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Is there a relationship between surgical case volume and mortality in congenital heart disease services? A rapid evidence review

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ABSTRACT

Objective: To identify and synthesise the evidence on the relationship between surgical volume and patient outcomes for adults and children with congenital heart disease.

Design: Evidence synthesis of interventional and observational studies.

Data sources: MEDLINE, EMBASE, CINAHL, Cochrane Library and Web of Science (2009–2014) and citation searching, reference lists and recommendations from stakeholders (2003–2014) were used to identify evidence.

Study selection: Quantitative observational and interventional studies with information on volume of surgical procedures and patient outcomes were included.

Results: 31 of the 34 papers identified (91.2%) included only paediatric patients. 25 (73.5%) investigated the relationship between volume and mortality, 7 (20.6%) mortality and other outcomes and 2 (5.9%) non-mortality outcomes only. 88.2% were from the US, 97% were multicentre studies and all were retrospective observational studies. 20 studies (58.8%) included all congenital heart disease conditions and 14 (41.2%) single conditions or procedures. No UK studies were identified. Most studies showed a relationship between volume and outcome but this relationship was not consistent. The relationship was stronger for single complex conditions or procedures. We found limited evidence about the impact of volume on non-mortality outcomes. A mixed picture emerged revealing a range of factors, in addition to volume, that influence outcome including condition severity, individual centre and surgeon effects and clinical advances over time.

Conclusions: 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.

Strengths and limitations of this study

- We conducted a rapid review in a very short timescale to identify key relevant evidence that could inform an ongoing service review.
- We used clear and reproducible methods for evidence searching, inclusion and exclusion criteria and data extraction.
- Time constraints means we could not exhaustively and so some relevant evidence may have been missed.
- Detailed quality appraisal of individual included studies was replaced with a narrative summary of methodology and study design limitations.

INTRODUCTION

An extensive evidence base supports an association between organisational factors and patient outcomes in elective surgery provision. The existence of a causal relationship between volume of activity and better patient outcomes is based on assumptions that more activity may be associated with better facilities, more experienced multidisciplinary teams and more experienced and specialist clinicians, rather than being simply attributable to increased workload.\(^1\) The volume and outcome association has been most extensively studied in the surgical specialties and for complex procedures where institutional and surgical experience and specialisation might be especially important in optimising outcomes.\(^2\) However, the underlying reasons for the observed associations between greater volumes of surgical activity and better outcomes for patients remain unclear and observed variations in outcomes, including mortality, remain unexplained.\(^3\)

Evidence on the relationship between volume and outcome of surgery is dominated by studies evaluating the relationship with...
mortality. However, volume may exert important effects on other patient outcomes such as morbidity and quality of life as well as service consequences, such as length of stay in hospital and costs.

Services for congenital heart disease (CHD) have been subject to scrutiny for over a decade, in the UK and internationally. In 2012 a series of recommendations was made for the reconfiguration of cardiac services for children in England. However, the process for making these recommendations was challenged and, following a judicial review, service reconfiguration was not implemented and a new service review considering the whole lifetime pathway for CHD undertaken.

The objective of this evidence synthesis was to inform the service review by examining whether there is evidence for a relationship between institutional and individual surgeon surgical volume and patient outcomes in CHD services. Evidence for other explanatory variables, including organisational features and other outcomes (such as complications) were examined in the full review. Here we summarise the evidence for the specific relationship between surgical volume and outcome.

METHODS
We undertook a keyword-based systematic literature search using a predefined protocol, (see online supplementary file 1) enhanced by supplementary search methods. Reporting follows the PRISMA guidelines. The review was completed within 3 months.

Search strategy
Relevant articles were identified using a database search strategy adapted from an earlier systematic review completed in 2009 (see online supplementary file 2). Search terms included population, volume, other organisational factors (eg, proximity to other services such as intensive care) and patient-related outcomes. We conducted searches (January and March 2014) of MEDLINE, EMBASE, CINAHL, Cochrane Library and Web of Science for the years 2009–2014.

These formal keyword-based literature searches were supplemented by four additional search methods designed to identify additional studies not included in the earlier systematic review for the 11-year period 2003–2009. These included citation searching using key references; responses from patient and public groups and clinical experts following a call for evidence; scrutiny of the reference lists of included papers and examination of the reference lists of published reviews, guideline documents and reports.

Selection criteria
Studies were eligible for inclusion if they reported an association between surgical volume (surgical unit or individual surgeon) and patient outcomes for children and/or adults undergoing treatment (surgical or interventional) for congenital heart disease. All types of patient-related outcomes (mortality, complications and quality of life) and health service outcomes (length of stay, costs) were eligible.

Studies eligible for inclusion were (1) observational studies and reports from trials. Qualitative or questionnaire-based studies were excluded. (2) Evidence from Organisation for Economic Cooperation and Development countries to ensure relative health system comparability to the UK. The review only included original research articles published in English and data from conference abstracts was excluded as these did not yield sufficient information. (3) Published in peer-reviewed journals to ensure that the evidence being synthesised had undergone methodological and expert scrutiny.

One author (LP) screened titles and abstracts using the inclusion and exclusion criteria. Second screening was undertaken for 10% of the references retrieved via the database searches by a second reviewer (KC) then five reviewers (JT, KC, AJ, CO and FC) screened the full text of any potentially relevant article. Each reviewer independently assessed the eligibility of each study, and the final list of included studies was agreed by consensus.

Data extraction
Five reviewers (JT, KC, AJ, CO and FC) independently extracted information into a standardised data extraction form, piloted on three studies and refined accordingly. The data extraction form collected information on the characteristics of each study, the results as reported by the authors, risk adjustment undertaken and key messages (table 1). The primary outcome measure was mortality reported as ORs for the risk of dying or differences in percentage mortality rate for comparisons of low and high volume centres or surgeons. Any disagreements or challenges in data extraction were resolved with another member of the review team.

