of California's Staffing Law on pediatric cardiac surgery outcomes. *J Nurs Admin* 2011;**41**:218–25. http://dx.doi.org/10.1097/NNA.0b013e3182171b2e

73. Chang RK, Klitzner TS. Can regionalization decrease the number of deaths for children who undergo cardiac surgery? A theoretical analysis. *Pediatrics* 2002;**109**:173–81. http://dx.doi.org/10.1542/peds.109.2.173

74. Jenkins KJ, Newburger JW, Lock JE, Davis RB, Coffman GA, Iezzoni LI. In-hospital mortality for surgical repair of congenital heart defects: preliminary observations of variation by hospital caseload. *Pediatrics* 1995;**95**:323–30.

75. Hughes GC, Zhao Y, Rankin JS, Scarborough JE, O'Brien S, Bavaria JE, *et al.* Effects of institutional volumes on operative outcomes for aortic root replacement in North America. *J Thorac Cardiovasc Surg* 2013;**145**:166–70. http://dx.doi.org/10.1016/j.jtcvs.2011.10.094

76. Lange R, Hoerer J, Schreiber C. What are the obstacles to training in surgery for congenital heart disease in Germany? *Thorac Cardiovasc Surg* 2013;**61**:273–7. http://dx.doi.org/10.1055/s-0033-1345024

77. Holden J. *The New Congenital Heart Disease Review: 18th Update*. NHS England; 2014. URL: www.england.nhs.uk/2014/02/24/john-holden-18/ (accessed 3 February 2014).

78. The German Heart Foundation. *Der Deutscher Herzbericht* 2011. Frankfurt: The German Heart Foundation; 2011.

79. Funkat A, Beckmann A, Lewandowski J, Frie M, Schiller W, Ernst M, *et al.* Cardiac surgery in Germany during 2011: a report on behalf of the German Society for Thoracic and Cardiovascular Surgery. *Thorac Cardiovasc Surg* 2012;**60**:371. http://dx.doi.org/10.1055/s-0032-1326724

80. The World Heart Congress, Cape Town, 2013. URL: http://livestreamsa.co.za/wcpccs/presentations/?step=4&l_id=320&p_id=308&a_id=2090 (last accessed 6 March 2014).

81. Dudley R, Johansen KL, Brand R, Rennie DJ, Milstein A. Selective referral to high-volume hospitals: Estimating potentially avoidable deaths. *JAMA* 2000;**283**:1159–66. http://dx.doi.org/10.1001/jama.283.9.1159

82. Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. *Ann Intern Med* 2002;**137**:511–20. http://dx.doi.org/10.7326/0003-4819-137-6-200209170-00012

83. Hannan EL, Siu AL, Kumar D, Kilburn H, Jr, Chassin MR. The decline in coronary artery bypass graft surgery mortality in New York State. The role of surgeon volume. *JAMA* 1995;**273**:209–13. http://dx.doi.org/10.1001/jama.1995.03520270043029

84. Sowden A, Deeks J, Sheldon T. Volume and outcome in coronary artery bypass graft surgery: true association or artefact? *BMJ* 1995;**311**:151–5. http://dx.doi.org/10.1136/bmj.311.6998.151

85. Ho JG, Cohen MD, Ebenroth ES, Schamberger MS, Cordes TM, Bramlet MT, *et al.* Comparison between transthoracic echocardiography and cardiac magnetic resonance imaging in patients status post atrial switch procedure. *Congenit Heart Dis* 2012;**7**:122–30. http://dx.doi.org/10.1111/j.1747-0803.2011.00571.x

86. Sinzobahamvya N, Kopp T, Photiadis J, Arenz C, Schindler E, Haun C, *et al.* Surgical management of congenital heart disease: correlation between hospital costs and the Aristotle complexity score. *Thorac Cardiovasc Surg* 2010;**58**:322–7. http://dx.doi.org/10.1055/s-0030-1249866

87. Catchpole KR. Task, team and technology integration in the paediatric cardiac operating room. *Progress in Pediatric Cardiology* 2011;**32**:85–8. http://dx.doi.org/10.1016/j.ppedcard.2011.10.005

88. Catchpole KR, Giddings AEB, Wilkinson M, Hirst G, Dale T, de Leval MR. Improving patient safety by identifying latent failures in successful operations. *Surgery* 2007;**142**:102–10. http://dx.doi.org/10.1016/j.surg.2007.01.033

89. Catchpole KR, Giddings AEB, de Leval MR, Peek GJ, Godden PJ, Utley M, *et al.* Identification of systems failures in successful paediatric cardiac surgery. *Ergonomics* 2006;**49**:567–88. http://dx.doi.org/10.1080/00140130600568865

90. Catchpole KR, de Leval MR, McEwan A, Piggott N, Elliott M, McQuillan A, *et al.* Patient handover from surgery to intensive care: using Formula 1 pit-stop and aviation models to improve safety and quality. *Pediatr Anesth* 2007;**17**:470–8. http://dx.doi.org/10.1111/j.1460-9592.2006.02239.x

91. Wahr JA, Prager RL, Abernathy JH, Martinez EA, Salas E, Seifert PC, *et al.* Patient safety in the cardiac operating room: human factors and teamwork: a scientific statement from the American Heart Association. *Circulation* 2013;**128**:1139–69. http://dx.doi.org/10.1161/CIR.0b013e3182a38efa

92. Carthey J, de Leval MR, Reason JT. The human factor in cardiac surgery: errors and near misses in a high technology medical domain. *Annals Thorac Surg* 2001;**72**:300–5. http://dx.doi.org/10.1016/S0003-4975(00)02592-3

93. Catchpole K, Godden P, Giddings A, Hirst G, Dale T, Utley M, *et al. Identifying and Reducing Errors in the Operating Theatre*. PSO12. Patient Safety Research Programme. 2005. URL: www.birmingham.ac.uk/Documents/college-mds/haps/projects/cfhep/psrp/finalreports/PS012FinalReportDeLeval.pdf (last accessed 26 August 2014).

94. Eggli YH. Surgical safety and hospital volume across a wide range of interventions. *Med Care* 2010;**48**:962–71. http://dx.doi.org/10.1097/MLR.0b013e3181eaf9f6

95. Allen SW, Gauvreau K, Bloom BT, Jenkins KJ. Evidence-based referral results in significantly reduced mortality after congenital heart surgery. *Pediatrics* 2003;**112**:24–8. http://dx.doi.org/10.1542/peds.112.1.24

96. Ashburn D, McCrindle BW, Tchervenkov CI, Jacobs ML, Lofland GK, Bove EL, *et al.* Outcomes after the Norwood operation in neonates with critical aortic stenosis or aortic valve atresia. *J Thorac Cardiovasc Surg* 2003;**125**:1070–82. http://dx.doi.org/10.1067/mtc.2003.183

97. Austin CR, Wood AE, Graham ANJ. Can low volume adult congenital surgery be delivered safely in a high volume adult cardiac surgery unit? *Ir J Med Sci* 2013;**182**:S377.

98. Bennett TD, Klein MB, Sorensen MD, De Roos AJ, Rivara FP, Bennett TD, *et al.* Influence of birth hospital on outcomes of ductal-dependent cardiac lesions. *Pediatrics* 2010;**126**:1156–64. http://dx.doi.org/10.1542/peds.2009-2829

99. Boucek DY. Does surgeon training or hospital (pediatric vs. adult) affect survival after heart transplant in adults with congenital heart disease? *J Heart Lung Transplant* 2013;**32**(Suppl.):S240–1. http://dx.doi.org/10.1016/j.healun.2013.01.617

100. Cabrera AGP. Interhospital transport of children requiring extracorporeal membrane oxygenation support for cardiac dysfunction. *Congenit Heart Dis* 2011;**6**:202–8. http://dx.doi.org/10.1111/j.1747-0803.2011.00506.x

101. d'Udekem Y, Galati JC, Konstantinov IE. Intersurgeon variability in long-term outcomes after transatrial repair of tetralogy of Fallot: 25 years' experience with 675 patients. *J Thorac Cardiovasc Surg* 2014;**147**:880–6. http://dx.doi.org/10.1016/j.jtcvs.2013.11.010

102. Davies RR, Pasquali SK, Jacobs ML, Jacobs JJ, Wallace AS, Pizarro C, *et al.* Current spectrum of surgical procedures performed for Ebstein's malformation: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. *Ann Thorac Surg* 2013;**96**:1703–9. http://dx.doi.org/10.1016/j.athoracsur.2013.05.005

103. DeCampli WM. Joint programmes in paediatric cardiothoracic surgery: a survey and descriptive analysis. *Cardiol Young* 2011;**21**:159–64. http://dx.doi.org/10.1017/S1047951111001740

104. Dimick JB, Welch HG, Birkmeyer JD. Surgical mortality as an indicator of hospital quality: the problem with small sample size. *JAMA* 2004;**292**:847–51. http://dx.doi.org/10.1001/jama.292.7.847

105. Freeman CL, Bennett TD, Casper TC, Larsen GY, Hubbard A, Wilkes J, *et al.* Pediatric and neonatal extracorporeal membrane oxygenation: does center volume impact mortality? *Crit Care Med* 2014;**42**:512–19. http://dx.doi.org/10.1097/01.ccm.0000435674.83682.96

106. Hannan ELC. Regulatory efforts to assess and improve the quality of pediatric cardiac surgery in New York State. *Prog Pediatr Cardiol* 2011;**32**:111–19. http://dx.doi.org/10.1016/j.ppedcard.2011.10.009

107. Jacobs JP, O'Brien SM, Pasquali SK, Jacobs ML, Lacour-Gayet FoG, Tchervenkov CI, *et al.* Variation in outcomes for risk-stratified pediatric cardiac surgical operations: an analysis of the STS Congenital Heart Surgery Database. *Ann Thorac Surg* 2012;**94**:564–71. http://dx.doi.org/10.1016/j.athoracsur.2012.01.105

108. Kang GS, Soh YF, Kofidis T, Lee CN, Kang GS, Soh YF, *et al.* Five-year experience with congenital cardiac surgery at National University Heart Centre, Singapore. *Singapore Med J* 2010;**51**:570–5.

109. Mahle WT, Kirshbom PM, Kanter KR, Kogon BM. Cardiac surgery in adults performed at children's hospitals: trends and outcomes. *J Thorac Cardiovasc Surg* 2008;**136**:307–11. http://dx.doi.org/10.1016/j.jtcvs.2008.04.020

110. Mascio CEA. Perioperative mechanical circulatory support in children: an analysis of the Society of Thoracic Surgeons congenital heart surgery database. *J Thorac Cardiovasc Surg* 2014;**147**:658–65. http://dx.doi.org/10.1016/j.jtcvs.2013.09.075

111. Morris SAE. Prenatal diagnosis, birth location, surgical center, and neonatal mortality in infants with hypoplastic left heart syndrome. *Circulation* 2014;**129**:285–92. http://dx.doi.org/10.1161/CIRCULATIONAHA.113.003711

112. Nykanen DW. Prospective risk stratification of pediatric cardiac catheterization procedures: a simple scoring system. *Catheter Cardiovasc Intervent* 2013;**81**:215.

113. Raj S, Tosi L, Rotta A. The incidence of cardiopulmonary resuscitation as an outcome variable in a pediatric cardiovascular critical care program. *Crit Care Med* 2011;**39**:150.

114. Rhee DP. Comparison of pediatric surgical outcomes by the surgeon's degree of specialization in children. *J Pediatr Surg* 2013;**48**:1657–63. http://dx.doi.org/10.1016/j.jpedsurg.2012.12.048

115. Sinzobahamvya NA. Minimal requirements for a congenital heart surgery programme: Contribution of the Aristotle complexity score. *Thorac Cardiovasc Surg* 2012:**60**:V47. http://dx.doi.org/10.1055/s-0031-1297437

116. Jacobs JP, Jacobs ML, Maruszewski B, Lacour-Gayet FG, Tchervenkov CI, Tobota Z, *et al.* Initial application in the EACTS and STS Congenital Heart Surgery Databases of an empirically derived methodology of complexity adjustment to evaluate surgical case mix and results. *Eur J Cardiothorac Surg* 2012;**42**:775–80. http://dx.doi.org/10.1093/ejcts/ezs026

Appendix 1 Final protocol

Rapid Evidence Synthesis Proposal - What evidence is there on how organisational features affect patient outcomes in congenital heart disease services?

Background: This proposal has been written in response to a request by NHS England to further examine the evidence around the delivery of congenital heart disease (CHD) services. The purpose of the evidence synthesis is to support the ongoing review about how these services should be best organised.

Services for children with CHD have been the subject of scrutiny for a number of years. In 2012, following an extensive review as part of the "Safe and Sustainable" work programme, a series of recommendations were made for the re-configuration of cardiac services for this patient group (NHS Specialised services, 2012). The recommendations of "Safe and Sustainable" were challenged and were subsequently the subject of a Judicial Review (JR) and an Independent Reconfiguration Panel (IRP) who concluded that the processes of the review were flawed. Consequently service reconfiguration was not implemented. These services are subject to a new review which will consider the whole lifetime pathway for CHD.

The JR and IRP (IRP 2013) identified a number of issues of concern with the "Safe and Sustainable" process including the use and interpretation of the existing evidence base on delivery of surgical services for CHD and patient outcome. In particular they questioned the reliance on evidence around the relationship between volume of cases and outcomes. A 2009 literature review (Ewart, 2009) had examined this evidence in detail and, although confirming the existence of a relationship between volume and outcome, also cautioned that this relationship alone was not sufficient to make recommendations on the size of units needed as the effects of other contributory system and process factors to this relationship were unclear in the published literature.

Rapid review process: This is a rapid evidence synthesis which needs to be completed within a very short timeframe to produce a review which is relevant and timely. Therefore rapid review methods will be used to ensure the efficient identification and synthesis of the most relevant evidence. The review will not attempt to identify all relevant evidence or to search exhaustively for all evidence that meets the inclusion criteria, although the proposed searching approach aims to identify the key evidence. Similarly the data extraction and

quality assessment will focus on the most critical information for evidence synthesis rather than aiming to exhaustively extract and critique all the available information in individual papers. Given time and resource constraints, and the need to work in a transparent and reproducible manner, our review will focus on identifying and synthesising the key evidence as described below.

Purpose of review: The purpose of this literature review is to examine what evidence there is on how organisational features affect patient outcomes in congenital heart disease services.

Review questions: The literature review can be more specifically framed to focus on two key organisational features. The rationale for this is based on the existing, evidence-based, consensus that there may be a relationship between the volume of CHD procedures and patient outcomes and the clinical consensus that reconfiguration which includes the co-location (or increased proximity) of specialist services may be related to better patient outcomes. The questions are as follows:

1a. What is the current evidence for the relationship between institutional and surgeon volume and patient outcomes and how is that relationship influenced by complexity of procedure and by patient case mix?

1b. How are patient outcomes influenced by proximity to/colocation with other specialist clinical services (e.g. co-location of services such as specialist cardiac paediatric intensive care)?

Scope: Clearly there is enormous scope to both search for and review related evidence as the subject area incorporates several different dimensions. The literature review will focus on evidence from CHD services for children and adults as this will be the most relevant. Evidence from other paediatric surgical services and evidence from general adult cardiac services may also be relevant to CHD services. Where there is limited evidence from the CHD literature, the review will potentially consider the wider literature on these other clinically similar services as feasible and where relevant. Appendix 1 sets out our proposed conceptual framework to guide the review process.

This framework will allow us to:

- Define the scope of the search strategy
- Define inclusion and exclusion criteria to specify what types of studies will be included in the final report
- Construct summary tables of all included studies to present key information and findings
- Synthesise the evidence from the included studies

The report will not appraise the evidence in terms of how future services should be provided or make recommendations about service configuration.

Methods:

Search – Our initial approach will be to develop a search strategy based on the search strategy of Ewart et al (2009) with some modifications in order to capture a wider evidence base around the other explanatory factors (see conceptual framework) and a wider range of interventions (both adult and paediatric surgical and interventional cardiology services), within the time constraints of a rapid review. The search strategy is structured relevant terms as follows:

- Population = adults and children receiving treatment for congenital heart disease
- Intervention = organisational factors (based on volume and proximity)
- Outcomes = mortality, complications and related outcomes

The databases that will be searched are: MEDLINE, EMBASE, Cochrane Library, Web of Science (Science Citation Index and Social Science Citation Index) and CINAHL.

In addition to the database search as outlined above, we will also undertake the following to identify key evidence for the review:

- Liaison with topic experts.
- Citation searching on papers included in Ewart (2009) and other key papers identified by topic experts.

- Scrutiny of reference lists of included primary studies and relevant systematic reviews.
- Scrutiny of recent reviews of services and guideline documents for relevant peer reviewed evidence.

Inclusion and Exclusion Criteria – the evidence included in the review will be restricted to quantitative studies to ensure it addresses the key review questions and outcomes of interest. This is likely to be observational evidence; however there may be evidence from trials. The included evidence will be restricted to OECD countries only to ensure relative health system comparability. We will only include peer reviewed evidence published in order to ensure we are synthesising evidence which has already undergone methodological and expert scrutiny. We will limit the included evidence on the relationship between volume and outcome in paediatric cardiac surgery to 2009-2014 as evidence prior to 2009 is available in the Ewart review (Ewart 2009), which has undergone scrutiny through its inclusion in the "Safe and Sustainable" work programme. Other evidence will be included if published 2003-2014 in English to ensure the most recent relevant evidence is prioritised within the constraints of the rapid review process.

The inclusion criteria can be summarised as follows:

Population = adults and children undergoing treatment for congenital heart disease.
Intervention = the organisation of treatment based on at least one of the following: volume of activity and/or proximity to/co-location with other related services. Only studies including either volume or proximity factors will meet the inclusion criteria of the review.
Comparator = other methods of organisation of treatment (only studies with a comparator group will be included)
Outcome = patient outcomes. Studies reporting process outcomes will only be included if they report at least one patient outcome.

Data Extraction – Formal data extraction of included papers will be undertaken and will include both the explanatory factors outlined in the conceptual framework and any other factors identified by included studies, as well as patient outcomes. This may include data on:

Patient factors: Age of the patient casemix, range of the patient casemix.

Organisation: volume of activity (institutional volume and staff volume), specialisation (adult/children/both), sub specialisation (nature and complexity of procedures), size of specialist unit (number of staff, number of beds etc.), proximity to/co-location with other specialist clinical services, hospital/surgeon/nursing workloads, the health system that organisations operate in, timing of procedures and hospital/surgeon/nursing training/experience.

Outcomes: mortality, life expectancy, morbidity, quality of life, complications of treatment; and possibly processes such as length of stay and unplanned readmission rates. Data on process outcomes will only be extracted from studies which report at least one patient outcome. We anticipate that outcomes will be reported using measures such as relative risks, odds ratios and mean differences. Where possible, given the time and resource limitations, these will be reported, alongside confidence intervals. We will also check which way around the data is reported in terms of a) the intervention and comparator (for example high versus low volume and vice versa) and b) the outcome (for example mortality or survival). Where possible, outcomes will be converted so that they are all in the same direction for both of the above factors.

Quality Assessment - Rather than using a standard checklist approach, instead, the focus will be on an assessment of the overall quality and relevance of the evidence included in the review. The assessment of relevance will be made based on a number of factors which may include the study type, the country in which the research was undertaken, whether the research is single centre or multi centre, whether it included more than one procedure/intervention. The assessment of quality will be based on study type and other key factors. This process of quality and relevance assessment will allow readers of the rapid evidence synthesis to make an assessment of the hierarchy of relevance and quality of evidence included in the review.

Timelines:

Draft Proposal – 15 January 2014

Final Proposal – 24 January 2014

First draft report – 1 April 2014

Review Team:

Elizabeth Goyder	Colin O'Keeffe
Andrew Booth	Fiona Campbell
Janette Turner	Katy Cooper
Louise Preston	Amrita Jesurasa

DOI: 10.3310/hsdr02430

Appendix a: conceptual framework

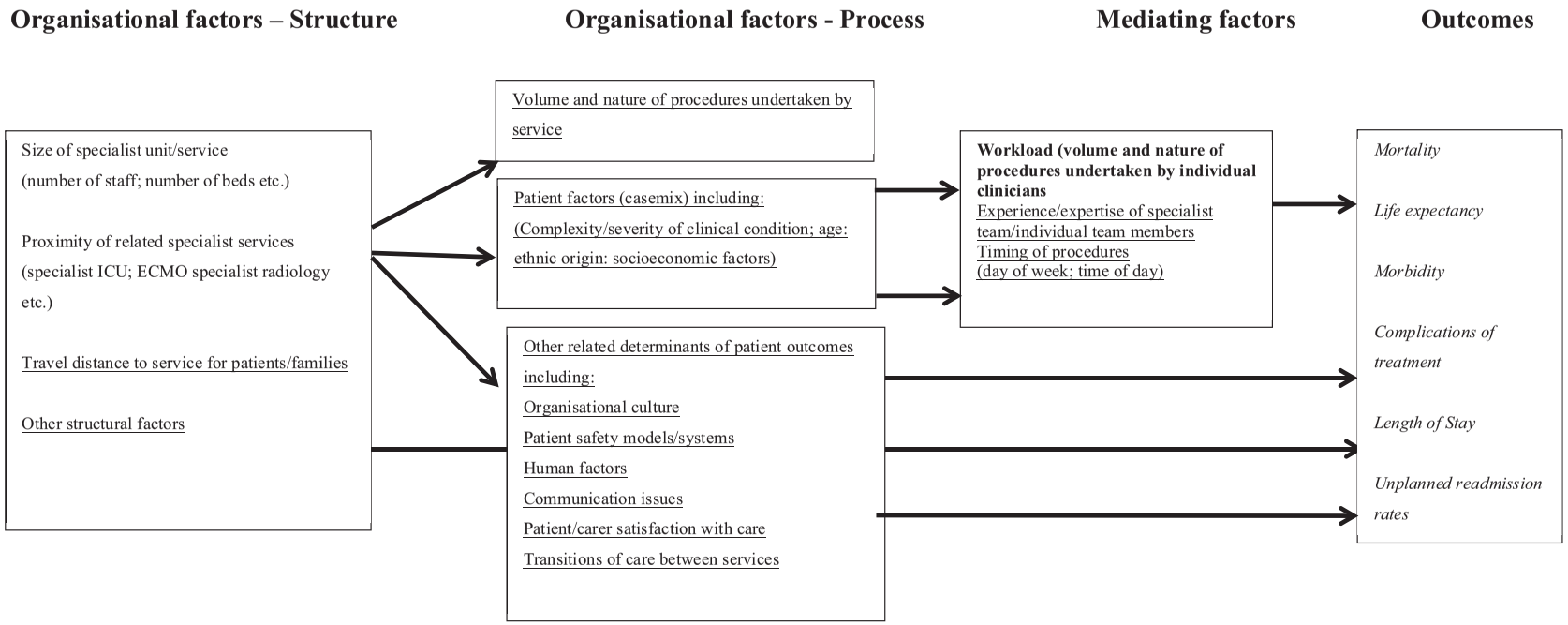
The proposed scope for a literature review on the organisational factors which may influence patient outcomes in surgical and interventional cardiology services for CHD in children and adults

Bold = Explanatory factors reported in included studies.

Underlined = Explanatory factors which may be reported in included studies. These factors may require evidence from beyond CHD.

Italics = Outcomes which may be reported in included studies.

(All relevant explanatory and outcome data will be extracted and reported as relevant – the model illustrates the potential breadth of included evidence)



Appendix b: proposed search strategy (based on Ewart[2])

1. exp Child/ or exp Infant/ or exp Infant, Newborn/
2. (infan* or newborn* or neonat*).tw.
3. (child* or pediatric* or paediatric*).tw.
4. 1 or 2 or 3
5. thoracic surgery/
6. exp Cardiac Surgical Procedures/ or exp Cardiac Care Facilities/
7. ((heart or cardiac or cardiol* or thoracic or cardiothoracic) adj5 (surge* or procedure* or intervent* or defect*)).tw.
8. 5 or 6 or 7
9. 4 and 8
10. exp Heart Defects, Congenital/su, th [Surgery, Therapy]
11. Heart Diseases/cn [Congenital]
12. (congenital adj (heart or cardiac)).tw.
13. 9 or 10 or 11 or 12
14. workload/
15. Physician's Practice Patterns/
16. "Personnel Staffing and Scheduling"/
17. (caseload* or case load* or workload* or work load*).tw.
18. volume*.tw.
19. activit*.tw.
20. 14 or 15 or 16 or 17 or 18 or 19
21. ((proximity or close* or locat* or near or adult or pediatric or paediatric or child*) adj3 (facilit* or site or hospital* or service* or specialis* or specializ*)).tw.
22. (rationali* or streamlin* or centralis* or centraliz* or co-location or co-locate or (single adj site)).tw.
23. 21 or 22
24. exp Mortality/
25 Survival/
26 exp "Outcome Assessment (Health Care)"/ or exp Treatment Outcome/
27. (mortality or death or survival or outcome* or complication*).tw.
28. 24 or 25 or 26 or 27
29. 13 and (20 or 23) and 28
30. limit 29 to yr="2009 - 2014"

Appendix c: references

Ewart, H (2009) The Relation Between Volume and Outcome in Paediatric Cardiac Surgery. A Literature Review for the National Specialised Commissioning Group. Available from http://www.specialisedservices.nhs.uk/library/30/The_Relation_Between_Volume_and_Outcome_in_Paediatric_Cardiac_Surgery__A_Literature_Review_for_the_National_Specialised_Commissioning_Group_Henrietta_Ewart_Consultant_in_Public_Health_Medicine_PHRU_Oxford__September_2009.pdf

IRP (2013) Advice on Safe and Sustainable Proposals for Children's Congenital Heart Services. Available from http://www.hsj.co.uk/Journals/2013/06/12/g/h/f/IRP-Report.pdf.

NHS Specialised services (2012). Review of children's congenital cardiac services in England: July 2012. Available from http://www.specialisedservices.nhs.uk/library/30/Safe_and_Sustainable_Review_of_Childrens_Congenital_Cardiac_Services_in_England_Decision_Making_Business_Case.pdf

Appendix 2 Literature search

Appendix a: stage 1 – database search strategy

MEDLINE

Via OvidSP.

Searched on 29 January 2014.

Search strategy

1. exp Child/ or exp Infant/ or exp Infant, Newborn/
2. (infan* or newborn* or neonat*).tw.
3. (child* or pediatric* or paediatric*).tw.
4. 1 or 2 or 3
5. thoracic surgery/
6. exp Cardiac Surgical Procedures/ or exp Cardiac Care Facilities/
7. ((heart or cardiac or cardiol* or thoracic or cardiothoracic) adj5 (surge* or procedure* or intervent* or defect*)).tw.
8. 5 or 6 or 7
9. 4 and 8
10. exp Heart Defects, Congenital/su, th [Surgery, Therapy]
11. Heart Diseases/cn [Congenital]
12. (congenital adj (heart or cardiac)).tw.
13. 9 or 10 or 11 or 12
14. workload/
15. Physician's Practice Patterns/
16. "Personnel Staffing and Scheduling"/
17. (caseload* or case load* or workload* or work load*).tw.
18. volume*.tw.
19. activit*.tw.
20. 14 or 15 or 16 or 17 or 18 or 19
21. ((proximity or close* or locat* or near or adult or pediatric or paediatric or child*) adj3 (facilit* or site or hospital* or service* or specialis* or specializ*)).tw.
22. (rationali* or streamlin* or centralis* or centraliz* or colocation or co-locate or (single adj site)).tw.
23. (Distance* or travel* or transport or regionali*).tw.
24. 21 or 22 or 23
25. exp Mortality/
26. Survival/
27. exp "Outcome Assessment (Health Care)"/ or exp Treatment Outcome/
28. (mortality or death or survival or outcome* or complication*).tw.
29. 25 or 26 or 27 or 28
30. 13 and (20 or 24) and 29
31. limit 30 to yr= "2009 - 2014"
32. Limit to Humans and language= English

The Cochrane Library

Via Wiley Online Library.

Searched on 29 January 2014.

Search strategy

#1 MeSH descriptor: [Child] explode all trees

#2 MeSH descriptor: [Infant] explode all trees

#3 infan* or newborn* or neonat*:ti,ab,kw (Word variations have been searched)

#4 child* or pediatric* or paediatric:ti,ab,kw (Word variations have been searched)

#5 #1 or #2 or #3 or #4

#6 MeSH descriptor: [Thoracic Surgery] explode all trees

#7 MeSH descriptor: [Cardiac Surgical Procedures] explode all trees

#8 MeSH descriptor: [Cardiac Care Facilities] explode all trees

#9 ((heart or cardiac or cardiol* or thoracic or cardiothoracic) near/5 (surge* or procedure* or intervent* or defect*)):ti,ab,kw (Word variations have been searched)

#10 #6 or #7 or #8 or #9

#11 #5 and #10

#12 MeSH descriptor: [Heart Defects, Congenital] explode all trees

#13 congenital near (heart or cardiac):ti,ab,kw (Word variations have been searched)

#14 #12 or #13

#15 #11 or #14

#16 MeSH descriptor: [Workload] explode all trees

#17 MeSH descriptor: [Physician Practice Patterns] explode all trees

#18 MeSH descriptor: [Personnel Staffing and Scheduling] explode all trees

#19 case load or caseload or work load or workload:ti,ab,kw (Word variations have been searched)

#20 volume or activity:ti,ab,kw (Word variations have been searched)

#21 #16 or #17 or #18 or #19 or #20

#22 ((proximity or close* or locat* or "near" or adult or pediatric or paediatric or child*) near/3 (facilit* or site or hospital* or service* or speciali*)):ti,ab,kw

#23 (rationali* or streamlin* or centrali* or colocation or co-locate or colocation or colocate or (single near/2 site) or distance* or travel* or transport or regionali*):ti,ab,kw

#24 #22 or #23

#25 MeSH descriptor: [Mortality] explode all trees

#26 MeSH descriptor: [Survival] explode all trees

#27 MeSH descriptor: [Outcome Assessment (Health Care)] explode all trees

#28 MeSH descriptor: [Treatment Outcome] explode all trees

#29 (mortality or death or survival or outcome* or complication*):ti,ab,kw

#30 #25 or #26 or #27 or #28 or #29

#31 #21 or #24

#32 #15 and #31 and #30 from 2009 to 2014

Cumulative Index to Nursing and Allied Health Literature (CINAHL)

Via EBSCO*host*.

Search strategy

S25 (S22 AND S23 AND S24)

S24 (S14 OR S17)

S23 S9 OR S10

S22 S18 OR S19 OR S20 OR S21

S21 TX mortality or death or survival or outcome* or complication*

S20 MH outcome assessment

S19 MH survival

S18 MH mortality

S17 S15 OR S16

S16 TX (rationali* or streamlin* or centralis* or centraliz* or colocation or co-locate or (single site) or distance* or travel* or transport or regionali*)

S15 TX ((proximity or close* or locat* or near or adult or pediatric or paediatric or child*) N3 (facilit* or site or hospital* or service* or specialis* or specializ*))

S14 (S11 OR S12 OR S13)

S13 TX volume* or activit*

S12 TX caseload* or case load* or workload* or work load*

S11 MH workload

S10 TX congenital N1 (heart or cardiac)

S9 S5 AND S8

S8 S6 OR S7

S7 TX ((heart or cardiac or cardiol* or thoracic or cardiothoracic) N5 (surge* or procedure* or intervent* or defect*))

S6 MH thoracic surgery

S5 (S1 OR S2 OR S3 OR S4)

S4 TX child or pediatric or paediatric

S3 TX (infant* OR newborn or neonat*)

S2 MH infant

S1 MH child

Web of Science

Via Web of Knowledge.

Search strategy

8 #6 AND #5 Refined by: PUBLICATION YEARS=(2013 OR 2010 OR 2012 OR 2009 OR 2011)

7 #6 AND #5

6 TITLE: ((caseload* or case load* or workload* or work load* or volume or activity or ((proximity or close* or locat* or adult or pediatric or paediatric or child*) near (facilit* or site or hospital* or service* or specialis* or specializ*)) or (rationali* or streamlin* or centralis* or centraliz* or colocation or co-locate or (single site) or distance* or travel* or transport or regionali*)))

5 #4 OR #3

4 #2 AND #1

3 TITLE: ((congenital NEAR (heart or cardiac)))

2 TITLE: (((heart or cardiac or cardiol* or thoracic or cardiothoracic) NEAR (surge* or procedure* or intervent* or defect*)))

1 TI=(infan* or newborn* or neonat* or child* or pediatric* or paediatric*)

Appendix b: stage 2 – citation searching

Citation searches were conducted on Google Scholar (14 February 2014) for any references citing any of the following eight studies included in the Ewart review:

1. Bazzani and Marcin[8]
2. Chang *et al.*[7]
3. Checchia *et al.*[15]
4. Hirsch *et al.*[23]
5. Tsang *et al.*[53]
6. Welke *et al.*[44]
7. Welke *et al.*[6]
8. Welke *et al.*[43]

One hundred and eight-four individual citations (from an initial combined set of 366) remained following de-duplication and removal of non-English references.

Appendix c: stage 3 – evidence suggested by stakeholders and reasons for inclusion/exclusion

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
Jo Glenwright (personal communication), NHS England, 9 January 2014	List of references from the Safe and Sustainable Review of Children's Congenital Cardiac Services (any references that are dated 2002 or earlier have not been included in this table for reasons of clarity)	Ewart 2009[2]	LP	Exclude: study type – review
		Caldarone and Al Radi 2008[54]	LP	Exclude: study type – discussion paper
		Hilton *et al.* 2005[55]	LP	Exclude: study type – discussion paper
		Hirsch *et al.* 2008[23]	LP	Include (already identified by ScHARR)
		Hudsmith and Thorne 2007[56]	LP	Exclude: study type – review
		Lacour-Gayet *et al.* 2004[57]	LP	Exclude: study type – no data on outcomes
		Queensland Government 2006[58]	LP/AB	Exclude: not peer reviewed. No original data on volume/ mortality. Reports findings of earlier Mellis review[59] and other international reviews, e.g. Kennedy report.[60] However, these are pre-2003
		Reid *et al.* 2004[61]	LP	Exclude: topic
		Welke *et al.* 2007[62]	LP	Exclude: topic – no cardiac subgroup for CHD
		Welke *et al.* 2008[6]	LP	Include
Jo Glenwright (personal communication), NHS England, 9 January 2014	Additional references in consultation document	Commission for Paediatric Heart Interventions 2009[63]	AB	Potentially relevant data on volumes and outcomes, but has not been subject to peer review. Translation not freely available. Includes five relevant papers – two of which were excluded after the full text was reviewed (Daenen *et al.* 2003,[51] O'Brien *et al.* 2007[64]). One is an abstract – exclude but use as source of evidence (Moons *et al.* 2009).[65] One is outside the date range of the review (Lundström 2000)[52] and one was already identified for inclusion (Welke *et al.* 2009)[47]
		Federal Ministry of Justice 2010[66]	AB	Translation not freely available
		Daenen *et al.* 2003[51]	AB	Provides suggested standards for number of procedures, etc. Not evidence-based standards but may be useful for discussion. No original data; therefore, exclude. Identifies a number of relevant references but all of these are outside the date range of the review