Quality assessment
As this was a rapid review we did not conduct a quality appraisal of individual included studies using a

| Study characteristics | Study findings |
|-----------------------|---------------|
| Study dates           | Volume analysed as continuous or categorical variable |
| Study aim             | Volume thresholds for categorical variables |
| Study design          | Covariates used in the analysis |
| Data source and type  | Crude associations of volume and outcome |
| Study population      | Adjusted associations of volume and outcome |
| Condition(s)          | Linear or non-linear relationship |
| Unit characteristics   | Summary of main findings |
| Intervention/procedure| Summary of limitations identified by authors |
| Definition of volume  | Number of events |
| Outcomes measured     | Number of participants |
| Sample size           | Number of events |
| Number of participants| Number of events |
| Number of events      | Number of events |
conventional quality assessment tool. Instead we used two complementary approaches to quality assessment to examine the collective contribution of the evidence base as a whole. First, we assessed the adequacy of the included evidence in addressing the aim of the research using a simple yes/no checklist for relevant factors including the study characteristics (eg, whether the study was single or multicentre or included more than one intervention/condition), the quality of the source data (eg, whether data collection was voluntary or mandatory) and the statistical analysis/adjustment (eg, whether the study adjusted for severity of condition and/or age). These relevance criteria for each included study are provided in online supplementary file 3. Second, we performed a study design level quality assessment to identify generic weaknesses. Similar study designs were coded with shared limitations. Judgements on quality were informed by limitations explicitly reported by study authors in the included studies. Assessment was undertaken by three authors (AB, JT and LP) and disagreements resolved by discussion.

Data synthesis
We extracted and tabulated the study information and used this to produce a narrative synthesis. A meta-analysis was not feasible given the considerable heterogeneity in the design, methods and settings of the included studies.

RESULTS
Study selection
The database search identified 2256 unique references of which 14 met inclusion criteria. An additional 20 papers were identified using additional non-database search methods giving a total of 34 included papers (figure 1).

Characteristics of the reviewed studies
The characteristics of the 34 included papers from 34 individual studies are summarised in table 2.

The majority of studies (88.3%) were conducted in the USA and most were multicentre (97%). No UK studies were identified. 31/34 included only paediatric patients. Thirty-one studies used routine data sets, including 19 voluntary clinical and/or administrative data sets, 12 using mandatory administrative data sets.5

Twenty-five of the 34 studies (73.5%) measured mortality or survival as the only outcome, eight studies measured mortality and other non-mortality outcomes including complications, length of stay in hospital, re-operation rates, length of ventilator treatment and time to extubation and costs. Two studies measured only non-mortality outcomes. Only 8 (25%) of the 32 studies reporting mortality measured this outcome postdischarge.

We have classified included studies into two groups—those where the primary objective was to explore the relationship between volume of service and outcomes for a range of CHD conditions (20/34) and those where the focus was on the relationship between volume and outcome for specific single conditions or procedures (14/34). For studies involving specific conditions or procedures these were mainly complex conditions such as hypoplastic left heart syndrome, transposition of great arteries and pulmonary atresia or procedures including Norwood Procedure, arterial switch operation and Blalock Taussig Shunt Procedure.8–11 Online supplementary table S3 provides a summary of the individual study characteristics for the two groups of included studies.

Findings as reported by the study authors
Results for the included studies are summarised in online supplementary table S4. In hospital mortality refers to death during the admission for the procedure. ORs signify the risk of death when different volumes are compared with 95% CIs where reported. Detailed analysis of the results of the 34 included studies is available in the full report.5

Studies on single conditions or procedures were more likely to identify an effect of volume on mortality but these focused on high risk conditions and procedures. Even within these highly selected groups there was considerable variation in effect depending on procedure type and individual centre or centre performance. The effect of surgeon volume illustrates this variability. Of four studies that included an examination of the effects of surgeon volume as well as centre volume, two found an association of decreasing mortality with increasing surgeon volume,35 41 one found increasing surgeon volume decreased mortality for only one of four complex conditions36 and one study found no association between surgeon volume and outcome.31

The findings from studies that included 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 this broader group of patients Two large, comprehensively adjusted studies showed that, while a volume relationship exists, effects are small in comparison to factors such as condition severity and associated surgical risk, and surgical era.23 26

Overall, the evidence does demonstrate a relationship between volume and outcome in the majority of studies, although this relationship is not consistent. While volume is an important factor to consider the evidence highlights the complex relationship between volume, outcome and other factors which may also have an effect.

DISCUSSION
This review found a substantial body of evidence reporting a positive relationship between volume and...
outcome, particularly for highly complex cases. However, interpretation is not straightforward. The 34 included studies revealed considerable variability highlighting the complexity of this relationship, as well as identifying variation in methods and findings across individual studies, and the methodological limitations imposed by the research approaches taken. Interpreting the evidence is particularly challenging due to a lack of information on clinical and service-related processes in the literature making it difficult to disentangle the volume/outcome relationship from other clinical and service processes and outcomes.

We have identified five key findings relevant to the organisation and delivery of CHD specialist services.

First, a range of factors influence mortality in CHD of which centre volume is only one. Our data extraction identified 67 different variables used to adjust for risk in the included studies, the most influential being condition severity.

Second, the included studies show that clinical advances, increasing expertise and changes in service provision have also influenced and improved outcomes for CHD over time. Five studies that analysed data over periods spanning up to 10 years found that, irrespective of other factors including volume and despite increasing complexity, mortality decreased over the study period. Therefore, the relevance of findings from historical data to contemporary services needs to be carefully considered.

Third, many studies used aggregated data from a large number of centres. Although this approach may show a difference in mortality rates between high and
The lack of any UK studies to contribute to the review with a larger number of cases or a combination of both.

The effects of some factors, such as condition severity, are well established but the effect of processes, systems and individual clinician effects on outcome remain unknown.

The full review also included evidence from three studies on adult CHD. One included heart transplant patients for a range of conditions in addition to CHD and so was of limited value. Two studies explored the effect of surgeon type in relation to outcome. Both studies found adult patients with CHD had better outcomes when operated on by paediatric surgeons in specialist children’s centres.

Strengths and weaknesses of this study
This review was commissioned to inform an ongoing service review and was completed within 3 months. Rapid reviews have evolved primarily to inform emergent decision-making in healthcare settings. The short time frame and streamlined methodology that they utilise require a compromise between the need for efficiency against exhaustive evidence identification and synthesis. An examination of recent rapid reviews found considerable variation in the methodologies adopted and acknowledges that there is not a ‘one size fits all’ approach. Methods used should therefore be clear and transparent. The key strengths of our approach are clear and reproducible methods for evidence searches; inclusion and exclusion criteria to identify relevant evidence and structured data extraction.