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
		Analysis undertaken of the Hospital Episodes Statistics data by National Cancer Services Analysis Team, September 2010 (John Waring, Central Manchester University Hospitals NHS Foundation Trust, personal communication, 2014)	LP	Exclude: not peer-reviewed evidence
		The Royal College of Surgeons of England[67]	LP	Exclude: not peer-reviewed evidence
		Ontario Ministry of Health and Long-Term Care 2002[68]	AB	Considers volume data, but no data on outcomes and has not been subject to peer review. Cites selected published evidence (but not within date range of the review)
		Welke *et al.* 2009[43]	LP	Include (already identified by ScHARR)
		Standard C9, National Specialised Commissioning Team, Safe and Sustainable: Children's Congenital Cardiac Services in England Service Standards, March 2010. (John Waring, Central Manchester University Hospitals NHS Foundation Trust, personal communication, 2014)	LP	Exclude: not peer-reviewed evidence

continued

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
John Wareing, Central Manchester University Hospitals NHS Foundation Trust, 4 March 2014		Giamberti *et al.* 2009[69]	AJ	Exclude: data – neither volume nor proximity appears to be variables under assessment in this study. It is an analysis of pre-operative and operative factors and their relationship to outcome variables, one of which is mortality, in one institution. The pre-operative factors are demographic and patient-level clinical factors. The conclusion in both the abstract and main paper that 'Reoperations in ACHD . . . were associated with a low mortality rate if performed in a centre with a considerable activity and a dedicated program'[69] does not appear to relate to the results of the study
		Kim *et al.* 2011[29]	LP	Include
John Wareing, Central Manchester University Hospitals NHS Foundation Trust, 3 March 2014	We note that the current list of references does not refer to pregnancy outcomes in women with CHD. While there is limited literature on the subject the above reference[70] contains a specific recommendation from the cardiac disease chapter that 'Women with a known history of cardiac disease must be referred to consultant-led obstetric care in a maternity unit where there is a joint obstetric/cardiology clinic or a cardiologist with expertise in the care of women with heart disease.' The last sentence of this chapter examining maternal mortality is 'Some women with known heart disease before pregnancy are not offered or referred to appropriate multidisciplinary care in specialist units.' Heart disease has been the leading cause of maternal death in the last two triennial reports	Centre for Maternal and Child Health 2011[70]	LP	The chapter on cardiac disease was examined. There is no evidence in this chapter linking either volume or proximity to outcomes for pregnant women

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
Robert Craig (personal communication), Royal Brompton & Harefield NHS Foundation Trust, 3 March 2014	Report commissioned by RB&H on the impact on RB&H of the proposed decommissioning of cardiac surgery under the 'Safe & Sustainable' Review (FH Partnership, January 2013). The report is marked 'strictly confidential' but was released to the IRP in January 2013. Pages 39–42 discuss the relationship between surgical volumes and outcomes	Pasquali *et al.* 2012[34]	LP	Include (already identified by ScHARR)
		Welke *et al.* 2012[48]	LP	Include (conference abstract already identified by ScHARR)
	Letter from Professor Pascal Vouhe (Paris) – undated, but received late 2012 – citing the 2003 EACTS paper[51] on the 'Optimal structure of a congenital heart surgery department', which falls within the wider time horizon (2003–14) identified in the ScHARR proposal	Daenen 2003[51]	LP	Exclude: paper about standards. Not evidence based
Pedro Del Nido, Children's Hospital Boston/ Harvard Medical School, 21 February 2014		Hickey and Gavreau 2013[71]	LP and project team	Exclude: topic – organisational factor under consideration is critical care nursing (i.e. clinical experience). There are no variables relating to either volume or proximity. While skill mix of staff is a variable for data extraction, this would only be extracted when there is evidence about volume or proximity as the main organisational variable
		Hickey *et al.* 2011[72]	LP and project team	Exclude: topic – organisational factor under consideration is staffing numbers and staffing ratios. There are no variables relating to either volume or proximity. While skill mix of staff is a variable for data extraction, this would only be extracted when there is evidence about volume or proximity as the main organisational variable

continued

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
David Barron, Birmingham Children's Hospital, 14 February 2014		'Publications on the experience with reconfiguration in Sweden and Netherlands that would be important to trace'	LP	The literature search did not identify any publications from either of these countries that were peer-reviewed evidence that included evidence on the relationship between either volume or proximity and outcomes
		Karamlou *et al.* 2014[45]	LP	Include as conference abstract
		Pasquali *et al.* 2012[35]	LP	Include (already identified by ScHARR)
		Welke *et al.* 2009[43]	LP	Include (already identified by ScHARR)
		Oster *et al.* 2011[33]	LP	Include (already identified by ScHARR)
		Chang and Klitzner 2002[73]	LP	Exclude: date
		Jenkins *et al.* 1995[74]	LP	Exclude: date
		Pasquali *et al.* 2012[34]	LP	Include (already identified by ScHARR)
		Tabbutt *et al.* 2012[40]	LP	Include (already identified by ScHARR)
		Hornik *et al.* 2012[24]	LP	Include (already identified by ScHARR)
		Karamlou *et al.* 2013[25]	LP	Include (already identified by ScHARR)
		Hughes *et al.* 2013[75]	EG	Exclude: population – not CHD
		Arnaoutakis *et al.* 2012[10]	LP	Include (already identified by ScHARR)
		Karamlou *et al.* 2008[26]	LP	Include (already identified by ScHARR)
		Lange *et al.* 2013[76]	EG	Exclude: no outcomes data reported in the paper
David Barron, Birmingham Children's Hospital, 27 February 2014	E-mail in response to list of 22 references circulated via NHS England's new CHD Review Blog post on 24 February 2014.[77] References were 2009–14 only	Welke *et al.* 2009[43]	LP	Include (already identified by ScHARR)
		Karamlou *et al.* 2008[26]	LP	
		Lange *et al.* 2013[76]	LP	Exclude: no outcomes data reported in the paper
		Hughes *et al.* 2013[75]	EG	Exclude: population – not CHD
		Arnaoutakis *et al.* 2012[10]	LP	Include (already identified by ScHARR)
		Karamlou *et al.* 2014[45]	LP	Conference abstract. Not identified by original search or in the list of references as abstract not obtained when the list was drawn up. On scrutiny of the reference, include in conference abstract table

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
Bob Ward, 13 February 2014	Included in letter supplied to ScHARR team, under paragraph 2	The German Heart Foundation 2011[78]	AB	Exclude: relevant population but no data linking volume and outcome
		Funkat *et al.* 2012[79]	AB	Table 31 reports distribution of units by number of procedures. However, this is not linked to outcome anywhere within the report. Despite the high quality and completeness of the data, the report (published in a peer-reviewed journal) is unable to address the volume/proximity–outcome question
		Press statement 18 May 2012 following inspection of RHSC Yorkhill by Sir Ian Kennedy's team (Bob Ward, Leeds, personal communication, 2014)	LP	Exclude: not peer-reviewed evidence
		Daenen *et al.* 2003[51]		Exclude: paper about standards. Not evidence based
		Chang and Klitzner 2002[73]	LP	Exclude: date
	Included in e-mail	Pasquali *et al.* 2012[34]	LP	Include (already identified by ScHARR)
	'We recently came across some interesting data from 50 of the largest centres in USA – and have plotted the results in Excel. This shows scarcely any variation of volume and outcome' (Bob Ward, Leeds, personal communication, 2014)	http://health.usnews.com/best-hospitals/paediatric-rankings/cardiology-and-heart-surgery/data?sort_by=surgical_mortality (accessed 15 February 2014)	LP	Exclude: this is not data from a peer-reviewed source. The topic is relevant as it does link volume and outcome

continued

TABLE 8 Evidence suggested by stakeholders and reasons for inclusion/exclusion (*continued*)

Source and date	Type of evidence	Bibliographic details	Reviewer?	Outcome
Bob Ward, 6 March 2014	Link to two presentations given at the World Heart Congress, Cape Town, 2013[80] Presentations include a number of references which were assessed for inclusion/exclusion	Daenen *et al.* 2003[51]	LP	Exclude: paper about standards. Not evidence based
		Dudley *et al.* 2000[81]	LP	Exclude: date
		Halm *et al.* 2002[82]	LP	Exclude: date
		Hannan *et al.* 1995[83]	LP	Exclude: date
		Sowden *et al.* 1995[84]	LP	Exclude: date
		Ho *et al.* 2000[85]	LP	Exclude: date
		Sinzobahamvya *et al.* 2010[86]	LP	Exclude: topic – relationship in question is costs for congenital heart surgery as related to the Aristotle Complexity Score
		Pasquali *et al.* 2012[35]	LP	Include (already identified by ScHARR)
		Hornik *et al.* 2012[24]	LP	Include (already identified by ScHARR)
		Welke *et al.* 2009[43]	LP	Include (already identified by ScHARR)
		Welke *et al.* 2012[48]	LP	Include (already identified by ScHARR)
Ken Catchpole, Cedars-Sinai Medical Centre, Los Angeles, CA, USA, 10 February 2014	Extract from e-mail 'The hypothesis – supported by the attached papers – is that **performance in congenital heart surgery is defined by the interactions between people and systems**' (Ken Catchpole, personal communication, 2014)	Catchpole 2011[87]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Catchpole *et al.* 2007[88]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Catchpole *et al.* 2006[89]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Catchpole *et al.* 2007[90]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Wahr *et al.* 2013[91]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Carthey *et al.* 2001[92]	LP	Exclude: does not include evidence that links volume or proximity to outcomes
		Catchpole *et al.* 2005[93]	LP	Exclude: does not include evidence that links volume or proximity to outcomes

ACHD, adult congenital heart disease; RB&H, Royal Brompton & Harefield NHS Foundation Trust.
Bold text denotes key part of quoted text.

Appendix d: stage 4 – references of reviews and other reports used as a source of evidence

Eggli 2010.[94]

Ewart 2009.[2]

Moons *et al.* 2010.[65]

Queensland Government 2006.[58]

Tsang and Utley 2009.[53]

Appendix e: list of full-text excludes and reasons for exclusion

TABLE 9 List of full-text excludes and reasons for exclusion

Bibliographic information	Reviewer?	Reason
Allen *et al.* 2003[95]	JT	Is about the efficacy of the referral process, rather than outcomes based on centre volume
Ashburn *et al.* 2003[96]	FC	Comparison of institutions, insufficient data reported
Austin *et al.* 2013[97]	EG	Data on case-mix, single centre compared with database but no comparison of case mix or outcome data from any other centre (so zero mortality impossible to interpret – could have just been all very low risk – only say '20 different ops'/'different complexity')
Bennett *et al.* 2010[98]	Team	Paper looks at the influence of location of birth hospital on outcomes
Boucek 2013[99]	LP	Explanatory variables were the type of surgeon (no detail given on actual volume of procedures on children or adults) and the hospital (again no detail given on volume)
Cabrera 2011[100]	JT	ECMO and transportation
d'Udekem *et al.* 2013[101]	LP	Surgeon volume and centre volume are not variables. Outcome measure is reoperation not mortality
Davies *et al.* 2013[102]	CO	No measure of volume or colocation of services – measure of regional factors
DeCampli 2011[103]	LP	Data are via survey instrument therefore will not be sufficient to address the volume/proximity and outcome relationship
Dimick *et al.* 2004[104]	FC	The study reported mortality rates but no relationship with unit size was reported
Freeman *et al.* 2014[105]	CO	The population is a combination of seven different diagnostic indications. While some of these seven were CHD, the volume/mortality relationship was measured for the seven indications as a whole
Giamberti *et al.* 2009[70]	AJ	Neither volume nor proximity appears to be a variable under assessment in this study. It is an analysis of pre-operative and operative factors and their relationship to outcome variables, one of which is mortality, in one institution. The pre-operative factors are demographic and patient-level clinical factors. The conclusion in both the abstract and main paper that 'Reoperations in ACHD . . . were associated with a low mortality rate if performed in a centre with a considerable activity and a dedicated program' does not appear to relate to the results of the study
Hannan 2011[106]	LP	This is an article on the regulatory system. It is not an article that contains data on outcomes associated with explanatory variables – it just addresses how these data are collected
Jacobs *et al.* 2012[107]	CO	No analysis based on volume or proximity. Data analysis for benchmarking
Kang *et al.* 2010[108]	LP	Exclude as evidence is from an non-OECD country
Mahle *et al.* 2008[109]	JT	This is a descriptive paper – it reports volume but does not test the relationship between volume and outcome
Mascio 2014[110]	JT	Paper does not look at the relationship between volume and outcome, rather the relationship between volume and likelihood of using mechanical circulatory support
Morris 2014[111]	Team	Paper looks at the influence of location of birth hospital on outcomes
Nykanen 2013[112]	EG	Conference abstract. Methods paper with no data on volume or other organisational factors (states 'risk and volume adjusted')
Raj *et al.* 2011[113]	EG	Conference abstract. Not relevant – testing the hypothesis that CPR rates predict mortality
Rhee 2013[114]	Team	Surgical experience cannot be used as a proxy for surgical volume
Sinzobahamvya 2012[115]	EG	Conference abstract. Methods paper on impact of using 'complexity score'. Insufficient data on explanatory variables

Appendix 3 Data extraction

Appendix a: list of criteria included on data extraction form

- Ref ID study (author, year, country).
- Aim of study.
- Data source/type of data/study design.
- Dates of study.
- Sample size.
- Population characteristics.
- Unit characteristics.
- Procedures included.
- Definition of volume/proximity.
- Type of risk adjustment (none, administrative data, clinical data, clinical data with robust prediction model).
- Covariates used.
- Relation of volume/proximity to mortality.
    - Crude.
    - Adjusted (case mix ± other).
    - Age adjusted.
    - Non-linear versus linear relationship.
- Relation of other characteristics to mortality (covariates used).
- Other outcomes.
- Comments.
- Headline/key messages.

Appendix b: study groupings

TABLE 10 Overview of study groupings

Group 1: volume and mortality – all CHD conditions		Group 2: volume and mortality – specific CHD conditions/procedures	Group 3: other – proximity, distance, non-mortality outcome
Arenz *et al.* 2011[9]	Welke *et al.* 2009[43]	[b]Arnaoutakis *et al.* 2012[10]	[d]Benavidez *et al.* 2007[11]
Bazzani and Marcin 2007[8]	Welke *et al.* 2008[6]	Berry *et al.* 2007[12]	[c]Burstein *et al.* 2011[14]
Chang *et al.* 2006[7]	Welke *et al.* 2006[44]	Berry *et al.* 2006[13]	[c]Eldadah *et al.* 2011[19]
Dinh 2010[18]		Checcia *et al.* 2005[15]	[c]Fixler 2012[20]
Grey *et al.* 2003[21]		Davies *et al.* 2011[16]	[d]Karamlou *et al.* 2013[25]
Hickey *et al.* 2010[22]		Dean 2013[17,50]	[d]Mery 2014[31]
Kazui 2007[28]		Hirsch *et al.* 2008[23]	[c]Pinto *et al.* 2012[37]
[a]Karamlou *et al.* 2008[26]		Hornik *et al.* 2012[24]	
[a]Kim *et al.* 2011[29]		Karamlou *et al.* 2010[27]	
Oster *et al.* 2011[33]		McHugh *et al.* 2010[30]	
Pasquali *et al.* 2012b[35]		Morales *et al.* 2010[32]	
Sakata 2012[38]		Pasquali *et al.* 2012a[34]	
Seifert *et al.* 2007[39]		Petrucci *et al.* 2011[36]	
Vinocur 2013[41]		Tabbutt *et al.* 2012[40]	
Welke *et al.* 2010[42]			

a Studies relating to adult CHD, volume.
b Studies relating to adult cardiac volume.
c Studies relating to paediatric CHD, proximity.
d Studies relating to other variables.

Appendix c: Study descriptive tables

TABLE 11 Study descriptive tables. Group 1: volume and mortality – all CHD conditions

Study, country	Study design	Population included	Data source and study dates	Sample size
Arenz *et al.* 2011,[9] Germany	Longitudinal study	Paediatric patients undergoing any CHD surgery. Surgical closure of patent ductus arteriosus in premature newborns and primary ECMO cannulation (excluded)	International study developing a composite complexity score (Aristotle complexity score) and mortality data (2006–9)	1828 patients (single centre)
Bazzani and Marcin 2007,[8] USA	Retrospective cohort (five separate analyses)	Paediatric cardiac surgery patients (< 18 years) identified by diagnosis and procedure codes	OSHPD Discharge database (1998–2003)	12,801 cases four analyses. 13,917 cases one analysis
Chang *et al.* 2006,[7] USA	Retrospective cohort study	Infants and children undergoing Norwood operation, VSD closure, ASD closure	OSHPD Discharge database (1989–99)	25,402 cardiac surgery cases from over 500 acute centres
Dinh and Maroulas 2010,[18] USA and Canada	Retrospective cohort	Paediatric cardiac surgeries	PCCC Database (1985–2004)	Approximately 80,000 consecutive surgeries from 47 small and medium-sized centres from different areas across the USA and Canada
Gray *et al.* 2003,[21] Sweden	Cross-sectional cohort	Primary or one-stage procedures, multistage procedures and major procedures performed to correct earlier procedure failures or to treat major operative complications. Excluded heart transplants, group 1 procedures (closed heart procedures) and straightforward open heart procedures (e.g. open correction of primum and secundum atrial septal defects, simple VSDs)	Hospital medical records	284 admissions involving 261 patients from four centres
Hickey *et al.* 2010,[22] USA	Retrospective cohort (patient and staffing analysis)	Patients < 18 years, all hospital discharges indicating surgical repair of a congenital heart defect Institutions < 25 cases in study period, heart transplants, premature infants or neonates with patent ductus arteriosus closure as only congenital heart surgery and cases that could not be assigned to a RACHS-1 risk category were excluded	PHIS Database (2005–6) for patient data National Association of Children's Hospitals and Related Institution data (staffing data)	19,736 congenital heart surgery cases from 38 paediatric centres
Kazui *et al.* 2007[28] Japan	Retrospective cohort	Open heart surgery in newborns and infants	Survey data collected by Japanese Association for Thoracic Surgery (2000–4)	11,197 open heart surgeries ($n = 2611$ in newborns; $n = 8586$ in infants)

continued

TABLE 11 Study descriptive tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Study design	Population included	Data source and study dates	Sample size
Oster *et al.* 2011,[33] USA	Retrospective cohort	Children (0–18 years) undergoing surgery for CHD	PHIS database (2006–8)	49,792 hospital encounters from 39 centres
Pasquali 2012 *et al.*,[35] USA	Retrospective cohort	Children 0–18 years undergoing cardiothoracic surgery	STS-CHD database	35,776 patients from 68 centres
Sakata 2012, Japan[38]	Retrospective cohort	Newborns and infants with CHD	Survey data collected by Japanese Association for Thoracic Surgery (2005–9)	13,074 patients with CHD (2825 newborns and 10,249 infants undergoing open heart surgery in 105 and 115 hospitals respectively)
Seifert *et al.* 2007,[39] USA	Retrospective cohort study	Ages 0–20 years undergoing cardiac surgery (all procedures except closure of patent ductus arteriosus)	HCUP-KIDS (2000)	10,282 patients
Vinocur 2013,[41] USA	Retrospective cohort	All paediatric cardiac operations (except isolated ductal ligation in preterm infants weighting < 2.5 kg). Excluded centres outside North America, or centres contributing incomplete data or performing < 10 operations	PCCC Database (1982–2007)	109,475 operations for volume calculations and 85,023 admissions for detailed statistical analysis from 49 centres
Welke *et al.* 2006,[44] USA	Retrospective cohort	All paediatric cardiac surgical procedures that could be risk scored on RACHS-1	Study data collected from 29 CHSS member institutions (2001–4)	12,672 (out of 16,805 procedures = 76%) could be placed into RACHS-1 categories from 11 CHSS institutions
Welke *et al.* 2008,[6] USA	Retrospective cohort	Paediatric (< 18y) cardiac operations identified by diagnosis and procedure codes	NIS database (1988 –2005)	55,164 operations from 307 hospitals
Welke *et al.* 2009,[43] USA	Retrospective cohort	Patients 18 years of age or less undergoing cardiac operation, which could be categorised by RACHS-1 or Aristotle risk categories Patients weighing ≤ 2500 g, undergoing patent ductus arteriosus ligation as primary procedure or missing age and/or weight data were excluded	STS-CHD database (2002–6)	32,413 operations from 48 programmes
Welke *et al.* 2010,[42] USA	Retrospective cohort	Congenital cardiac surgical procedures performed on patients < 18 years of age identified by ICD-9-CM diagnosis and procedure codes	Nationwide Inpatient Sample Database (2000–5)	21,709 operations from 161 hospitals

ASD, atrial septal defect; CHSS, Congenital Heart Surgeon's Society; HCUP-KIDS, Healthcare Cost and Utilization Project – Kids Inpatient Database; PCCC, Paediatric Cardiac Care Consortium; PHIS, Paediatric Health Information Service; NIS, National Inpatient Sample; STS-CHD, Society of Thoracic Surgeons – Congenital Heart Disease.