Time constraints meant we did not search exhaustively but aimed to identify all key evidence of relevance. It is possible that we may have missed relevant evidence. However, we did conduct citation searches on all included studies to minimise the likelihood of omitting eligible studies. Data extraction focused on identifying critical information for evidence synthesis rather than exhaustively extracting and critiquing all available information within individual papers. We were only able to conduct limited checking for screening and data extraction. A second reviewer screened 10% of the references identified from the searches. Data extraction was undertaken by five reviewers with but double data extraction was undertaken for a sample of included papers to refine the data extraction form and queries about data extraction or inclusions were resolved by discussion within the review team.

A meta-analysis of the evidence on volume and outcome was judged to be of limited value given the identified heterogeneity of context and populations. Further review of the broader fields of cardiac surgery outside CHD could contribute to identifying clinical and

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**Table 2** Characteristics of included studies

| Study characteristics | Number (%) |
|-----------------------|------------|
| Total number full papers included | 34 (100) |
| Volume and outcome relationship all conditions | 20 (58.8) |
| Volume and outcome relationship specific conditions/procedures | 14 (41.2) |
| Country | |
| USA/Canada | 30 (88.2) |
| Japan | 2 (5.9) |
| Germany | 1 (2.9) |
| Sweden | 1 (2.9) |
| Centre type | |
| Multicentre | 33 (97) |
| Single centre | 1 (3) |
| Data sources | |
| Voluntary (STS-CHD, HCUP-KIDS, PCCC, UHC) | 19 (55.9) |
| Involuntary/registry (PHIS, NIS, OSHPD, UNOS, Texas birth defects registry) | 12 (35.3) |
| Study specific | 3 (8.8) |
| Patient population | |
| All children (0–20) | 19 (55.9) |
| Newborns and infants only | 12 (35.3) |
| Adults | 3 (8.8) |
| Outcomes measured | |
| Survival/mortality only | 25 (73.5) |
| Survival/mortality and other outcomes | 7 (20.6) |
| Other outcomes only | 2 (5.9) |
| Design | |
| Retrospective cohort | 28 (82.4) |
| Retrospective observational | 1 (2.9) |
| Cross-sectional | 3 (8.8) |
| Longitudinal | 1 (2.9) |
| RCT (data source) | 1 (2.9) |

**RCT**, randomised controlled trial.
service-related processes and outcomes that may be relevant and provide a framework for future data collection.

Instead of conducting a detailed quality appraisal of individual studies, we examined study methodology and generic study design limitations, including self-reported generic limitations, to construct a collective assessment of study quality.

**Strengths and weaknesses of included studies**
Information bias might result from missing data, miscoding or misinterpretation of information provided in routine databases. Several studies included in this review cited incomplete data as an issue.35 39 25 27 for example, missing surgeon identifiers,15 limited exploration of the surgeon volume and outcome relationship. Some data sources relied on voluntary completion 25 36 40 which introduces potential selection bias through coverage, membership or criteria for case submission.34 36 Inconsistency in coding, particularly over time, can lead to errors and routine databases may not include information on important contextual details about individual institutions such as team composition, training and experience, type of facility and access to specialist facilities, services and care pathways. Critical details such as non-intervention, transfers between institutions and pre-operative mortality are frequently not recorded. This lack of information means the ability to assess the impact of other aspects of care will remain constrained.

Data relating to a single institution is unlikely to be generalisable. Analysing data from a single year overcomes some of the confounding effects related to structural or process changes over time and the associated danger that results measured at different time points may be misinterpreted. Study reports of a single surgical procedure can produce valuable insights for a discrete area of surgical practice but these usually involve rare and complex conditions and small numbers. This combined with the decreasing mortality reducing power, particularly as surgical procedures improve, limits the value of the reported results.

Included studies illustrate significant advances in methodology and analytic approaches over the time period covered by this review.24 Increasingly sophisticated tools to score for condition complexity and associated risk of mortality are being developed and methods for handling data as continuous, rather than a categorical, variables is now considered essential. The predominant method of using a step-wise volume category approach to establish a threshold for change in outcome used in many of the included studies is frequently criticised for being unsophisticated and misleading.

**Implications for future research**
Our review reveals a clear evidence gap in understanding the relationships between organisational factors in CHD services, how these can potentially predict a range of outcomes relevant to patients and their families, and the causal pathways between organisational factors and outcomes. Better understanding of these relationships is key to the development of methods for assessing and monitoring surgical performance that are not based solely on volume and mortality rates.3 While existing databases have value in helping understand some relationships and can help inform policy decisions there is scope to develop more comprehensive, high quality clinical and administrative databases to collect information on a range of organisational factors and outcomes related to quality of care. In the UK there is scope to expand the existing National Institute for Cardiovascular Outcomes Research (NICOR) database to capture more of this information. A more sophisticated information resource could then be used to conduct high quality studies of the relationship between organisational factors, volume and outcomes of direct relevance to the NHS and to improve the evidence base to support decisions about the organisation and delivery of CHD services.

**CONCLUSION**
This attempt to locate intervention or observational studies on the relationship between volume and other related organisational features and patient outcomes for adults and children with CHD identified a substantial volume of studies. Observational studies reported the relationship between volume and outcome in congenital heart services, particularly for paediatric surgery. This extensive body of evidence reveals a range of factors, in addition to volume, that influence outcome. These include condition severity, individual centre and surgeon effects and clinical advances over time. 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.

**Contributors**
LP, JT, AB and EG conceived and designed the study. LP and AB designed the search strategy and undertook the searches. JT, FC, KC, AJ and COK did data extraction and constructed summary tables and JT led the evidence synthesis. LP, JT, AB and EG wrote the first draft of the manuscript. LP, JT, AB, EG, FC, KC, AJ and COK contributed content to further drafts and critically revised the manuscript for important intellectual content. JT is the guarantor of the study. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis, and revised and approved the final version of the article.