TABLE 12 Study descriptive tables. Group 1: volume and mortality – adult CHD, volume

Study, country	Study design	Population included	Data source and study dates	Sample size
Karamlou *et al.* 2008,[26] USA	Retrospective observational study	Adults with CHD for open heart or thoracic aorta procedures	NIS (1988–2003)	30,250 operations
Kim *et al.* 2011,[29] USA	Retrospective cohort	Admission ages 18–49 years with ICD-9-CM codes indicating at least one congenital heart surgery procedure. Excluded cardiac transplants, transcatheter interventions and pacemaker placements if it was the sole surgical procedure coded. Upper age limit was < 50 years to minimise inclusion of acquired heart disease	PHIS (2000–8)	3061 admissions from 42 centres

NIS, National Inpatient Sample; PHIS, Paediatric Health Information Service.

TABLE 13 Study descriptive tables. Group 2: volume and mortality – specific conditions or procedures

Study, country	Study design	Population included	Data source and study dates	Sample size
Berry *et al.* 2006,[13] USA	Retrospective cohort study	Children with HLHS undergoing stage 1 palliation (mitral stenosis, aortic atresia/ stenosis, or aortic hypoplasia systemic to pulmonary arterial shunt). Exclusions were right ventricle to pulmonary artery conduit (Sano modification, cardiac transplantation) Stage 2 surgical palliation or stage 3 surgical palliation	HCUP-KIDS Database (1997 and 2000)	754 in 1997 880 in 2000
Berry *et al.* 2007,[12] USA	Retrospective cohort	Children 0–18 years having VSD surgery with cardiopulmonary bypass	HCUP-KIDS database (2003)	2301 patients from general children's hospitals, children's hospitals within an adult teaching hospital or children's speciality hospitals
Checcia *et al.* 2005,[15] USA	Retrospective cohort	Principal diagnosis of HLHS and age on admission of 30 days or less undergoing the Norwood procedure	PHIS Database (1998–2001)	801 patients from 29 hospitals
Davies *et al.* 2011,[16] USA	Retrospective cohort	Paediatric heart transplants in patients aged under 19 years	United Network for Organ Sharing Standard Transplant and Research Data set (1992–2007)	4647 transplants from 136 centres
Dean *et al.* 2013,[17] USA	Retrospective cohort study	Patients with a diagnosis of HLHS undergoing three palliative procedures: • stage 1 palliative (the Norwood procedure with either Blalock–Taussig shunt or Sano modifications) • stage 2 palliative procedure (Glenn procedure) • stage 3 procedure (Fontan procedure)	University Health System Consortium Database (1998–2007)	2761 patients

continued

TABLE 13 Study descriptive tables. Group 2: volume and mortality – specific conditions or procedures (*continued*)

Study, country	Study design	Population included	Data source and study dates	Sample size
Hirsch *et al.* 2008,[23] USA	Cross-sectional analysis	Neonates undergoing either the Norwood procedure for HLHS and ASO for d-TGA	HCUP-KIDS database (2003)	547 patients with the diagnosis of d-TGA undergoing an ASO in 74 hospitals 624 patients with the diagnosis of HLHS undergoing the Norwood procedure in 60 hospitals
Hornik 2012, USA[24]	Retrospective cohort	Infants (median age 6 years) undergoing the Norwood procedure	STS-CHD database (2000–9)	2555 patients, 53 centres and 111 surgeons
Karamlou *et al.* 2010,[27] Canada/USA	Retrospective cohort	Four groups of neonates, either undergoing the Norwood procedure or with one of three conditions: TGA; IAA; PAIVS	STS-CHD database. Dates for each of four groups vary from 5 to 10 years' worth of data during years 1987–2000	Total of 2421 operations (the Norwood procedure 710; TGA 829; IAA 474; PAIVS. 408) from between 24 and 33 CHSS institutions
McHugh *et al.* 2010,[30] USA	Retrospective cohort	All paediatric hospital admissions with a diagnosis of HLHS. Included procedures were stage 1–3 palliation (S1P–S3P), cardiac transplant, biventricular repair, coarctation of the aorta repair, percutaneous valvuloplasty and balloon atrial septostomy	UHC database (1998–2007)	9187 hospital admissions (5416 patients) from 118 institutions; 1949 S1Ps were performed at 48 institutions 1279 S2Ps were performed at 48 institutions 1084 S3Ps performed at 47 institutions
Morales *et al.* 2010,[32] USA	Retrospective cohort study	All patients aged 20 years or younger undergoing VAD discharged from hospital for cardiac conditions including cardiomyopathy (40%), CHD (21%), myocarditis (12%)	HCUP-KIDS database (2006)	187 patients from 67 centres
Pasquali *et al.* 2012,[34] USA	Retrospective cohort	Infants (median age 6 years) undergoing the Norwood procedure regardless of underlying anatomy	STS-CHD database (2000–9)	2557 infants, 53 centres
Petrucci *et al.* 2011,[36] USA	Retrospective cohort	Neonates who received a MBTS with or without cardiopulmonary bypass, and with or without concomitant ligation of a patent ductus arteriosus; aged < 30 days; weight > 1.5kg	STS-CHD database (2002–9)	1273 operations from 70 hospitals
Tabbutt *et al.* 2012,[40] USA	Analysis of randomised controlled trial data	Children undergoing either the Norwood procedure with right ventricular–pulmonary artery shunt or MBTS	2005–8 (extracted from randomised controlled trial, clinical and outcome data)	549 cases in 15 centres

IAA, interrupted aortic arch; CHSS, Congenital Heart Surgeon's Society; d-TGA, dextro-transposition of the great arteries; HCUP-KIDS, Healthcare Cost and Utilization Project – Kids Inpatient Database; MBTS, modified Blalock–Taussig shunt; PAIVS, pulmonary atresia with intact ventricular septum; PHIS, Paediatric Health Information Service; STS-CHD, Society of Thoracic Surgeons – Congenital Heart Disease; UHC, University HealthSystem Consortium.

TABLE 14 Study descriptive tables. Group 2: volume and mortality – specific conditions or procedures; adult cardiac (not all CHD)

Study, country	Study design	Population included	Data source and study dates	Sample size
Arnaoutakis *et al.* 2012,[10] USA	Retrospective cohort	Adult (> 18 years) OHT recipients	UNOS Standard Transplant and Research Dataset (2000–10)	18,226 OHT recipients at a total of 141 unique centres

OHT, orthotopic heart transplant; UNOS, United Network for Organ Sharing.

TABLE 15 Study descriptive tables. Group 3: other – proximity, distance, non-mortality outcome; paediatric CHD, proximity

Study, country	Study design	Population included	Data source and study dates	Sample size
Burstein *et al.* 2011,[14] USA	Retrospective cohort analysis of volume and proximity	Patients were 0–18 years. All CHD-related surgery except children weighing < 2.5 kg and undergoing patent ductus arteriosus ligation	Two data sources 1. STS-CHD database (patient data) 2. A survey of US ICU models in centres performing CHD surgery (structural/ service model data)	20,922 patients from 47 centres
Eldadah *et al.* 2011,[19] USA	Before-and-after study (single centre) of proximity	All paediatric post-operative cardiac admissions to the general ICU and then to cardiac ICU	Hospital records (September 2004–8)	443 cases (199 with general ICU compared with 244 in the cardiac ICU)
Fixler 2012,[20] USA	Retrospective cohort	Inclusion infants with estimated first-year mortality > 25%, having the diagnoses of HLHS, single ventricle, pulmonary valve atresia and PAIVS, pulmonary valve atresia with VSDs, tricuspid atresia, interrupted aortic arch, Ebstein's malformation of the tricuspid valve, and truncus arteriosus, born in Texas. Exclusion: infants with trisomy 13 and 18	Texas Birth Defects Registry (1996–2003)	1213 patients from multiple paediatric hospitals and birthing centres in Texas
Pinto *et al.* 2012,[37] USA	Cross-sectional cohort	Neonates < 30 days of age at the time of surgery undergoing congenital heart surgery. Patients who died before discharge from the surgical hospital or who had inoperable CHD and patients who underwent minor surgical procedures were excluded from the study	Clinical data (2005–6)	271 patients (status unknown for 15) from single large paediatric referral hospital

PAIVS, pulmonary atresia with intact ventricular septum; STS-CHD, Society of Thoracic Surgeons – Congenital Heart Disease.

TABLE 16 Study descriptive tables – Group 3: other – proximity, distance, non-mortality outcome – other variables

Study, country	Study design	Population included	Data source and study dates	Sample size
Benavidez *et al.* 2007,[11] USA	Cross-sectional study	Congenital heart surgery admissions aged < 18 years that could be assigned to a RACHS-1 risk category. Excluded transcatheter closure of atrial septal defects, VSDs, patent ductus arteriosus and balloon atrial septectomy, vessel repair, or occlusion	HCUP-KIDS Database (2000)	10,032 congenital heart surgical admissions from 100 centres
Karamlou *et al.* 2013,[25] USA[25]	Retrospective cohort	Paediatric patients (< 20 years) undergoing ECMO of cardiac indication which could be scored on RACHS-1 risk categories	HCUP-KIDS database (2000–9)	4954 (86%) cardiac cases mapped to RACHS-1 categories
Mery 2014,[31] USA	Retrospective cohort study	All patients younger than 18 years who underwent congenital heart surgery	PHIS (2004–11)	77,777 patients included from 43 tertiary care paediatric hospitals

HCUP-KIDS, Healthcare Cost and Utilization Project – Kids Inpatient Database; PHIS, Paediatric Health Information Service.

DOI: 10.3310/hsdr02430

Appendix d: data tables

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Arenz *et al.* 2011,[9] Germany	To measure if surgical performance changes over time in relation to complexity and case volume	None	Volume/mortality • Relationship tested is for performance/volume. Mortality is a characteristic of the performance score. Over 4 years basic and comprehensive unit performance increased from baseline 100% to 124.9% and 132.9% respectively. Volume increased from 407 to 487 operations per year. Crude mean survival 97.5% Other variables associated with mortality: • Exponential relationship between comprehensive complexity score and early mortality (high complexity = high mortality)	Paper does not correlate volume/outcome. It does show that as volume increases, so does complexity of cases but performance can be maintained and improved. Very complex cases are rare (1%)
Bazzani and Marcin 2007,[8] USA	Replicated four previous studies and developed own model based on previous studies	Volume treated as a continuous variable and then model rerun with annual volume dichotomised to 75 paediatric congenital open heart surgeries/year. (California guidelines on minimum volume/year.) Excluded hospitals. < 20 cases/year	Volume/mortality • Unadjusted: non-significant link for volume/mortality (OR 1.00, 95% CI 0.94 to 1.07) • Adjusted: significant relationship for volume/mortality (OR 0.86 per 100 patient increase in annual volume, 95% CI 0.81 to 0.92), equates to one fewer deaths per 200 operations performed. Removal of largest hospital reduced OR to 0.93 (95% CI 0.82 to 1.05). Other four replicated analyses found inconsistent relationship for volume/mortality. Significant relationship for volume/mortality only in children < 30 days (OR 0.97 95% CI 0.95 to 0.97). Volume/mortality by surgical complexity only significant for level 4 complexity group (OR 0.95) Other variables associated with mortality: • Not reported Other outcomes: • Not reported	1. 100-patient increase in annual volume associated with 13.9% decrease in odds of mortality 2. Weaker/less consistent volume–mortality relationship than reported previously 3. Association dependent on highly leveraged covariate patterns found in largest-volume hospital 4. Limitations of subanalysis in infants: exclusions used in analyses (i.e. patients with very low birth weight and patients aged < 3 months receiving certain surgical procedures) limit generalisability of findings to infant population as a whole 5. Low-volume hospitals may already avoid specific surgeries they are ill-equipped to perform

continued

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Chang *et al.* 2006,[7] USA	To characterise the epidemiology of post-discharge death among infants and children undergoing cardiac surgery and to identify risk factors for early and late post-discharge death	Hospital average annual case volume used to define the hospitals as low volume (≤ 100 cases per year) and high volume (> 100 cases per year)	Volume/mortality • Unadjusted: higher-volume hospitals had higher rates of post-discharge mortality vs. low-volume (0.64 vs. 0.54) • Adjusted: lower-volume hospitals had higher rates of combined in-hospital and post-discharge mortality (OR 1.23; $p < 0.01$). No differences in post-discharge mortality Other variables associated with mortality: • Sex, race/ethnicity, home income, and hospital case volume were not significant predictors of post-discharge deaths. Risk factors for post-discharge death were young age and the type of surgery performed. Neonates and infants who undergo the Norwood procedure, aortopulmonary shunt, total anomalous pulmonary vein repair, and truncus arteriosus repair are at high risk for post-discharge death	Findings suggest that predictors of mortality post-discharge may be different from risk factors for in-hospital mortality. In this population, lower hospital volume was associated with higher overall mortality but did not show an effect on post-discharge mortality
Dinh and Maroulas 2010,[18] USA and Canada[18]	To determine if hospital surgical volume is related to better patient outcomes in terms of in-hospital mortality, and whether or not there are differences for both high and low complexity paediatric cardiac procedures. To determine evidence for a hospital surgical volume threshold	Volume = continuous variable	Volume/mortality • For 1985–9 ($p = 0.005$) and 1990–4 ($p = 0.0156$), there is a linear decreasing dependency between the mortality risk and the volume. For the two consecutive periods, 1995–9 ($p = 0.0426$) and 2000–4 ($p = 0.045$), the decreasing dependency changes to a power law. The closer to the present year, the lower the mortality risk becomes. Threshold volume: after 1000–1200 surgeries for the period 1995–9 and after 850–1000 surgeries for the period 2000–4, the decreasing rate does not change drastically	1. Identifies inverse relationship between in-hospital mortality and paediatric cardiac surgical volume in small and medium-sized centres 2. Similar inverse relationship was found for both low and high complexity cases after stratifying the data by risk category using the RACHS-1 3. Given relationship, a threshold on volume to reach the lowest attainment of surgical mortality is suggested when it is attainable