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**Competing interests**
None declared.

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**Data sharing statement**
No additional data are available.
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REFERENCES

1. Luft HS. The relation between surgical volume and mortality: an exploration of causal factors and alternative models. Med Care 1980;18:940–59.
2. Pieper D, Mathes T, Neugebauer E, et al. State of evidence on the relationship between high-volume hospitals and outcomes in surgery: a systematic review of systematic reviews. J Am Coll Surg 2013;216:1015–25.
3. Kafai D, Chai P, Bacha E. Surgical volume-to-outcome relationship and monitoring of technical performance in pediatric cardiac surgery. Pediatr Cardiol 2014;35:899–905.
4. NHS Specialised Services. Review of Children's Cardiac Services in England: Decision Making Business Case. London: NHS Specialised Services, 2012. http://www.webarchive.org.uk/wayback/archive/20130328000255/http://www.specialisedservices.nhs.uk/safe_sustainable/childrens-congenital-cardiac-services
5. Turner J, Preston L, Booth A, et al. Literature searching for social science systematic reviews: consideration of a range of search techniques. Health Inf Libr J 2010;27:114–22.
6. Moher D, Liberati A, Tetzlaff J, et al., The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. PLoS Med 2009;6:e1000973.
7. Azen C, Asfour B, Hruska V, et al. Congenital heart surgery: surgical performance according to the Aristotle complexity score. Eur J Cardiothorac Surg 2011;39:e33–7.
8. Bazzani LG, Marcin JP. Case volume and mortality in pediatric surgical patients in California, 1998–2003. Circulation 2007;115:2652–59.
9. Benavidez OJ, Gauvreau K, Del Nido P, et al. Complications and risk factors for mortality during congenital heart surgery admissions. Ann Thorac Surg 2007;84:147–55.
10. Chang RK, Rodriguez S, Lee M, 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;152:86–93.
11. Dinh K, Maroulas V. Statistical modelling of mortality risk for congenital heart defects. J Appl Quantit Method 2010;5:670–8.
12. Gray DT, Louhairi I, Ahonen J, et al. Inter-institutional variation in risk-adjusted paediatric cardiac surgical outcomes. Prog Pediatr Cardiol 2003;18:33–42.
13. Hickey P, Gauvreau K, Connor J, et al. The relationship of nurse staffing, skill mix, and Magnet recognition to institutional volume and mortality in congenital heart surgery. J Nurs Admin 2010;40:226–32.
14. Karamouli T, Diggs BS, Preston L, 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.
15. 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.
16. Mery CM, Moffett BS, Khan MS, et al. Incidence and treatment of chylothorax after cardiac surgery in children: analysis of a large multi-institutional database. J Thorac Cardiovasc Surg 2014;147:678–86.
17. Kim YY, Gauvreau K, Bacha EA, et al. Risk factors for death after adult congenital heart surgery in pediatric hospitals. Circ Cardiovasc Qual Outcomes 2011;4:433–9.
18. Oster ME, Strickland MJ, Mahle WT, et al. Impact of prior hospital mortality versus surgical volume on mortality following surgery for congenital heart disease. J Thorac Cardiovasc Surg 2011;142:882–9.
19. Pasquali SK, Li JS, Burstein DS, et al. Association of center volume with mortality and complications in pediatric heart surgery. Pediatrics 2012;129:e370–6.
20. Sakata R, Kuwano H, Yokomise H, et al. Hospital volume and outcomes of cardiothoracic surgery in Japan: 2005–9 national survey. Gen Thorac Cardiovasc Surg 2012;60:625–38.
21. Seifert HA, Howard DL, Silber JH, et al. Female gender increases the risk of death during hospitalization for pediatric cardiac surgery. J Thorac Cardiovasc Surg 2007;133:668–75.
22. Vinocur JM, Menk JS, Connjet J, et al. 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.
23. Welke KF, Shen I, Ungerleider RM, et al. Current assessment of mortality rates in congenital cardiac surgery. Ann Thorac Surg 2006;82:164–70.
24. Welke KF, Diggs BS, Karamouli T, 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.
25. Welke KF, O’Brien SM, Peterson ED, et al. The complex relationship between pediatric cardiac surgical case volumes and mortality rates in national databases. J Thorac Cardiovasc Surg 2009;137:1133–40.
26. Welke KF, Karamouli T, Ungerleider RM, et al. Mortality rate is not a valid indicator of quality differences between pediatric cardiac surgical programs.
27. Arenz C, Asfour B, Hraska V, et al. Literature searching for social science systematic reviews: consideration of a range of search techniques. Health Inf Libr J 2010;27:114–22.
28. Azen C, Asfour B, Hruska V, et al. Congenital heart surgery: surgical performance according to the Aristotle complexity score. Eur J Cardiothorac Surg 2011;39:e33–7.
29. Bazzani LG, Marcin JP. Case volume and mortality in pediatric surgical patients in California, 1998–2003. Circulation 2007;115:2652–59.
30. Benavidez OJ, Gauvreau K, Del Nido P, et al. Complications and risk factors for mortality during congenital heart surgery admissions. Ann Thorac Surg 2007;84:147–55.
31. Chang RK, Rodriguez S, Lee M, 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;152:86–93.
32. Dinh K, Maroulas V. Statistical modelling of mortality risk for congenital heart defects. J Appl Quantit Method 2010;5:670–8.
33. Gray DT, Louhairi I, Ahonen J, et al. Inter-institutional variation in risk-adjusted paediatric cardiac surgical outcomes. Prog Pediatr Cardiol 2003;18:33–42.
34. Hickey P, Gauvreau K, Connor J, et al. The relationship of nurse staffing, skill mix, and Magnet recognition to institutional volume and mortality in congenital heart surgery. J Nurs Admin 2010;40:226–32.
35. Karamouli T, Diggs BS, Preston L, 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.
36. 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.
37. Mery CM, Moffett BS, Khan MS, et al. Incidence and treatment of chylothorax after cardiac surgery in children: analysis of a large multi-institutional database. J Thorac Cardiovasc Surg 2014;147:678–86.
38. Kim YY, Gauvreau K, Bacha EA, et al. Risk factors for death after adult congenital heart surgery in pediatric hospitals. Circ Cardiovasc Qual Outcomes 2011;4:433–9.
39. Oster ME, Strickland MJ, Mahle WT, et al. Impact of prior hospital mortality versus surgical volume on mortality following surgery for congenital heart disease. J Thorac Cardiovasc Surg 2011;142:882–6.
40. Pasquali SK, Li JS, Burstein DS, et al. Association of center volume with mortality and complications in pediatric heart surgery. Pediatrics 2012;129:e370–6.
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:

1. Define the scope of the search strategy
2. Define inclusion and exclusion criteria to specify what types of studies will be included in the final report
3. Construct summary tables of all included studies to present key information and findings
4. 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:

| Liddy Goyder | Colin O’Keeffe |
|-------------|---------------|
| Andrew Booth| Fiona Campbell|
| Janette Turner| Katy Cooper |
| Louise Preston| Amrita Jesuras |
Appendix One: Conceptual framework illustrating 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.

Black = Explanatory factors reported in included studies.
Blue = Explanatory factors which may be reported in included studies. These factors may require evidence from beyond CHD.
Green = 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)

Organisational factors – Structure

- Size of specialist unit/service (number of staff; number of beds etc.)
- Proximity of related specialist services (specialist ICU; ECMO specialist radiology etc.)
- Travel distance to service for patients/families
- Other structural factors

Organisational factors - Process

- Volume and nature of procedures undertaken by service
- Patient factors (casemix) including:
  - Complexity/severity of clinical condition; age; ethnic origin; socioeconomic factors
- Other related determinants of patient outcomes including:
  - Organisational culture
  - Patient safety models/systems
  - Human factors
  - Communication issues
  - Patient/carer satisfaction with care
  - Transitions of care between services

Mediating factors

- Workload (volume and nature of procedures undertaken by individual clinicians)
- Experience/expertise of specialist team/individual team members
- Timing of procedures (day of week; time of day)

Outcomes

- Mortality
- Life expectancy
- Morbidity
- Complications of treatment
- Length of Stay
- Unplanned readmission rates
Appendix Two: Search Strategy (based on Ewart 2009)

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 Three: 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. 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.
Supplementary File 1 – Sample Search – Medline

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. thoracicsurgery/
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. (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
### Supplementary file 3 – Assessment of key quality criteria

| Study                           | Adjusted for severity of condition? | Adjusted for age? | Multi-centre? | Included > 1 intervention/condition? |
|--------------------------------|------------------------------------|-------------------|---------------|-------------------------------------|
| Arenz et al (2011)             | YES                                | YES               | NO            | YES                                 |
| Arnaoutakis et al (2012)        | YES                                | YES               | YES           | NO                                  |
| Bazzani and Marcin (2007)       | YES                                | YES               | YES           | YES                                 |
| Benavidez et al (2007)          | YES                                | YES               | YES           | YES                                 |
| Berry et al (2007)              | NO                                 | NO                | YES           | NO                                  |
| Berry et al (2006)              | YES                                | NO                | YES           | NO                                  |
| Chang et al (2006)              | YES                                | YES               | YES           | YES                                 |
| Checcia et al (2005)            | NO                                 | NO                | YES           | NO                                  |
| Davies et al (2011)             | YES                                | YES               | YES           | NO                                  |
| Dean (2013)                     | NO                                 | NO                | YES           | NO                                  |
| Dinh and Maroulas (2010)        | YES                                | YES               | YES           | YES                                 |
| Gray et al (2003)               | YES                                | YES               | YES           | YES                                 |
| Hickey et al (2010)             | YES                                | YES               | YES           | YES                                 |
| Hirsch et al (2008)             | YES                                | NO                | YES           | NO                                  |
| Hornik et al (2012)             | YES                                | YES               | YES           | NO                                  |
| Karamlou et al (2008)           | YES                                | YES               | YES           | YES                                 |
| Karamlou et al (2010)           | YES                                | YES               | YES           | NO                                  |
| Study                                      | Adjusted for severity of condition? | Adjusted for age? | Multi-centre? | Included > 1 intervention/condition? |
|-------------------------------------------|-------------------------------------|-------------------|---------------|--------------------------------------|
| Kazui et al (2007)                        | NO                                  | NO                | YES           | YES                                  |
| Kim et al (2011)                          | YES                                 | YES               | YES           | YES                                  |
| McHugh et al (2010)                       | YES                                 | NO                | YES           | NO                                   |
| Mery (2014)                               | YES                                 | YES               | YES           | YES                                  |
| Morales et al (2010)                      | YES                                 | NO                | YES           | NO                                   |
| Oster et al (2011)                        | YES                                 | YES               | YES           | YES                                  |
| Pasquali et al (2012a)                    | YES                                 | YES               | YES           | NO                                   |
| Pasquali et al (2012b)                    | YES                                 | YES               | YES           | YES                                  |
| Petrucci et al (2011)                     | YES                                 | NO                | YES           | NO                                   |
| Sakata et al (2012)                       | NO                                  | NO                | YES           | YES                                  |
| Seifert et al (2007)                      | YES                                 | YES               | YES           | YES                                  |
| Tabbutt et al (2012)                      | YES                                 | NO                | YES           | NO                                   |
| Vinocur (2013)                            | YES                                 | YES               | YES           | YES                                  |
| Welke et al (2010)                        | YES                                 | YES               | YES           | YES                                  |
| Welke et al (2009)                        | YES                                 | YES               | YES           | YES                                  |
| Welke et al (2008)                        | YES                                 | YES               | YES           | YES                                  |
| Welke et al (2006)                        | YES                                 | YES               | YES           | YES                                  |
### Supplementary table 3: Description of included studies