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Gray *et al.* 2003,[21] Sweden	To conduct institutional comparison of risk-adjusted 30-day post-operative mortality	Total number of admissions in 1992. Largest hospital used as a referent in analyses	Volume/mortality • Unadjusted: ORs for three centres were 0.44 [centre A (smallest)] 0.27 [centre B (third largest)] and 0.39 [centre C (second largest)] ($p = 0.1130$) • Adjusted (for risk): ORs = 0.24, 0.12 and 0.32 ($p = 0.0001$). Centres B and C had lowest risk-adjusted mortality. Relationship for group II and III admission volumes in individual centres/survival not linear Other variables associated with mortality: • Not reported Volume/other outcomes: • Not reported	Higher institutional volumes of complex procedures not consistently associated with increased survival. Adjusting for pre-operative risk significantly altered institutional mortality ORs Risk-adjusted analysis addressed concerns that hospitals might be 'penalised' for treating patients with more complex disease
Hickey *et al.* 2010,[22] USA	To examine the relationship of nurse staffing, skill mix, and Magnet[a] recognition to institutional volume and mortality for congenital heart surgery in children's hospitals	Institution cardiac surgery volume = annual number of CHD procedures at each paediatric hospital over 2 years (2005–6)	Volume/mortality • Adjusted: risk using RACHS-1, higher annual volume was associated with lower mortality; ORs corresponding to each increase of 100 cases = 0.93, 95% CI 0.90 to 0.96; $p < 0.001$ Volume/other outcomes • No relationship between nursing skill mix and hospital volume; however, higher ICU worked hours per day was significantly associated with higher unit volume ($r_s = 0.39$; $p = 0.027$) Other variables associated with mortality • No association for any nursing characteristics/mortality (both univariate analysis and after risk adjustment)	After risk adjustment using RACHS-1 method, higher annual cardiac surgery volume associated with lower mortality Nursing characteristics varied in ICUs in children's hospitals treating congenital heart surgery but were not associated with mortality ICU nurse staffing levels (in children's hospitals in study) may be above threshold to find difference for outcome of mortality

continued

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Kazui *et al.* 2007,[28] Japan	To investigate the relationship between hospital volume and outcome for 10 cardiac, lung and oesophageal surgical procedures. Open heart surgery in newborns and infants of relevance	Categorical Newborn group; 1–4 cases, 5–9 cases, 10–19 cases, ≥ 20 cases per year Infant group; 1–4 cases, 5–19 cases, 20–49 cases, ≥ 50	Volume/mortality • Unadjusted: ○ 1) Newborns – centres with < 5 cases per year had a mortality of 19.3% compared with 9.7% in centres with ≥ 20 cases (OR 2.20, 95% CI 0.95 to 5.09). 2) Infants – centres with < 5 cases per year had a mortality of 7.7% compared with 1.3% in centres with ≥ 50 cases (OR 3.69, 95% CI 20.2 to 6.73)	An inverse correlation was noted between hospital volume and operative mortality, although there were wide variations in clinical outcome among the very low-volume hospitals. Further analysis is warranted using risk-adjusted data
Oster et al. 2011,[33] USA	To assess the relationships of a hospital's past adjusted in-hospital mortality and surgical volume with future in-hospital mortality after surgery for CHD	Surgical volume and SMR (SMR = observed number of deaths/expected number of deaths adjusted for surgery type) calculated for January 2004 to June 2006 and July 2006 to Dec 2008 separately	Volume/mortality • Unadjusted: ○ Inverse relationship between prior surgical volume and subsequent SMR ($p = 0.0089$) ○ Prior hospital surgical volume was of borderline significance, with an increase in surgical volume of 40 cases annually corresponding to decrease in RR of inpatient mortality of 2.0% • Adjusted: ○ Prior hospital surgical volume was not significant for lower risk categories ($p = 0.4122$) but was of borderline significance for higher risk categories ($p = 0.0678$) • Other variables associated with mortality: ○ Positive relationship between SMR from 2004–06 and 2006–08 ($p = 0.0002$); for every 0.1 unit decrease in prior hospital SMR, 3.4% decrease in RR of inpatient mortality ($p < 0.0001$) ○ Adjusted for risk, prior to risk adjustment hospital SMR was significantly associated with future mortality for both lower risk RACHS-1 categories ($p = 0.0105$) and higher risk categories ($p = 0.0015$)	After adjusting for multiple factors including prior hospital surgical mortality, prior surgical volume tended towards significant for higher-risk operations for CHD but was not significant for lower risk operations for CHD Prior in-hospital mortality was significantly associated with future in-hospital mortality after surgery for CHD across all risk strata, even after adjusting for multiple factors including prior hospital surgical volume Prior hospital mortality may be an appropriate consideration in the referral process – target quality improvement efforts and not just expansion efforts

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages

Pasquali *et al.* 2012,[35] USA	Measurement of relationship between:
	1. centre volume and mortality
	2. centre volume and post-operative complications and
	3. centre volume and inpatient mortality due to post-operative complications
		Categorical and continuous variables for volume (four categories: < 150 operations, 150–250 operations, 250–350 operations and > 350 operations)	Volume/mortality:
			• Unadjusted: lower centre volume associated with
			  ○ higher mortality
			  ○ higher mortality in patients with complications
			• Adjusted: continuous volume; lower centre volume significantly associated with:
			  ○ higher inpatient mortality (OR 1.10, 95% CI 1.04 to 1.17; $p = 0.002$)
			  ○ higher mortality following post-operative complications (OR 1.10, 95% CI 1.01 to 1.20; $p = 0.03$)
			• Adjusted: categorical volume showed lowest centre volume (< 150) significantly associated with:
			  ○ higher inpatient mortality (OR 1.60, 95% CI 1.23 to 2.08; $p = 0.0004$) and
			  ○ higher mortality following post-operative complications (OR 1.59; 95% CI 1.16 to 2.18; $p = 0.004$)
			• Significant association between volume/mortality and mortality in patients with a complication in high-risk groups only (RACHS categories 4–5) for both continuous and categorical data
			Volume/other outcomes:
			• Lower volume not significantly associated with rate of complications (OR 1.07; 95% CI 0.90 to 1.25; $p = 0.45$)
				Lower mortality in high-volume centres in part due to lower mortality in patients with a post-operative complication. Quality improvement should be aimed at not only reducing complications, but also recognising and managing complications that occur

continued

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages

Sakata *et al.* 2012,[38] Japan	Measurement of relationship between hospital volume and cardiothoracic outcome (30-day mortality)	Case volume calculated as mean number of cases per year for 5 years	Volume/mortality
			• Unadjusted analysis – no association between hospital volume and mortality at 30 days in either newborns or infants
			• Categorical analysis (unadjusted) showed:
			  ○ infants in hospitals with very small average volumes (1–4 cases per annum) had significantly higher odds of dying vs. those with 20 + cases; OR 2.46, 95% CI 1.45 to 4.17
			  ○ newborns in hospitals with average volumes < 50 cases had significantly higher odds of dying vs. 50 +; OR 3.54 95% CI 1.53 to 6.85
				Wide variation in 30-day mortality between low- and high-volume hospitals. Need to evaluate performance in low-volume hospitals using risk adjustment

Seifert *et al.*, USA,[39] 2007	To determine if sex is a determinant of in-hospital mortality after CHD surgery and identify other associated factors	Annual number of paediatric cases used to calculate quartiles. Lowest quartile was reference	Volume/mortality • Unadjusted: overall mortality rate was 4.5%; for second, third, fourth quartiles mortality was 4.6%, 4.8%, 3.6% respectively ($p = 0.003$ for highest) • Adjusted: mortality was lower in highest-volume quartile (OR 0.5, 95% CI 0.35 to 0.71; $p < 0.001$) as well as in middle quartile (OR 0.68, 95% CI 0.46 to 1.00; $p = 0.049$), compared with lowest-volume quartile Other variables associated with mortality: • Adjusted: female sex, no. of days between admission and operation; African American race; young age (neonates and < 1 year), pulmonary hypertension, and the Norwood procedure all associated with increased mortality	Although study aims were to determine the relationship with sex, findings suggest hospital volume is independent predictor of in-hospital mortality

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Vinocur 2013,[41] USA	To analyse relationship of surgical volume and other risk factors on post-operative mortality in all operations performed for paediatric CHD over five time periods between 1992 and 2007	Surgical volume modelled as continuous and categorical (divided into approximate tertiles)	Volume/mortality • Adjusted: significant inverse correlation between continuous volume measure and mortality (OR 0.84 per additional 100 operations/year, 95% CI 0.78 to 0.90; $p < 0.0001$). Correlation varied by risk categories (no effect in risk category 1). Volume reduced variability of centre effect on mortality by 20.2%, although centre-specific variation remained significant ($p < 0.0001$) Other variables associated with mortality: • Risk category, age at operations and time period contributed more to prediction of death after paediatric cardiac surgery than centre volume, the centre random effect, or patient sex (comparing relative contributions with logarithmic likelihood ratio chi-squared of each variable) • Adjusted: post-operative mortality decreased more than 10-fold over study period (analysing surgical year as a categorical variable, 1982 vs. 2007: OR 12.27, 95% CI 8.52 to 17.66; $p = 0.0001$)	Over study period RACHS-1 score remained best predictor of post-operative mortality Increased surgical volume significant positive impact on post-operative mortality. The effect was clinically relevant (relative odds reduction generally 10–30%) but modest compared with that of other variables. Volume/mortality relationship varied significantly by risk category (no effect at lowest risk) Volume is a relatively weak predictor of a centre's mortality rate and volume should not be used in insolation to predict quality at the level of individual institutions
Welke *et al.* 2006,[44] USA	To evaluate whether or not published and widely quoted mortality rates for paediatric cardiac surgery accurately reflect current expectations. Hypothesises that (1) mortality rates at high-quality paediatric cardiac programmes are lower than published national results despite (2) change in case mix with shift away from low complexity operations. Hypothesises that, unlike RACHS-1 category, hospital volume is poor discriminator of mortality	Hospital volume – average number of RACHS-1 categorised procedures performed per year over 4 years of study i. volume evaluated as continuous variable ii. hospital volume categorised into tertiles by dividing sample into three relatively equal-sized hospital cohorts: low (< 200 a year), medium (200–300 a year) and high (> 300 a year)	Volume/mortality • Several approaches used to define hospital volume/mortality: ○ Unadjusted mortality rates across volume groups compared using the chi-squared statistic for linear trend • Discrimination of volume alone as predictor of mortality assessed by *c*-statistic. Overall in-hospital mortality for categorised operations was 2.9%. No significant association for hospital surgical volume/mortality. Hospital volume poor predictor of mortality [*c*-statistic of 0.55 (remaining poor when volume was divided into tertiles $c = 0.55$)]. Hospital volume did not contribute significantly to predictive value of multivariate model containing RACHS-1 category and adjusted for clustering within centre. Ability of hospital volume by RACHS-1 category to predict mortality for each category (e.g. ability of category 4 volume to predict category 4 mortality), also poor	Mortality was most related to case mix – mortality rates declined, despite an increase in case mix complexity. Lack of association for hospital surgical volume/mortality suggests that other factors determine outcomes at high-quality institutions

continued

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
			Other variables associated with mortality: • Significant decrease in percentage of category 1 operations. Significant increases in category 2, 4 and 6 operations. Significant decreases in category 2, 3, 4 and 6 mortality rates: mortality rates for category 1 (median 0.0 deaths per number of cases; range 0.0–3.1 deaths per number of cases) and category 2 (median, 0.8; deaths per number of cases, range 0.0–1.9 deaths per number of cases) were low. Five centres had no deaths in category 1, two centres had no deaths in category 2. Slightly more variability in category 3 mortality rates (median, 3.0; deaths per number of cases range, 1.0–3.9 deaths per number of cases) with one centre outperforming the group mean. Mortality rate strongly influenced by case mix. Category 4 (median, 5.6 deaths per number of cases; range, 0.0–18.2 deaths per number of cases) mortality rates differed more, but owing to wider CIs (secondary to lower numbers. of operations) only one centre performed better than group mean. Greatest variation was for category 6 mortality (median, 16.7; range, 1.2–48.8); one centre outperformed and one centre underperformed group mean. When ranked by mortality rates for each RACHS-1 category, no centre consistently best/worst performer. RACHS-1 category good discriminator of mortality ($c = 0.77$) Volume/other outcomes: 1. Not reported	

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Welke *et al.* 2008,[6] USA	To determine the relationship between hospital surgical volume and mortality after paediatric cardiac surgery	Volume evaluated as continuous variable. Then, volume groups created using the following criteria: (1) natural cut-off points in the data, (2) previously studied volume thresholds, and (3) maintenance of a sufficient number of hospitals in each volume group to minimise impact of any individual hospital. All volume thresholds from 1 to 300 cases per year were investigated	Volume/mortality • In-hospital mortality by discharge disposition; paediatric cardiac surgical mortality adjusted for surgical volume, RACHS-1 risk category, patient age and year of operation. Mortality modelled for (1) volume alone and (2) volume/RACHS-1/patient age • Unadjusted mortality: very small hospitals no different from very large hospitals (OR 1.0, 95% CI 0.7 to 1.4) • Adjusted for volume/year of operation, no difference very large vs. very small hospitals in mortality (OR 0.99; $p = 0.94$). Small/medium hospitals significantly higher mortality vs. very large hospitals (small vs. very large OR 1.47, 95% CI 1.25 to 1.73; and medium vs. very large OR 1.29, 95% CI 1.10 to 1.52). Predictive value of volume/mortality low ($c = 0.6$). Adjusting for volume, RACHS-1 and age, adjusted mortality for large hospitals performed significantly better vs. very low-volume hospitals (OR 1.88; $p < 0.01$). Small/medium hospitals significantly higher mortality vs. large hospitals (OR 1.85; 95% CI 1.56 to 2.20 and OR 1.48; 95% CI 1.24 to 1.77). Predictive value of model on mortality was higher (c-statistic = 0.81) Other variables associated with mortality: • Not reported Volume/other outcomes • Not reported	1. Volume alone is a poor predictor of mortality 2. Case mix/age-adjusted mortality rates significantly better for hospitals performing > 200/year vs. all other low volume categories of hospitals 3. Non–linear relationship for volume/mortality 4. Volume thresholds somewhat arbitrary 5. Individual hospitals < 200/year with low mortality rates and a broad range of mortality rates within volume groups 6. Patient's own risk characteristics/level of disease burden accounts for majority of mortality risk. Impact of hospital volume may be small – volume a likely surrogate for process measures/characteristics of systems that lead to better outcomes

continued

TABLE 17 Data tables. Group 1: volume and mortality – all CHD conditions (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Welke *et al.* 2009,[43] USA	To determine the association between paediatric cardiac surgical volume and mortality using sophisticated case-mix adjustment and a national clinical database	Volume: number of admissions for which the index operation was cardiovascular. (Surgical volumes: total number of cardiovascular operations.) Categorical – small, < 150 cases per year; medium, 150–249 cases per year; large, 250–349 cases per year; and very large, ≥ 350 cases per year. Categories chosen to ensure adequate sample size. Volume/mortality explored as categorical, single continuous linear variables and to explore nonlinear volume effects	Volume/mortality • Unadjusted: overall mortality rate was 3.7%. With volume as *categorical* variable, unadjusted mortality rates did not differ significantly/consistently by volume groups. When mortality risk modelled as a function of programme volume categories volume alone was a poor predictor of mortality ($c = 0.53$) • Adjusted: inverse relationship for overall surgical volume as continuous variable/(in-hospital) mortality ($p < 0.002$). Number of programmes is small, 95% CIs not sufficiently narrow. Mortality for small programmes vs. very large programmes significantly higher (OR 1.51; $p < 0.0005$). Adjustment for patient risk factors/surgical case mix improved model substantially ($c = 0.84$) • Sensitivity analysis: no substantial difference after removal of largest/two largest/lowest mortality programmes Other variables associated with mortality • For low-difficulty operations (i.e. Aristotle difficulty ≤ 3.0), volume groups performed similarly ($p = 0.29$). For high-difficulty operations (i.e. Aristotle difficulty > 3.0), small programmes had substantially higher adjusted mortality relative to very high-volume programmes (OR 2.41; $p < 0.0001$). For the Norwood procedure, very high-volume programmes outperformed all other volume groups [low volume 36.5% (23/63) vs. very large volume 16.9% (81/479), $p < 0.0001$] Volume/other outcomes: none	1. Overall unadjusted volume was a poor discriminator of mortality 2. After adjustment for patient risk factors/surgical case mix, larger programmes achieved superior results for more complex operations 3. Relationship for volume/mortality complex, making volume a difficult choice as quality measure for paediatric cardiac surgery

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Welke *et al.* 2010,[42] USA	To demonstrate that case volumes and mortality rates present in paediatric cardiac surgery are too low to allow the use of mortality to, statistically, differentiate between hospitals	Hospital annual surgical volumes = number of operations performed in a year. Actual volumes compared with thresholds necessary to detect doubling and a 5 percentage point increase in mortality rate	Volume/mortality • One-tailed test: if all RACHS cases aggregated, 167 operations needed to detect a 5% difference from the national mean mortality rate 4.2% = 15% of hospitals ≥ threshold. A median volume hospital, 61 operations/year, would have to have a mortality rate of 15% to be statistically different from the national mean mortality rate. Similarly, to detect doubling of mortality rate for all RACHS-1 patients, 220 patients are required and only 7.9% ($n = 20$) of hospitals met minimum case load. Similar results for two-tailed test. Minimum case volumes necessary to detect a 5% point increase in mortality: 71 cases for RACHS-1 category 1 to 588 cases for RACHS-1 category 5. Minimum hospital case volumes needed to detect a doubling of mortality ranged from 11 cases for RACHS-1 category 5 to 2935 cases for RACHS-1 category 1	1. No hospital had a sufficient annual case volume to determine a doubling of or 5% increase in mortality for any individual operation and a minority of hospitals (0% to 5.6%) had sufficient volume to detect these differences for RACHS-1 categories. Paediatric cardiac surgery operations are performed too infrequently or have mortality rates that are too low to allow mortality-based hospital quality comparisons

CI, confidence interval; OR, odds ratio; RR, relative risk; SMR, standardised mortality ratio.
a Nationally recognised characteristic of excellent quality in nursing and healthcare institutions.

TABLE 18 Data tables. Group 1: volume and mortality – adult CHD, volume

Study, country	Main question/ objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Karamlou *et al.* 2008,[26] USA	To assess whether or not outcomes for adult CHD surgery vary between paediatric and non-paediatric surgeons	Volume defined as percentage of paediatric operations performed annually by a surgeon (continuous variable)	Volume/mortality • Unadjusted: overall in-hospital mortality for adult CHD patients 4.7%. Mortality lower in adult CHD patients operated on by paediatric surgeons (1.9%) vs. non-paediatric (4.8%) • Adjusted (case mix ± other): higher in-hospital mortality for adult CHD cases operated on by non-paediatric surgeons vs. paediatric (OR 4.5, 95% CI 2.1 to 9.5; $p < 0.0001$). Lower in-hospital mortality for adult CHD cases operated on by surgeons with greater paediatric CHD experience (OR 0.92, CI 0.89 to 0.95) or greater paediatric plus adult CHD experience (OR 0.65, CI 0.43 to 0.99) Volume/other outcomes • Low annual percentage of paediatric heart cases associated with longer LOS and higher costs Other variables associated with mortality • Female sex, type of cardiac abnormality, comorbid congestive heart failure, cardiovascular disease, renal failure and diabetes associated with higher in-hospital mortality	Lower adjusted mortality for adult CHD cases operated on by surgeons with greater paediatric CHD experience
Kim *et al.* 2011,[29] USA	To assess relationship between adult CHD surgery mortality and (1) adult CHD surgery volume and (2) total (adult and paediatric) CHD surgery volume	Annual adult CHD surgical volume – low (< 10 operations per year), medium (10–19 operations per year) or high (≥ 20 operations per year) Total (adult + paediatric) CHD surgery volume – low (< 200), medium (200–399) or high (≥ 400)	Volume/mortality • Adjusted (for age, complexity and other): high adult CHD surgery volume in paediatric hospitals (≥ 20 cases annually) associated with lower risk of inpatient mortality vs. low adult CHD surgery volume (< 10 cases annually); OR 0.4; 95% CI 0.2 to 0.7. No association for total (adult and paediatric) CHD surgery volume/adult CHD mortality: high volume (≥ 400) vs. low volume (< 200): adjusted OR 1.6 (CI not reported) Other variables associated with mortality • Adjusted: older adults, male sex, government-sponsored insurance and higher RACHS-1 risk category associated with higher mortality	Adult CHD surgery associated with lower risk of inpatient mortality in paediatric hospitals with higher adult CHD surgery volumes. No relationship for total (adult and paediatric) CHD surgery volume and adult CHD mortality

CI, confidence interval; OR, odds ratio.