| Author, Year, Country | Study design         | Population included                                      | Data source and study dates                                                                 | Sample size & No. centres |
|-----------------------|----------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------|---------------------------|
| **Studies on volume and mortality including all CHD conditions** |                      |                                                          |                                                                                           |                           |
| Arenz, 2011, Germany [8] | Longitudinal         | Paediatric CHD surgery                                   | Aristotle database and mortality data (2006-9)                                             | 1828 Single centre        |
| Bazzani and Marcin, 2007, USA [9] | Retrospective cohort   | Paediatric CHD surgery (0-18 years)                      | California Office of Statewide Health Planning and Development Discharge (OSHPD) database (1998-2003) | 12,801 cases 4 analyses. 13,917 cases 1 analysis. |
| Benavidez, 2007, USA [10] | Cross-sectional      | CHD surgery (0-18 years)                                 | Healthcare Cost and Utilisation Project-KIDS (HCUP-KIDS) Database (2000)                    | 10,032 100 centres       |
| Chang, 2006, USA [11] | Retrospective cohort | Infants and children undergoing Norwood operation, VSD closure, ASD closure | California OSHPD Discharge database (1989-1999)                                           | 25402 500 centres        |
| Dinh and Maroulas, 2010 USA and Canada [12] | Retrospective cohort   | Paediatric CHD surgery                                   | Paediatric Cardiac Care Consortium Database (1985-2004)                                     | 80,000 47 centres        |
| Gray, 2003, Sweden [13] | Cross sectional cohort | Paediatric CHD surgery                                   | Hospital medical records                                                                    | 284 4 centres            |
| Hickey, 2010, USA [14] | Retrospective cohort | Paediatric CHD surgery (0-18 years)                      | National Association of Children’s Hospitals Paediatric Health Information System (PHIS) Database (2005-2006) | 19,736 38 centres        |
| Karamlou, 2008, USA [15] | Retrospective observational | Adult CHD open heart or thoracic aorta procedures | Nationwide Inpatient Sample (NIS) (1988-2003)                                              | 30,250 operations        |
| Kazui, 2007, Japan [16] | Retrospective cohort | CHD surgery in newborns and infants                       | Survey data collected by Japanese Association for Thoracic Surgery (2000-2004)              | 11,197                    |
| Mery, 2014, USA [17] | Retrospective cohort | CHD surgery (0-18 years)                                 | PHIS (2004-2011)                                                                           | 77,777 43 centres        |
| Kim, 2011, USA [18] | Retrospective cohort | CHD surgery adults (18-49 years)                         | PHIS (2000-2008)                                                                           | 3061 42 centres          |
| Author, Year, Country | Study design | Population included | Data source and study dates | Sample size & No. centres |
|-----------------------|--------------|---------------------|-----------------------------|---------------------------|
| Oster, 2011, USA [19] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | PHIS (2006-2008) | 49792 patients, 39 centres |
| Pasquali, 2012b, United States [20] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | Society of Thoracic Surgeons Congenital Heart Disease (STS-CHD) database | 35,7776 patients, 68 centres |
| Sakata, 2012, Japan [21] | Retrospective cohort | CHD surgery in newborns and infants | Survey data collected by Japanese Association for Thoracic Surgery (2005-2009) | 13,074 operations, 220 centres |
| Seifert, 2007, USA [22] | Retrospective cohort | Paediatric CHD surgery (0-20 years) | HCUP-KIDS (2000) | 10282 patients |
| Vinocur, 2013, USA [23] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | PCCC Database (1982 – 2007) | 109475 operations, 85 023 admissions, 49 centres |
| Welke, 2006, USA [24] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | Congenital Heart Surgeon’s Society (CHSS) member institutions (2001-2004) | 12,672 operations, 11 centres |
| Welke, 2008, USA [25] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | NIS database (1988 -2005) | 55,164 operations, 307 centres |
| Welke, 2009, USA [26] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | STS-CHD database (2002-2006) | 32,413 operations, 48 centres |
| Welke, 2010, USA [27] | Retrospective cohort | Paediatric CHD surgery (0-18 years) | NIS (2000 to 2005) | 21,709 operations, 161 centres |

**Studies on volume and mortality specific conditions or procedures**

| Author, Year, Country | Study design | Population included | Data source and study dates | Sample size & No. centres |
|-----------------------|--------------|---------------------|-----------------------------|---------------------------|
| Arnaoutakis, 2012, USA [28] | Retrospective cohort | Adult (>18 years) orthotopic heart transplant (not all CHD) | United Network for Organ Sharing (UNOS) Standard Transplant and Research Dataset database (2000-2010) | 18,226 operations, 141 centres |
| Berry, 2006, USA [29] | Retrospective cohort | Children with Hyperplastic Left Heart Syndrome (HLHS) undergoing stage 1, 2 and 3 palliation | HCUP-KIDS Database (1997 and 2000) | 754 in 1997, 880 in 2000 admissions |
| Berry, 2007, USA [30] | Retrospective cohort | Children 0-18 years having Ventricular Septal Defect surgery with | HCUP-KIDS database (2003) | 2301 operations |
| Author, Year, Country | Study design       | Population included                                                                 | Data source and study dates                      | Sample size & No. centres |
|-----------------------|--------------------|-------------------------------------------------------------------------------------|--------------------------------------------------|---------------------------|
| Checcia, 2005, USA [31] | Retrospective cohort | HLHS, age <30 days and Norwood Procedure                                              | PHIS Database (1998-2001)                        | 801 centres               |
| Davies, 2011, USA [32]  | Retrospective cohort | Heart transplants patients aged <19 years                                             | UNOS Standard Transplant and Research Dataset (1992-2007) | 4647 centres              |
| Dean, 2013, USA [33]    | Retrospective cohort | Children with HLHS undergoing stage 1, 2 and 3 palliation                           | University Health System Consortium (UHC) Database (1998-2007) | 2761 patients             |
| Hirsch, 2008, USA [34]  | Cross-sectional    | Neonates undergoing Norwood procedure or Arterial Switch Operation (ASO)             | HCUP-KIDS database (2003)                        | Norwood – 624, 60 centres ASO - 547, 74 centres |
| Hornik, 2012, United States [35] | Retrospective cohort | Infants undergoing Norwood procedure                                                  | STS -CHD database (2000-2009)                    | 2,555 centres             |
| Karamlou, 2010, Canada/USA [36] | Retrospective cohort | Neonates 1)undergoing Norwood procedure or 2) with Transposition of Great Arteries (TGA) 3) Interrupted Aortic Arch (IAA); 4)Pulmonary Atresia with Intact Ventricular Septum (PAIVS) | STS-CHD Database. Each group varies using 5 to 10 years of data during 1987-2000 | 2421 (Norwood 710; TGA 829; IAA 474; PAIVS 408) 24 - 33 CHSS centres |
| McHugh, 2010, USA [37]  | Retrospective cohort | Children with HLHS undergoing stage 1, 2 and 3 palliation                           | UHC Database (1998 to 2007)                      | 9187 (Stage 1 1949; Stage 2 1279; Stage 3 1084) 118 centres (Stage 1 48; Stage 2 48; Stage 3 47) |
| Morales, 2010, USA [38] | Retrospective cohort | All patients ≤20 years undergoing Ventricular Assist Device (CHD 21%)               | HCUP-KIDS Database (2006)                        | 187 centres               |
| Pasquali, 2012a, United States [39] | Retrospective cohort | Infants undergoing Norwood procedure                                                 | STS -CHD database (2000-2009)                    | 2,557 centres             |
| Petrucci, 2011,         | Retrospective      | Neonates aged ≤30 days, weight>1.5kg                                               | STS -CHD database (2002-2009)                    | 1273                      |
| Author, Year, Country | Study design | Population included                                                                 | Data source and study dates                                      | Sample size & No. centres |
|-----------------------|-------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------|---------------------------|
| United States [40]    | cohort      | receiving modified Blalock-Taussig shunt                                            |                                                                  | 70 centres                |
| Tabbutt, 2012, USA [41]| Analysis of randomised controlled trial data | Children undergoing Norwood procedure with right ventricular-pulmonary artery shunt (RVPAS) or modified Blalock-Taussig shunt (MBTS) | RCT clinical and outcome data (2005-2008) | 549 15 centres            |
Supplementary table 4: Summary of results and main findings of included studies