TABLE 19 Data tables. Group 2: volume and mortality – specific conditions or procedures

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Berry *et al.* 2006,[13] USA	To evaluate mortality of HLHS in children undergoing stage I surgical palliation in teaching and non-teaching hospitals	Four volume categories based on annual HLHS stage I palliation volume. Median institutional stage I volume did not vary by teaching status in 1997; in 2000, teaching hospitals had a higher median volume vs. non-teaching hospitals	Volume/mortality • Unadjusted: low-volume hospitals performing stage I palliation for HLHS were associated with increased in-hospital mortality in 1997 (range: 49% low-volume to 25% high-volume; $p = 0.03$) and 2000 (range: 47% low-volume to 19% high-volume; $p = 0.01$) • Adjusted: mortality higher for low-volume vs. high-volume (OR 3.1, 95% CI 1.1 to 8.3) in 1997; adjusted analysis not undertaken for year 2000 Other variables associated with mortality • In 1997 but not in 2000, in-hospital mortality remained higher in non-teaching hospitals after controlling for stage I palliation hospital volume and condition-severity diagnoses	Hospitals performing a low volume of stage I palliation were associated with increased adjusted mortality in 1997 (not assessed for year 2000) In-hospital mortality for stage I palliation higher in non-teaching hospitals in 1997
Berry *et al.* 2007,[12] USA	To describe hospital volumes for common paediatric speciality operations and evaluate outcomes from hospital volumes	Volume – number of annual surgical cases per hospital for operation type. Case load quartiles calculated for each procedure and hospitals in lowest quartile designated as low volume	Volume/mortality • Crude • Adjusted (case mix ± other). In-hospital mortality for VSD 2% overall and for volume lowest 1.1%, second quartile 2.1%, third quartile 3.1% and highest 1.7% • Age-adjusted • Non-linear vs. linear relationship Volume/other outcomes • Not reported Other variables associated with mortality • Complications – 1.7% for VSD (quartiles low to high 0; 1.4%; 2.2%; 1.8%)	No relationship for volume/mortality for VSD

continued

TABLE 19 Data tables. Group 2: volume and mortality – specific conditions or procedures (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Checcia *et al.* 2005,[15] USA	To quantify the relative effects of institution and surgeon experience on patient outcome	Institutional volume measured as continuous and categorical variables. Categorical measure of institutional volume (for 4-year total case volume). Three groups (1) low < 16 cases, (2) medium 16–30 cases, (3) higher > 30 cases. Surgeon volume measured continuously	Volume/mortality • Unadjusted: (1) categorical hospital volume no relationship with mortality; (2) continuous hospital volume showed significant trend for increasing institutional volume ($p = 0.02$) with mortality; (3) unadjusted surgeon volume/mortality: no significant trend for increasing surgeon volume/mortality ($p = 0.13$) • Adjusted for predictor variables: lower risk-unadjusted mortality after the Norwood procedure associated with higher institutional volume ($R^2 = 0.18$; $p = 0.02$) but not for number of procedures done by a surgeon/mortality ($p = 0.312$). Survival after the Norwood procedure increased 4% (95% CI, 1% to 7%) per 10 additional procedures performed over 4-year study period per institution Other variables associated with mortality: • Not reported Volume/other outcomes • Neither institutional/surgeon volume associated with average LOS in survivors or time to mortality in non-survivors	Greater association for risk-unadjusted survival and institutional surgical volume of Norwood procedures vs. individual surgeon volume. Small number of cases seen by most surgeons may mean inadequate power to detect surgeon effect. Data suggest that regionalisation of individual, high-risk procedure might improve outcome

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages

Davies *et al.* 2011,[16] USA	To assess the volume of paediatric heart transplants performed at each centre in the USA over 10-year period (1998–2007) and estimate the influence of centre volume on outcomes	Transplants assigned to one of three categories determined by the 25th and 75th percentiles of volume (based on the number of paediatric heart procedures in the previous 5 years at transplant centre). Categories were: high-volume (≥ 63 procedures in the preceding 5 years), medium volume (19–62 procedures) or low volume (< 19 procedures)	Volume/mortality
			• Unadjusted: post-operative mortality higher in low vs. high-volume group (11.5% vs. 8.7%; OR 1.36; 95% CI 1.04 to 1.79). At 1 year, mortality remained highest in low-volume group vs. high-volume group (18.1% vs. 12.9% OR 1.48, 95% CI 1.18 to 1.86). Long-term mortality also higher ($p < 0.001$)
			• Adjusted (multivariate logistic regression): ORs for post-operative mortality were 1.60 (95% CI 1.13 to 2.24) for low-volume centres (< 19 transplants over 5 years) and 1.24 (95% CI 0.92 to 1.67) for medium-volume centres (19–62 transplants over 5 years), compared with high-volume centres
			Volume/other outcomes:
			• Patients at low-volume vs. high-volume centres more likely to:
			  ○ require a pacemaker (3.0% vs. 0.7%, OR 4.60; 95% CI 2.00 to 10.59)
			  ○ require additional operative procedures (16.9% vs. 12.8%, OR 1.39, 95% CI 1.10 to 1.75)
			• Patient in high-volume group had shorter LOS (21.9 days) after transplants vs. low-volume group (25.6 days, $p = 0.02$) or medium-volume group (26.3 days, $p = 0.0017$)
				Adjusted analysis (multivariate logistic regression) showed volume remained a significant predictor of post-operative mortality. The volume of transplants performed at any one centre has a significant impact on outcomes. Regionalisation of care is one option for improving outcomes in paediatric cardiac transplantation

continued

TABLE 19 Data tables. Group 2: volume and mortality – specific conditions or procedures (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Dean 2013,[17] USA	To investigate the effect of race, ethnicity and sex on the in-hospital mortality for three palliative procedures commonly used in the management of HLHS procedures: stage 1, stage 2 and stage 3 palliation (S1P, S2P and S3P)	For each of the three surgical procedures, the five institutions that performed most procedures are 'large-volume institutions'. The remaining institutions are 'small volume institutions'	Volume/mortality • Unadjusted: for S1P in-hospital mortality rate significantly lower at large-volume institutions vs. small volume institutions (23.6% vs. 34.3% $p < 0.0001$). For S2P the in-hospital mortality rate was similar to that at the small volume institutions (5.5% and 5.3%, respectively, $p = 0.84$). For S3P institutional surgical volume did not influence mortality • Adjusted: for other variables, surgical volume remained a significant risk factor for in-hospital mortality for S1P only: large vs. small volume: OR 0.57, 95% CI 0.45 to 0.71 but not for S2P or S3P Other variables associated with mortality • For S1P, mortality rate was also significantly higher for patients admitted from home vs. those born at or transferred to the institution performing the procedure. Ethnicity also significant risk factor for S1P and S2P (higher mortality for black and 'other' for S1P and black and Hispanic for S2P) but not for S3P. Racial differences in mortality for S2P only observed in lower-volume hospitals	Identified other risk factors which might influence in-hospital mortality – for one procedure admission from home was a risk factor; for two procedures ethnicity was a significant predictor of mortality

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Hirsch 2008,[23] USA	To determine the effect of institutional volume on hospital mortality for the Norwood and ASO as representative high-complexity neonatal cardiac procedures	Institutional volume as a continuous variable, but for descriptive purposes specific point estimates are highlighted on the continuum of data points	Volume/mortality • Significant inverse associations for institutional volume/in-hospital mortality for the Norwood procedure ($p \leq 0.001$) and ASO ($p = 0.006$). In-hospital mortality decreased for ASO as institutional volume increased. Mortality rates of 9.4% for institutions performing two ASOs per year, 3.2% for 10 ASOs per year and 0.8% for 20 ASOs per year. For ASO, decreased in-hospital mortality was greater with incremental increases in institutional volume for low-volume (0–10 ASOs per year) institutions with smaller effect as institutional volume increases. In-hospital mortality rates for HLHS were 34.8% for two Norwood procedures per year, 25.7% for 10 Norwood procedures per year, and 16.7% for 20 Norwood procedures per year. For the Norwood procedure, strong trend for decreasing hospital mortality with increasing institutional volume. Continuous non-linear inverse relation suggests decreasing in-hospital mortality with increasing institutional volume Other variables associated with mortality • No confounding for sex/race in either logistic regression model Volume/other outcomes • Not reported	Inverse relation for in-hospital mortality/institutional volume for both the ASO and the Norwood procedures

continued

TABLE 19 Data tables. Group 2: volume and mortality – specific conditions or procedures (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Hornik *et al.* 2012,[24] USA	Relative impact of (1) surgeon volume and (2) centre volume on inpatient mortality following the Norwood procedure	Centre and surgeon volume calculated as categorical and continuous variables. Centre volume 0–10, 11–20, > 20 annual Norwood procedures. Surgeon volume 0–5, 6–10, > 10 annual procedures	Volume/mortality • Adjusted • Centre volume (continuous variable): lower centre volume associated with higher inpatient mortality ($p = 0.03$) • Centres with lowest category volume significantly increased risk of inpatient mortality vs. highest category (OR 1.56, 95% CI 1.05 to 2.31; $p = 0.03$) • Surgeon volume (continuous) associated with higher inpatient mortality ($p = 0.02$) • Lowest surgeon volume category significantly higher mortality vs. highest (OR 1.6, 95% CI 1.12 to 2.27; $p = 0.01$) • Adjusting for individual surgeon and centre volume reduced impact of each variable • Surgical volume did not impact significantly on outcome across three volume categories	Centre and surgical volume significantly associated with inpatient mortality and both need to be taken into account when considering policy. Further study of factors in addition to volume need to be undertaken, i.e. training, availability of personnel, composition of care teams
Karamlou *et al.* 2010,[27] Canada/USA	To identify impact of institution and surgeon factors on 5-year survival from complex CHD surgery	Five domains for centre volume: (1) total case volume over study period; (2) total number of years procedure done for; (3) cases per year per institution; (4) rank order of cases; and (5) case velocity over time. Surgeon volume calculated for same five domains for the Norwood procedure and TGA only	Volume/mortality • Unadjusted: not reported • Adjusted (case mix ± other): institution experience only associated with an improvement in outcome for TGA. < 50 TGA cases per year associated with increasing mortality. Improvement associated with arterial vs. atrial switch (for arterial switch including case velocity over time (parameter estimate: -0.06 ± 0.13 per case; $p < 0.001$) and total procedure time (parameter estimate: and inversely related to total procedure time estimate -0.24 ± 0.10 per year; $p = 0.01$) were both associated with decreased 5-year mortality • Age-adjusted not reported – neonates only • Non-linear vs. linear relationship	Institution and surgeon experience are not the only factors influencing outcome in complex CHD. Overall no clear relationship for volumes/outcome. Excellence in one area not translated to others. Experience should be composite measure not just volume. One institution with improved Norwood procedure outcomes had neutralised effect of low birth weight suggesting institutional management protocols may play a part

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
			Other variables associated with mortality: • Not reported Volume/other outcomes: • Institutional performance – considerable variation. Institutional excellence in some groups not translated to equally superior performance for others. Surgeon factors – increasing surgeon experience associated with improved survival for TGA as rank order of cases increased indicating potential learning curve	
McHugh *et al.* 2010,[30] USA	To assess the impact of institutional volume and surgical era for patients undergoing surgery for HLHS over a 10-year period (1998–2007)	Hospitals categorised as small (< 20), medium (20–64), or large (> 64) on number of procedures for HLHS performed during the 10-year study period. Categories determined independently for S1P, S2P and S3P	Volume/mortality • Unadjusted: S1P cases – average mortality rate among six large volume institutions ($n > 64$ S1P cases) = 22% (range 14–33%), for institutions with medium ($n = 16$) volume = 32% (range 14–55%). Average mortality for small volume ($n = 26$) institutions = 51% (range 0–100%) • Adjusted (multivariate analysis): surgery performed at smaller volume institutions vs. large institutions (OR 2.5 vs. 1.8 for small- vs. medium-sized institutions) S2 and S3 palliation Compared with large volume centres, small (but not medium) institutional volume was a risk factor for mortality for S2P (OR 2.09, 95% CI 1.06 to 4.11). However, medium (but not small) volume was associated with higher mortality for S3P (OR 1.70, 95% CI 1.13 to 2.57) Other variables associated with mortality: • Operative mortality by surgical era (1998–2002 vs. 2003– 2007) • Newborn admissions (age < 30 days) reduced from 43% in 1998 to 18% in 2007. Multivariate analysis showed surgery had higher odds of mortality in the first 5-year period (OR 1.6)	Inverse relationship for institution surgical volume/ mortality for S1P of HLHS. Large-volume centres generally had low mortality rates. However, large range of mortality rates present for medium-sized centres, and some smaller centres achieved excellent results

continued

TABLE 19 Data tables. Group 2: volume and mortality – specific conditions or procedures (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Morales *et al.* 2010,[32] USA	To characterise the use of VAD in children in the USA	For VAD, high volume characterised as five or more procedures per year	Volume/mortality • Unadjusted survival 89% in high-volume LTH vs. 61% in other hospitals. Survival not affected by hospital type (adult, children, etc.) • Adjusted (case mix ± other) mortality for high-volume LTH OR 0.07 (95% CI 0.02 to 0.24) (protective against mortality) Volume/other outcomes: • Costs higher and LOS longer in children's hospitals but age VAD placed was younger Other variables associated with mortality: • Use of ECMO or need for congenital heart surgery before VAD associated with greater mortality • ECMO and acute renal failure both predictive of mortality • Transplant highly associated with survival	Increasing use of VAD may be best served in terms of outcomes and resource use by being centralised to high-volume teaching hospitals
Pasquali *et al.* 2012,[34] USA	(1) Evaluating whether or not risk status of patients impacts on relationship between centre volume and outcome. (2) Extent to which differences in centre volume account for between-centre variation in outcome	Annual Norwood procedure volume (continuous variable), Also categorical outcome with three categories of volume 0–10 annual Norwood procedures (34 centres), 11–20 (13 centres), > 20 (six centres)	Volume/mortality • Unadjusted categorical volume/inpatient mortality was significantly associated ($p = 0.037$) • Adjusted: (patient characteristics) centre volume remained significantly associated with inpatient mortality (volume as continuous variable $p = 0.04$; categorical measure of volume 0–10 cases significantly higher risk of mortality vs. highest category > 20 (OR 1.54; 95% CI 1.02 to 2.32; $p = 0.04$) • Adjusted: pre-operative risk showed volume relationship with mortality equal across all risk groups • Adjusted: mortality for each centre and percentage centre variation in mortality explained by volume = 14% (adjusting for centre volume significant variation between-centre inpatient mortality remained ($p = 0.001$)	Centre volume modestly associated with inpatient mortality (regardless of pre-operative risk status, centre volume accounts for only a small proportion of between-centre variation (centre-specific risk-adjusted outcome may be more appropriate than centre volume as marker of quality)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Petrucci *et al.* 2011,[36] USA	To identify potential risk factors (including centre volume) for morbidity and mortality in neonates undergoing MBTS	Continuous only	Volume/mortality • Relationship of centre volume to discharge mortality: OR per 10-unit increase in average MBTS volume of 0.98 (95% CI 0.85 to 1.13; $p = 0.78$) Other variables associated with mortality: • Pre-operative ventilation support; weight of < 3 kg; preoperation diagnosis of PAIVS. All associated with increased risk of death	Mortality rate after the neonatal MBTS remains high, particularly for infants weighing < 3 kg and those with the diagnosis of PAIVS. Patient-specific factors play a more important role than system factors in this population
Tabbutt *et al.* 2012,[40] USA	To identify risk factors for mortality and morbidity after performance of the Norwood procedure for ventricular reconstruction	Centre volume defined as patients with single RV screened per centre per year. Categorised as ≤ 15 (lowest volume), 16–20, 21–30 or > 30 (highest volume) patients per centre per year. Surgeon volume defined as patients with single RV scheduled for the Norwood procedure screened per surgeon per year. Categorised as ≤ 5 (lowest volume), 6–10, 11–15, > 15 (highest volume) patients per surgeon per year	Volume/mortality • Mortality not related to centre or surgeon volumes in univariate or multivariate analysis Volume/other outcomes • Lower centre volume associated with renal failure, sepsis, time to extubation and length of ventilation, LOS. Lower surgeon volume associated with renal failure, time to extubation and length of ventilation Other variables associated with mortality: • Independent risk factors for mortality were lower birth weight, genetic abnormality, longer duration of deep hypothermic circulatory arrest, ECMO, open sternum procedures	While centre and surgeon volume was not associated with mortality in this population, a range of patient- and procedure-related variables were associated with mortality Lower centre and surgeon volume were associated with some causes of post-operative morbidity and poorer clinical outcomes

CI, confidence interval; LTH, large teaching hospital; MBTS, modified Blalock–Taussig shunt; OR, odds ratio; PAIVS, pulmonary atresia with intact ventricular septum.