| Study | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)] | Main findings |
|-------|----------------|-----------------------------|-----------------------------------------------|---------------|
| **Studies on volume and mortality including all CHD conditions** |
| Arenz, 2011, Germany [8] | Yes | In hospital Within 30 days | Performance score (including mortality) increased from 100% baseline to 124.9% and 132.9% | Performance over 3 years maintained despite increasing complexity and volume |
| Bazzani and Marcin, 2007, USA [9] | Yes | Within 30 days | OR = 0.86/ increase of 100 cases (0.81 to 0.92) OR=0.75 (0.55 to 1.02) >75 cases/year versus < 75 cases | For each 100 patient increase in annual volume there was a 13.9% decrease in the odds of dying. Effect lost by removing single highest volume centre. |
| Benavidez, 2007, USA [10] | Yes | In hospital | Diagnosed complication v no complication OR=2.4 (1.9 to 3.0) (p< 0.0001)] | Complications are associated with increased risk of death in CHD surgery. |
| Chang, 2006, USA [11] | Yes | In hospital 30, 90 & 365 days | Total mortality (in hospital and post discharge) OR=1.23, p<0.01 | Lower volume hospitals had higher mortality for all cases. No difference in post discharge only deaths. |
| Dinh and Maroulas, 2010 USA and Canada [12] | Yes | In hospital | Linear decreasing dependency (mortality and volume) 1985-1989 (p=0.005); 1990-1994 (p =0.016); 1995-1999 (p=0.043); 2000-2004 (p=0.045) | Modelling study. Inverse relationship between volume and mortality. In small and medium sized centres the smaller the volume the higher the risk of dying. |
| Gray, 2003, Sweden [13] | Yes | 30 day post-operative | Volume/Mortality comparing 4 centres OR for each centre compared to highest volume = 0.24, 0.12, 0.32 (p=0.0001) | No consistent relationship of smaller volume centres having lower mortality than the highest volume centre |
| Hickey, 2010, USA [14] | Yes | In hospital | Volume/Mortality OR = 0.93/increase of 100 cases (0.90 to 0.96) | For each 100 patient increase in annual volume there was a 7% decrease in the odds of dying. |
| Study                          | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)] | Main findings                                                                                                                                 |
|-------------------------------|----------------|-----------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Karamlou, 2008, USA [15]      | Yes            | In hospital                 | Non-paediatric vs paediatric surgeons OR = 4.5 (2.1 to 9.5); More vs less paediatric CHD experience OR= 0.92  (0.89 to 0.95); More vs less paediatric plus adult CHD experience OR =0.65 (0.43 to 0.99) | Adult patients operated on by paediatric surgeons have lower mortality which decreases further as surgeon volume increases.                      |
| Kazui, 2007, Japan [16]       | No             | In hospital                 | Volume/Mortality Newborns OR=2.20 (0.95 to 5.09) Infants OR=3.69 (20.2 to 6.73)                                                             | Higher mortality in lowest volume centres compared to highest volume centres for subgroup of cardiothoracic procedures. No adjustment for risk |
| Mery, 2014, USA [17]          | Yes            | In hospital                 | Complications – highest-volume quartile lower incidence of chylothorax vs lowest volume OR 0.49 (0.42 to 0.58)                  | Patients cared for in lowest-volume centres are more likely to develop this specific complication when compared with the highest-volume centres |
| Kim, 2011, USA [18]           | Yes            | In hospital                 | Total CHD volume ≥400 cases vs <200: OR 1.6 (CI not reported)] High vs low adult CHD surgery volume OR= 0.4 (0.2 to 0.7)         | No volume mortality relationship for all cases. Adult CHD patients have lower mortality highest volume group compared to two lower volume groups. |
| Oster, 2011, USA [19]         | Yes            | In hospital                 | Volume/Mortality p=0.41 low risk, p=0.067 high risk                                                                                     | Standardised Mortality Ratio calculated from previous performance. Previous hospital mortality was more significantly associated with future mortality than volume indicating factors other than volume have an effect. |
| Pasquali, 2012b, United States [20] | Yes            | In hospital                 | Volume/Mortality OR= 1.10 [1.04 to 1.17 ( p=0.002)]                                                                                        | Complex analysis comparing cases with and without complications. Mortality greatest in low volume centres for all cases and those with complications. |
| Sakata, 2012, Japan [21]      | No             | 30 days                     | Volume/Mortality - Pearson correlation co-efficient Newborns: -0.108 (p=0.273); Infants: -0.151 (p=0.149)                         | No relationship between volume and mortality for subgroup of paediatric cardiothoracic procedures                                         |
| Study                  | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)]                                                                 | Main findings                                                                                                                                                                                                 |
|------------------------|----------------|-----------------------------|---------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Seifert, 2007, USA [22]| Yes            | In hospital                 | Volume/Mortality - Highest vs lowest volume quartile OR =0.5 [CI 0.35 to 0.71 (p<0.001)]; middle quartile vs lowest OR =0.68, [0.46 to 1.00(p=0.049)]          | Assessed gender effect on mortality. Volume used as a co-variate. Mortality lower in highest volume centres and may be one factor influencing outcome.                                                                 |