TABLE 20 Data tables. Group 2: volume and mortality – specific conditions or procedures; adult cardiac (not all CHD), volume

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages

Arnaoutakis 2012,[10] USA	To develop a recipient risk index predicting short-term mortality OHT. To examine the relationship between institutional volume and recipient risk on post-OHT mortality
	
	Note: only 3% CHD; mean age 52 years
		Annual centre volume categorised as low (seven OHT procedures), medium (8–15 procedures) or high (> 15 procedures)	Volume/mortality
			
			• For OHT (only 3% CHD; mean age 52 years):
			  ○ Unadjusted: mortality at 30 days: 4.6% (high volume), 5.6% (medium volume) and 9.3% (low volume). At 1 year: 11.6% (high-volume), 13.5% (medium volume) and 18.1% (low volume)
			  ○ Adjusted (risk, age, other factors), medium- and low-volume centres associated with higher mortality vs. high-volume centres. For 30-day mortality: low vs. high volume: OR 1.9 (95% CI 1.5 to 2.4); medium vs. high volume: OR 1.3 (95% CI 1.1 to 1.5). For 1-year mortality: low vs. high volume: OR 1.6 (95% CI 1.3 to 1.9); medium vs. high volume: OR 1.2 (95% CI 1.1 to 1.3). Effect more pronounced for high-risk patients
			
			Volume/other outcomes:
			
			• Post-operative complications, unadjusted data: rates of cardiac reoperation and post-operative stroke were similar irrespective of volume. New-onset dialysis and drug-treated rejection in first year after transplant more common at low- and medium-volume centres
			
			Other variables associated with mortality:
			
			• Adjusted: higher risk category (complexity, etc.), older age, longer allograft ischaemic time associated with higher 30-day and 1-year mortality
				For OHT (3% CHD; mean age 52 years), adjusted 30-day and 1-year mortality was higher for medium and low-volume vs. high-volume centres. Effect was more pronounced for high-risk patients

CI, confidence interval; OHT, orthotopic heart transplant; OR, odds ratio.

TABLE 21 Data tables. Group 3: other – proximity, distance, non-mortality outcome; paediatric CHD, proximity

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Burstein *et al.* 2011,[14] USA	To identify if there are differences in post-operative outcomes in children cared for in dedicated CICU vs. other ICU	Proximity – CICU 'a stand-alone unit dedicated to care of paediatric patients with congenital and acquired heart disease'.[14] Volume – median number of operations per year stratified as < 150 operations; 150–249 operations; 250–349 operations; ≥ 350 operations	Proximity/mortality • In-hospital mortality ○ Crude mortality – overall 3.8% (CICU 3.6% vs. PICU 4.1%; $p = 0.04$) Adjusted: no overall difference between CICU and PICU, OR 0.88 (95% CI 0.65 to 1.19); for STS-EACTS 3 OR 0.47 (95% CI 0.25 to 0.86) in favour of CICU Volume/other outcomes: • Crude and adjusted analysis showed no difference in LOS or post-op complications Other variables associated with mortality: • STS-EACTS 3; CICU 2.2% vs. PICU 4.9%, OR 0.47 (95% CI 0.25 to 0.86)	A dedicated CICU does not appear to have an impact on mortality, LOS or post-operative complications following surgery for CHD. Potential benefits for specific subgroups of patients. Probably a complex pattern of structure, training, surgeon performance and protocols contribute to outcome
Eldadah *et al.* 2011,[19] USA	To determine whether the designation of a separate, dedicated cardiac ICU affected outcomes (morbidity and mortality) for post-operative cardiac care in children	Proximity – introduction of an on-site dedicated paediatric cardiac care unit, instead of just general PICU. Volume not a variable as unchanged over time	Proximity/mortality Mortality declined from 7 of 199 (3.5%) to 2 of 244 (0.8%); $p < 0.05$ Volume/other outcomes: • Morbidity declined as evidenced by a decrease in wound infection; need for chest re-exploration; fewer children requiring resuscitation after introduction of CICU	1. The designation of a specific area for post-operative cardiac care was instrumental in the accelerated improvement in patient care and a decline in morbidity and mortality 2. Our study represents the experience of one hospital and one programme which may mean that it is not possible to duplicate these results in another institution

continued

TABLE 21 Data tables. Group 3: other – proximity, distance, non-mortality outcome; paediatric CHD, proximity (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Fixler 2012,[20] USA	To determine the effect of home distance to a cardiac centre, or having a Latin American-born parent, on first-year mortality in infants with severe CHD	Distances stratified as: 50 miles, 50–100 miles and > 100 miles	Proximity/mortality • Unadjusted: first-year mortality not significantly related to distance to centre, for all patients or specific racial or ethnic categories. 50–100 miles vs. < 50 miles: HR 0.83 (95% CI 0.57 to 1.22); for > 100 miles vs. < 50 miles: HR 1.08 (95% CI 0.86 to 1.36) Other variables associated with mortality • Unadjusted. Ethnicity: no significant differences in overall first-year survival according to race/ethnicity or for Latin American-born parents. Survival lower for Hispanic vs. white infants in specific high-risk subgroups: HLHS ($p < 0.05$) or PAIVS ($p = 0.10$); no differences for black vs. white infants • Adjusted (for CHD defect type): infant birthweight, gestational age, presence of extracardiac birth defects, and residence in a county bordering Mexico were associated with higher risk of first-year mortality. Cases without identifiable cardiac centre (often in counties bordering Mexico) had higher unadjusted mortality	Neither home distance to a cardiac centre nor race, ethnicity or parental birth country were related to unadjusted first-year survival. Survival was lower in Texas counties bordering Mexico (which have high rates of poverty) and in Hispanic infants with HLHS

Study, country	Main question/objective	Definition of volume/proximity	Results – volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Pinto *et al.* 2012,[37] USA	In neonates undergoing congenital heart surgery, to determine association between patient travel time and post-discharge mortality and adverse events	Distance to surgical centre calculated as car travel time from patient's primary residence	Proximity/mortality • Overall post-discharge mortality 8% (16/202). Those living 90–300 minutes away had non-significantly higher mortality (14.5%) vs. those < 90 minutes away (6.2%) or > 300 minutes away (2.9%); $p = 0.09$; limited by small numbers • Adjusted (complexity): post-discharge mortality for those living 90–300 minutes away non-significantly higher vs. those < 90 minutes away (HR 2.1; 95% CI 0.7 to 5.7) Proximity/other outcomes • After discharge: 45% ($n = 49$) unplanned readmission; 40% ($n = 43$) unplanned cardiac reintervention; 21% ($n = 23$) both • Adjusted (complexity): those living 90–300 minutes away less likely to have unplanned readmissions or unplanned cardiac reinterventions after discharge vs. those < 90 minutes away (HR 0.5; 95% CI 0.2 to 0.9). No difference for > 300 minutes vs. < 90 minutes (HR 1.1, 95% CI 0.6 to 2.1) Other variables associated with mortality: • Non-white race independent predictor of post-discharge mortality	Patients living 90–300 minutes from centre were less likely to have unplanned readmissions or reinterventions vs. those living < 90 minutes away, though the relationship was non-linear (no difference for those > 300 minutes away)

CI, confidence interval; CICU, children's intensive care unit; OR, odds ratio; PAIVS, pulmonary atresia with intact ventricular septum; PICU, paediatric intensive care unit.

TABLE 22 Data tables. Group 3: other – proximity, distance, non-mortality outcome – other variables

Study, country	Main question/ objective	Definition of volume/proximity	Results – Volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Benavidez *et al.* 2007,[11] USA	To examine association of an occurrence of complication during congenital heart surgery admissions on risk of death	Categorical < 150, 150–299, 300–449, > 450 (CHD surgery cases per year)	Volume/mortality • Adjusted: volume adjusted for RACHS-1 case mix and other variables showed volume category < 150 cases had significantly higher odds of death; OR 3.2 (95% CI 1.9 to 5.5; $p < 0.001$) vs. reference category of ≥ 450 cases. Intermediate volumes had higher mortality vs. high volume: 150–299 cases vs. ≥ 450 cases: OR 1.8 (95% CI 1.1 to 3.0), 300–449 cases vs. ≥4 50 cases: OR 2.2 (95% CI 1.0 to 4.8) Other variables associated with mortality: • The following significantly associated with death (adjusted for case mix and other): any complications; RACHS-1 category 2–6; younger age; prematurity; female sex; black race	Hospitals with < 150 CHD surgical cases per year had threefold higher adjusted odds of death vs. hospitals with ≥ 450 cases. Hospitals with intermediate volumes had higher mortality vs. those with high volumes
Karamlou *et al.* 2013,[25] USA	To measure the association between centre volume of cases of ECMO and survival in patients requiring ECMO	Annual ECMO volume calculated as continuous variable and three categories: < 15 patients/year, 15–30 patients/year and > 30 patients/year	Volume/mortality • Unadjusted: volume/mortality showed significantly higher mortality in lowest-volume category vs. highest-volume category (49% vs. 43%; $p < 0.015$) • Adjusted: centres within highest category of volume for ECMO associated with a significantly reduced in-hospital mortality (OR 0.51, 95% CI 0.30 to 0.87; $p < 0.01$) Other variables associated with mortality: • Older age significantly associated with risk of mortality	Higher annual ECMO volume associated with improved outcomes in paediatric cardiac cases requiring ECMO. Regionalisation of care in which majority of cardiac ECMO support is provided should be considered

Study, country	Main question/ objective	Definition of volume/proximity	Results – Volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Mery *et al.* 2014,[31] USA	To determine the incidence, risk factors, current treatment strategies and outcomes of children with chylothorax after heart surgery	Median annual RACHS procedure volume was calculated for each hospital and hospitals divided into quartiles according to cumulative median volumes. A similar analysis was done for median surgeon volume	Volume/mortality • Not reported Volume/other outcomes • Hospitals in highest-volume quartile had significantly lower incidence of chylothorax after adjustment for procedure complexity and other covariates (OR 0.49, 95% CI 0.42 to 0.58) vs. lowest-volume hospitals. Even though hospitals with higher volume tended to have lower incidence of chylothorax, some low-volume hospitals had similar incidence of chylothorax to the high-volume centres. No significant association found for surgeon annual median volume/incidence of chylothorax Other variables associated with mortality: • Adjusted: age, procedure complexity, neck or upper vein thrombosis, and hospital volume, significant association for development of chylothorax/length of the hospital stay ($p < 0.0001$) and in-hospital mortality (OR 2.13, 95% CI 1.75 to 2.61)	Hospitals in the highest quartile for volume had half the incidence of chylothorax of those in the lowest quartile after adjustment for procedure complexity Development of chylothorax consistently associated with greater risk of in-hospital mortality, even after adjustment for hospital volume. Differences in specific complication rates may therefore mediate relationship for volume/mortality Unclear whether or not relationship is related to better pre-operative selection, differences in post-operative patient care and feeding protocols, differences in reporting between centres, or differences in surgical technique. May suggest that certain practices, not identified in this study, prevalent in high-volume centres and some lower-volume centres, are responsible for lower incidence of chylothorax

CI, confidence interval; OR, odds ratio.

Appendix e: conference abstracts descriptive table

TABLE 23 Conference abstracts descriptive table

Study, country	Population included	Data source	Study dates	Sample size
Welke *et al.* 2012,[48] USA	Congenital cardiac operations performed on patients < 18 years	Society of Thoracic Surgeons Congenital Heart Surgery Database	2005–10	71,745 operations, 197 surgeons at 85 hospitals
Scheurer *et al.* 2011,[47] USA	Neonates undergoing the Norwood procedure	Paediatric Health Information System database	2004–8	2051 neonates who underwent the Norwood procedure at 29 freestanding paediatric hospitals
Karamlou *et al.* 2014,[45] USA	Neonates undergoing ASO for d-TGA with or without VSD repair	Society of Thoracic Surgeons Congenital Heart Surgery Database	2005–12	2404 patients (84 centres, 155 surgeons)
Kochilas *et al.* 2009,[46] USA	Children (paediatric cardiac procedures)	Paediatric Cardiac Care Consortium	2000–4	22,148 surgical procedures in 29 centres

d-TGA, dextro-transposition of the great arteries.

Appendix f: conference abstracts data table

TABLE 24 Conference abstracts data table

Study, country	Main question/objective	Definition of volume/proximity	Results – Volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Welke *et al.* 2012,[48] USA	To test the hypothesis that surgeon volume is associated with mortality after accounting for hospital volume	Annual volume hospitals low (< 150 cases per year), medium (150–249 cases per year), high (≥ 250 cases per year). Surgeons low (< 75 cases per year), medium (75–124 cases per year), high (≥ 25 cases per year)	Both surgeon and hospital volume inversely associated with mortality ($p < 0.0001$). Surgeons – low vs. high (OR 1.6, 95% CI 1.3 to 1.9; $p = 0.0001$). Hospitals low vs. high (OR 1.4, 95% CI 1.2 to 1.8) Low-volume surgeons had higher adjusted mortality rates regardless of hospital volume The addition of surgeon volume to the hospital volume models attenuated, but did not mitigate, the association of hospital volume with mortality (relative attenuation of OR 53% in low and 22% in medium-volume hospitals)	Hospital and surgeon volume associated with in-hospital mortality when adjusting for case mix
Scheurer *et al.* 2011,[47] USA	To explore the impact of dedicated paediatric intensive care units on high-risk neonatal populations (after the Norwood procedure)	Presence or absence of CICU	Patients undergoing the Norwood procedure treated at hospital with CICU did not differ in terms of mortality (OR 0.91, 95% CI 0.57 to 1.45), duration of mechanical ventilation (MF 0.85, 95% CI 0.58 to 1.23) log ICU LOS (MF 0.95, 95% CI 0.66 to 1.36) or log hospital LOS (MF 0.92, 95% CI 0.76 to 1.1) Centres with a CIU had decreased variability in outcomes (decreased median SD for: ventilation time 13 hours vs. 18 hours ($p = 0.04$), ICU LOS 19 days vs. 27 days ($p = 0.04$), hospital LOS 22 days vs. 28 days ($p = 0.13$)	Presence of CICU is not associated with better patient outcomes at freestanding paediatric hospitals

continued

TABLE 24 Conference abstracts data table (*continued*)

Study, country	Main question/objective	Definition of volume/proximity	Results – Volume/proximity and mortality; volume/proximity other outcomes; other variables associated with mortality	Key findings and messages
Karamlou *et al.* 2014,[45] USA	Association of surgeon and centre volume with early outcome following ASO	Categorical – annual centre volume 2 cases, 5 cases or 7 cases vs. 10 cases. Annual surgeon volume 1 case, 3 cases or 5 cases vs. 6 cases	Lower centre volume (2 cases vs. 10 cases: OR 2.08, 95% CI 1.34 to 3.24) and lower surgeon volume (1 case vs. 6 cases: OR 2.00, 95% CI 1.33 to 3.24) associated with composite end point (adjusted) Centre volume + surgeon volume attenuated OR by 31%. Surgeon volume + centre volume attenuated OR by 7%	Surgeon and centre volume affect outcomes following ASO. Surgeon volume appears to be more important than centre volume
Kochilas 2009,[46] USA	Whether or not surgical volume is a determinant of centre-specific differences in surgical mortality for CHD	< 100 procedures per year (9 centres), 101–200 procedures per year (10), 201–290 procedures per year (7), > 290 procedures per year (3)	Significant inverse relationship between in-hospital mortality and surgical volume ($p = 0.0001$). Similar results when grouping surgeries by risk category	

CI, confidence interval; CICU, children's intensive care unit; MF, multiplication factor; OR, odds ratio.

Appendix 4 Supporting evidence

Appendix a: data source description table

TABLE 25 Data source description table

Database	Type	Database description
The NIS database	Administrative, involuntary	An administrative database developed by the HCUP, NIS is the largest all-payer inpatient care database in the USA. It is a stratified, cross-sectional sample taken from the State Inpatient database (SID) comprising approximately 20% of all community (non-Federal) hospital discharges in the USA. It contains discharge data on approximately 8 million hospital stays between 1988 and 2011 from over 1000 hospitals, drawn from 46 states. The NIS contains both clinical and resource-use information including primary and secondary diagnoses; admission and discharge status; patient demographics; hospital characteristics; discharge status; severity and comorbidities
The STS-CHD database	Clinical registry, voluntary	This was set up to facilitate quality improvement and patient safety. The STS-CHD database is a clinical register collecting operative, perioperative and outcomes information on all patients at participating institutions undergoing paediatric and congenital heart surgery from 1989 to the present day. Approximately 85% of all US paediatric heart surgery centres voluntarily participate in these databases. This equates to outcomes data on > 250,000 patients from 105 participating hospitals. Data quality and reliability are ensured through intrinsic verification of data and a process of site visits and data audits. Data collected include patient demographics (including age, sex, weight and ethnicity), diagnoses, pre-operative risk factors including non-cardiac abnormalities, procedures undertaken, post-operative data and complications, and discharge status
HCUP-KIDS database	Predominantly administrative with limited clinical data	Sponsored by the Agency for Healthcare Research and Quality, KIDS is the only national, all-payer database for inpatient paediatric care in the USA (represents 36 states). It contains a systematic random sample of paediatric discharges from all community, non-rehabilitation hospitals participating in the HCUP. The sampling frame for the KIDS is approximately 97% of all hospital discharges in the USA and the sample of data approximates a 20% stratified sample of US community hospitals. It contains data from approximately 8 million inpatient episodes and when weighting is applied it estimates data on over 40 million episodes. Hospitals are stratified by geographic region, location (urban vs. rural), teaching status, bed size and ownership/control (government vs. private, not-for-profit status, etc.). Key data items collected include: primary and secondary diagnoses and procedures, admission and discharge status, patient demographics (e.g. sex, age, race, median income for ZIP code), hospital characteristics (e.g. ownership, size and teaching status), expected payment source, total charges, LOS and severity and comorbidity measures
The PHIS	Administrative	PHIS is a large multicentre administrative database containing inpatient, emergency department, ambulatory surgery and observational data from not-for-profit paediatric tertiary care hospitals that are members of the Child Health Corporation of America (CHCA). Member hospitals contribute information on demographics, diagnoses, procedures, interventions and outcomes for all inpatient episodes. The database currently holds data on over six million inpatient episodes from 44 tertiary care centres. Forty-two of these hospitals also submit resource utilisation data (e.g. pharmaceutical, imaging and laboratory resources) into PHIS. Data are collected directly from each participating hospital's electronic medical and financial record systems. Data are subjected to reliability and validity checks between participating hospitals and the CHCA

continued

TABLE 25 Data source description table (*continued*)

Database	Type	Database description
The PCCC	Clinical registry, voluntary	This database contains data from approximately 137,000 consecutive surgeries from up to 57 small and medium-sized (≤ 300 surgeries per year) centres from different areas across the USA and Canada for the period 1982–2007. Founded in 1982, centres participate voluntarily and membership has varied over the time span with 35 centres contributing at least 10 years' worth of data. The PCCC prospectively collects detailed clinical data on cardiac operations (except isolated ductal ligation for prematurity). The PCCC classifies operations into six categories based on expected early mortality rates using the RACHS-1, a validated and widely used system
UHC clinical database	Clinical database, voluntary	UHC is an alliance of 101 academic medical centres and 178 of their affiliated hospitals sharing diagnostic, demographic, procedural and outcome data on all hospital discharges. The Clinical Database/ Resource Manager provides an expanded set of comparative data by combining patient encounter level and line-item transactional detail to yield information on patient outcomes and high-impact resource utilisation
The UNOS STAR data set	Clinical registry, involuntary	The UNOS is an organisation that manages the organ transplant system, the Organ Procurement and Transplant Network, in the USA. UNOS collects information on every organ donation and transplant event occurring in the USA since 1 October 1987 on a secure internet-based transplant information database. The database allows individual centres to register patients for transplants, match donated organs to waiting patients and manage the time-sensitive, life-critical data of all patients, before and after their transplants. The STAR data set contains data variables on transplant recipients collected on UNOS data forms and contains patient-level data for all kidney, pancreas, liver and thoracic transplant candidates and/or recipients. The data set includes > 500 variables from most UNOS forms, a number of calculated variables and extensive documentation of data variables
OSHPD Discharge database	Administrative and clinical registry, involuntary	This database includes data on all discharges collected from all licensed California hospitals (> 500 acute care hospitals), including inpatient, emergency care, and ambulatory surgery data, hospital emergency departments, and licensed stand-alone ambulatory surgery clinics in the state. OSHPD data contains ICD-9-CM discharge, diagnosis and procedure codes assigned by California hospitals to each individual discharge during the year. Among other variables, the data set includes primary procedure and diagnosis and up to 20 secondary procedures and 24 secondary diagnoses
Texas Birth Defects Registry	Population registry	The Birth Defects Epidemiology and Surveillance Branch of the Texas Department of State Health Services manages this population-based active registry. Data are collected from a variety of medical facilities in the state to identify instances of major birth malformations in offspring of Texas-resident mothers (structural malformations and chromosomal disorders). Through these multiple sources of information, the Registry monitors all births in Texas (approximately 400,000 births each year) and identifies cases of birth defects. Once identified, detailed demographic and diagnostic data are abstracted and entered into the electronic registry

HCUP, Healthcare Cost and Utilization Project; HCUP-KIDS, Healthcare Cost and Utilization Project – Kids Inpatient Database; NIS, National Inpatient Sample; PCCC, Paediatric Cardiac Care Consortium; PHIS, Paediatric Health Information Service; OSHPD, Office of State-wide Health Planning and Development (California); STAR, Standard Transplant and Research; STS-CHD, Society of Thoracic Surgeons – Congenital Heart Disease; UHC, University Health System Consortium; UNOS, United Network for Organ Sharing.

Appendix b: risk adjustment for congenital heart surgery (based on Jacobs *et al.* 2012[116])

Complexity stratification tools have seen increasing popularity in the analysis of outcomes associated with congenital and paediatric cardiac surgery, reflecting the fact that so many different distinct types of operations are performed. Since 2002, complexity stratification has been used extensively by the STS-CHD database and the EACTS Congenital Heart Surgery Database.

Aristotle Complexity Score

The Aristotle Basic Complexity Score defines the complexity of an operation through three factors: potential for mortality, potential for morbidity, and technical difficulty of the operation.

When designed in 2000, the Aristotle Complexity Score was entirely based on subjective probability. This approach, based on the opinion of experts, was considered a good solution owing to the limited number of data available at that time. The Aristotle score evaluates basic surgical performance and more complex surgical performance through two complexity scores: 1) the basic complexity score (1.5–15 points), which is a procedure-adjusted complexity comprising four levels of complexity, and 2) the comprehensive complexity score (1.5–25 points), which adds patient-adjusted complexity (0–10 points) to the procedure-adjusted complexity and comprises six categories.

Risk Adjustment for Congenital Heart Surgery-1

The RACHS-1 is a mortality risk-adjustment methodology based on paediatric cardiac procedures for CHD. The method was created to adjust for differences in case mix when examining in-hospital death rates after congenital heart surgery. RACHS-1 was developed using a consensus approach involving a nationally representative panel of paediatric cardiologists and surgeons in the USA. The focus of RACHS-1 is on short-term mortality after surgery with inpatient mortality as the indicator for this outcome, as it is easily available in administrative data and other data sets.

The RACHS-1 method involves the grouping of different cardiac procedures with similar risks for in-hospital mortality into six risk categories, several of which are stratified by age or diagnosis. The procedures are organised into the six categories to form an ordinal scale of increasing risk for inpatient mortality, where category 1 has the lowest risk of death and category 6 the highest. In instances where a patient is undergoing multiple cardiac surgical procedures, the procedures are placed in the category corresponding to the single highest risk procedure. The risk categories were created by consensus judgement of the panel primarily using common coding systems such as ICD-9-CM. The allocation of procedures was subsequently refined by using mortality data from two large multicentre data sets. In order to measure case mix as accurately as possible, the risk categories are usually included in multivariable models with other key variables such as age, prematurity and the presence of a major non-cardiac structural anomaly, such as cleft lip/palate or anal atresia.

Society of Thoracic Surgeons – European Association for Cardio-Thoracic Surgery Congenital Heart Surgery Mortality Categories

The STS-EACTS Congenital Heart Surgery Mortality Score, an objective, empirically based index used to identify the statistically estimated risk of in-hospital mortality by procedure and to group procedures into risk categories. When modelled with three patient-level factors (age, weight and pre-operative LOS) STS-EACTS has a *c*-statistic of 0.816. The tool was developed using primarily objective data with minimal use of subjective probability. The risk of mortality prior to discharge from the hospital after cardiac surgery was estimated for 148 types of operative procedures by using actual data from 77,294 patients entered into the Congenital Heart Surgery Databases of the EACTS (33,360 patients) and the STS (43,934 patients) between 2002 and 2007. Procedure-specific mortality rate estimates were calculated using a Bayesian model that adjusted for small denominators. Each procedure was assigned a numeric score (the STS-EACTS Congenital Heart Surgery Mortality Score). Claimed advantages of the STS-EACTS Mortality Score and Categories include that it is based on objective evidence, rather than expert opinion, that it is able to classify more procedures than RACHS-1 or Aristotle Complexity Score and that it demonstrates a higher correlation with outcome (observed mortality) by *c*-statistic.

Appendix c: table of covariates of included studies

TABLE 26 Covariates of included studies – patient factors

Patient factors	Study
Age	Chang *et al.* 2006,[7] Bazzani *et al.* 2007,[8] Benavidez *et al.* 2007,[11] Burstein *et al.* 2011,[14] Dean 2013,[17] Eldadah *et al.* 2011,[19] Hornik *et al.* 2012,[24] Karamlou *et al.* 2013,[25] Karamlou *et al.* 2008,[26] Kim *et al.* 2011,[29] Mery 2014,[31] Morales *et al.* 2010,[32] Oster *et al.* 2011,[33] Pasquali *et al.* 2012,[34] Pasquali *et al.* 2012,[35] Seifert *et al.* 2007,[39] Tabbutt *et al.* 2012,[40] Welke *et al.* 2009[43]
Sex/gender	Chang *et al.* 2006,[7] Benavidez *et al.* 2007,[11] Dean 2013,[17] Eldadah *et al.* 2011,[19] Hirsch *et al.* 2008,[23] Hornik *et al.* 2012,[24] Karamlou *et al.* 2013,[25] Karamlou *et al.* 2013,[26] Kim *et al.* 2011,[29] McHugh *et al.* 2010,[30] Pasquali *et al.* 2012,[34] Seifert *et al.* 2007[39]
Race/ethnicity	Chang *et al.* 2006,[7] Benavidez *et al.* 2007,[11] Dean 2013,[17] Fixler 2012,[20] Hirsch *et al.* 2008,[23] Kim *et al.* 2011,[29] Oster *et al.* 2011,[33] Pinto *et al*. 2012,[37] Seifert *et al.* 2007[39]
Prematurity	Benavidez *et al.* 2007,[11] Berry *et al.* 2006,[13] Dean 2013,[17] McHugh *et al.* 2010[30]
Weight at surgery	Burstein *et al.* 2011,[14] Hornik *et al.* 2012,[24] Pasquali *et al.* 2012,[34] Pasquali *et al.* 2012,[35] Petrucci *et al.* 2011,[36] Pinto *et al*. 2012,[37] Welke *et al.* 2009[43]
Insurance status	Chang *et al.* 2006,[7] Benavidez *et al.* 2007,[11] Berry *et al.* 2007,[12] Oster *et al.* 2011[33]
Family income	Chang *et al.* 2006,[7] Seifert *et al.* 2007[39]
Gestational age	Arnaoutakis *et al.* 2012;[10] Tabbutt *et al.* 2012[40]

TABLE 27 Covariates of included studies – condition related

Category (of covariates)	Covariates	Studies (adjusting for covariates)
Cardiac diagnosis	CHD; single ventricle; double ventricle; pulmonary atresia; intact ventricular septum; aortic atresia; endocardial cushion defect; pulmonary venous return; arrhythmia; double outlet right ventricle; dominant ventricle	Berry *et al.* 2006,[13] Burstein *et al.* 2011,[14] Davies *et al.* 2011,[16] Hornik *et al.* 2012,[24] McHugh *et al.* 2010,[30] Pasquali *et al.* 2012,[34] Petrucci *et al.* 2011[36]
Comorbidities/other non-cardiac abnormalities	Genetic syndrome; risk factor; abnormality; chromosomal anomaly	Berry *et al.* 2006,[13] Burstein *et al.* 2011,[14] Hornik *et al.* 2012,[24] Kim *et al.* 2011,[29] McHugh *et al.* 2010,[30] Oster *et al.* 2011,[33] Pasquali *et al.* 2012,[34] Pasquali *et al.* 2012,[35] Tabbutt *et al.* 2012[40]
	Renal abnormalities	Morales *et al.* 2010,[32] Welke *et al.* 2009,[43] Petrucci *et al.* 2011[36]
	Major non-cardiac structural anomaly	Benavidez *et al.* 2007,[11] Berry *et al.* 2006[13]
ICD-9-CM diagnostic code		Bazzani *et al.* 2007,[8] Berry *et al.* 2006[13]

TABLE 28 Covariates of included studies – procedure related

Category (of covariates)	Covariates	Studies (adjusting for covariates)
Year (or era) in which procedure undertaken		Davies *et al.* 2011,[16] Dean 2013,[17] Hornik *et al.* 2012,[24] Karamlou *et al.* 2013,[25] Pasquali *et al.* 2012,[34] Welke *et al.* 2009[43]
Surgical complexity	STS-EACTS	Bazzani *et al.* 2007,[8] Arenz *et al.* 2011,[9] Benavidez *et al.* 2007,[11] Burstein *et al.* 2011,[14] Dinh and Maroulas 2010,[18] Eldadah *et al.* 2011,[19] Gray *et al.* 2003,[21] Hickey *et al.* 2010,[22] Karamalou *et al.* 2010,[27] Kim *et al.* 2011,[29] Oster *et al.* 2011,[33] Pasquali *et al.* 2012,[34] Pasquali *et al.* 2012,[35] Pinto *et al.* 2012,[37] Vinocur 2013,[41] Welke *et al.* 2010,[42] Welke *et al.* 2009,[43] Welke *et al.* 2006[44]
	RACHS 1	
	Aristotle Basic Complexity	
	Other	
Procedure		Chang *et al.* 2006,[7] Checchia *et al.* 2005,[15] Mery 2014,[31] Oster *et al.* 2011,[33] Welke *et al.* 2009[43]
Admission type – planned or emergency		Bazzani *et al.* 2007,[8] Berry *et al.* 2007,[12] Dean 2013,[17] Seifert *et al.* 2007[39]
Pre-operative LOS		Hornik *et al.* 2012,[24] Pasquali *et al.* 2012,[34] Pasquali *et al.* 2012,[35] Welke *et al.* 2009[43]
Ventilator use/support		Burstein *et al.* 2011,[14] Eldadah *et al.* 2011,[19] Petrucci *et al.* 2011,[36] Welke *et al.* 2009[43]
Pre-operative mechanical ventilation support		Hornik *et al.* 2012,[24] Pasquali *et al.* 2012,[34] Petrucci *et al.* 2011[36]
Use of ECMO		Karamlou *et al.* 2013,[25] Tabbutt *et al.* 2012,[40] Morales *et al.* 2010[32]
Characteristics of donor		Arnaoutakis *et al.* 2012,[10] Davies *et al.* 2011[16]
Cardiopulmonary support/bypass		Bazzani *et al.* 2007,[8] Eldadah *et al.* 2011[19]
Acidosis		Petrucci *et al.* 2011,[36] Welke *et al.* 2009[43]
Post-operative sepsis		Burstein *et al.* 2011,[14] Morales *et al.* 2010[32]
Re-exploration of the chest/ reoperative sternotomy		Davies *et al.* 2011,[16] Eldadah *et al.* 2011[19]

TABLE 29 Table of covariates of included studies – hospital factors

Hospital factors	
Surgeon volume (including volume by procedure and volume by adult/paediatric)	Kim *et al.* 2011,[29] Mery 2014,[31] Tabbutt *et al.* 2012[40]
Hospital type (teaching or non-teaching) (rural or urban)	Hirsch *et al.* 2008,[23] Karamlou *et al.* 2013,[25] Karamlou *et al.* 2008[26] Morales *et al.* 2010,[32] Seifert *et al.* 2007[39]
Distance from patient's home to hospital/travel time	Fixler 2012,[20] Pinto *et al.* 2012[37]
Bed size of hospital	Karamlou *et al.* 2013,[25] Mery 2014[31]

Appendix d: assessment of relevance table

TABLE 30 Assessment of relevance table

Study	Adjusted for severity of condition?	Adjusted for age?	Multicentre?	Included > 1 intervention/condition?
Arenz *et al.* 2011[9]	Yes	Yes	No	Yes
Arnaoutakis *et al.* 2012[10]	Yes	Yes	Yes	No
Bazzani and Marcin 2007[8]	Yes	Yes	Yes	Yes
Benavidez *et al.* 2007[11]	Yes	Yes	Yes	Yes
Berry *et al.* 2007[12]	No	No	Yes	No
Berry *et al.* 2006[13]	Yes	No	Yes	No
Burstein et al. 2011[14]	Yes	Yes	Yes	Yes
Chang *et al.* 2006[7]	Yes	Yes	Yes	Yes
Checcia *et al.* 2005[15]	No	No	Yes	No
Davies *et al.* 2011[16]	Yes	Yes	Yes	No
Dean 2013[17,51]	No	No	Yes	No
Dinh and Maroulas 2010[18]	Yes	Yes	Yes	Yes
Eldadah *et al.* 2011[19]	Yes	Yes	No	Yes
Fixler 2012[20]	Yes	Yes	No	Yes
Grey *et al.* 2003[21]	Yes	Yes	Yes	Yes
Hickey *et al.* 2010[22]	Yes	Yes	Yes	Yes
Hirsch *et al.* 2008[23]	Yes	No	Yes	No
Hornik *et al.* 2012[24]	Yes	Yes	Yes	No
Karamlou *et al.* 2013[25]	Yes	Yes	Yes	Yes
Karamlou *et al.* 2008[26]	Yes	Yes	Yes	Yes
Karamlou *et al.* 2010[27]	Yes	Yes	Yes	No
Kazui *et al.* 2007[28]	No	No	Yes	Yes
Kim *et al.* 2011[29]	Yes	Yes	Yes	Yes
McHugh *et al.* 2010[30]	Yes	No	Yes	No
Mery 2014[31]	Yes	Yes	Yes	Yes
Morales *et al.* 2010[32]	Yes	No	Yes	No
Oster *et al.* 2011[33]	Yes	Yes	Yes	Yes
Pasquali *et al.* 2012[34]	Yes	Yes	Yes	No
Pasquali *et al.* 2012[35]	Yes	Yes	Yes	Yes
Petrucci *et al.* 2011[36]	Yes	No	Yes	No
Pinto *et al.* 2012[37]	Yes	Yes	No	Yes
Sakata *et al.* 2012[38]	No	No	Yes	Yes
Seifert *et al.* 2007[39]	Yes	Yes	Yes	Yes
Tabbutt *et al.* 2012[40]	Yes	No	Yes	No

continued

TABLE 30 Assessment of relevance table (*continued*)

Study	Adjusted for severity of condition?	Adjusted for age?	Multicentre?	Included > 1 intervention/condition?
Vinocur 2013[41]	Yes	Yes	Yes	Yes
Welke *et al.* 2010[42]	Yes	Yes	Yes	Yes
Welke *et al.* 2009[43]	Yes	Yes	Yes	Yes
Welke *et al.* 2008[6]	Yes	Yes	Yes	Yes
Welke *et al.* 2006[44]	Yes	Yes	Yes	Yes

EME
HS&DR
HTA
PGfAR
PHR

Part of the NIHR Journals Library
www.journalslibrary.nihr.ac.uk

Published by the NIHR Journals Library