| Vinocur, 2013, USA [23]| Yes            | In hospital                 | Volume/Mortality OR= 0.84/increase of 100 cases [0.78 to 0.90 (p=0.0001)]                                       | For each 100 patient increase in annual volume there was a 16% decrease in the odds of dying. Mortality decreased 10 fold over this time period indicating improving care. Individual centre effect contributed more to risk model than volume. |
| Welke, 2006, USA [24]  | Yes            | In hospital                 | Volume not predictor of mortality; c statistic 0.55                                                        | Mortality most associated with case-mix and not volume.                                                                                                                                                     |
| Welke, 2008, USA [25]  | Yes            | In hospital                 | Volume/Mortality - Small/medium hospital vs. large hospitals OR=1.85 (1.56 to 2.20) and 1.48 (1.24-1.77)     | Mortality rates significantly better for hospitals performing >200 operations per year but volume mortality relationship was not linear. Age and complexity better predictors of mortality than volume.                                      |
| Welke, 2009, USA [26]  | Yes            | In hospital                 | Volume/Mortality - no effect for low difficulty operations P = 0.29. Difficult operations (Aristotle >3) OR= 2.41 [1.89-3.06 (p< 0.0001)]               | An inverse relationship between surgical volume and mortality was found and this was associated with case complexity. No relationship between volume and mortality for low difficulty operations but low volume centres did not perform as well as higher volume for complex procedures. |
| Welke, 2010, USA [27]  | Yes            | In hospital                 | Only 8% hospital had minimum caseload required to detect 5% difference in mortality                           | Paediatric cardiac surgery operations are performed too infrequently or have very low mortality. Mortality rates are a poor measure for comparing hospital performance.                                                   |
| Study                  | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)] | Main findings                                                                                                                                 |
|-----------------------|----------------|-----------------------------|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Arnoutakis, 2012, USA  | Yes            | 30 days, 1 year             | 30-day mortality: low vs high volume: OR= 1.9 (1.5 to 2.4); medium vs high volume: OR= 1.3 (1.1 to 1.5). 1-year mortality: low vs high volume: OR= 1.6 (1.3 to 1.9); medium vs high volume: OR= 1.2 (1.1 to 1.3). | Heart transplants (CHD only 3% of cases). Mortality lower in high volume centres at 30 days and one year. High risk patients had higher mortality in low volume centres suggesting higher volume moderates the effect of risk. |
| Berry, 2006, USA      | Yes            | In hospital                 | Highest volume vs lowest mortality rate OR= 1.59 (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, 2007, USA,     | Yes            | In hospital                 | Low volume vs high volume OR= 3.1 (1.1 to 8.3)          | Comparing HLHS mortality in 4 volume groups found mortality was worse in the lowest volume group but no difference between the other 3 groups. |
| Checcia, 2005, USA    | Yes            | In hospital                 | Volume r2 =0.18, p= .02. Survival increased 4% (1% to 7%) per 10 additional procedures | Norwood procedure. Number of cases per surgeon too small to detect an effect. For each additional increase of 10 cases per year there is a 4% improvement in survival. |
| Davies, 2011, USA     | Yes            | In hospital, 1 year         | Low vs high volume OR = 1.60 (1.13 to 2.24 ); medium vs high volume OR=1.24 (0.92 to 1.67) | Heart transplants including non-CHD. Low & medium volume centres have worse mortality than expected when compared to high volume centres. |
| Dean, 2013, USA       | Yes            | In hospital                 | Stage 1 palliation large vs small volume: OR= 0.57 (0.45 to 0.71) | HLHs. For stage 1 palliation, mortality was lower in highest volume centres. Mortality in medium volume centres not investigated. No relationship between volume and mortality for stages 2 & 3 palliation. |
| Study                          | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)]                                      | Main findings                                                                                       |
|-------------------------------|----------------|-----------------------------|-----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Hirsch, 2008, USA [34]        | Yes            | In hospital                 | Significant inverse associations for institutional volume/in-hospital mortality for Norwood procedure (p ≤ 0.001) and Arterial Switch Operation (ASO) (p = 0.006). | Norwood versus ASO. As volume of cases per year increases mortality decreases.                       |
| Hornik, 2012, United States   | Yes            | In hospital                 | Volume as continuous variable - lower centre volume associated with higher inpatient mortality (p=0.03). Surgeon volume associated with higher inpatient mortality (p=0.02). Volume as categorical variable lowest vs highest volume OR =1.56 [1.05 to 2.3 (p=0.03)]. Lowest vs highest surgeon volume OR= 1.6 [1.12 to 2.27 (p=0.01)]. | Both high volume centres and high volume individual surgeon caseload have lower mortality than low volume centres and low caseload surgeons. |
| Karamlou, 2010, Canada/USA    | Yes            | In hospital                 | Centre volume impact on adjusted mortality p<0.001 for TGA and IAA  
Surgeon total case volume p=0.002 for TGA  
Centre volume on adjusted mortality p=0.17 for Norwood and p=0.07 for PAIVS  
Surgeon total case volume p=0.4 Norwood | Good outcomes for one group didn’t translate to all groups. No relationship between centre or surgeon volume for Norwood and PAIVS. Higher volume centres had lower mortality for TGA and IAA and higher surgeon volume had lower mortality for TGA only. |
| McHugh, 2010, USA [37]        | Yes            | In hospital                 | Stage 1 small vs high volume OR = 2.49 (1.51 to 4.07); medium vs high volume OR=1.75 (1.23 to 2.49).  
1998-2002 vs 2003-7 OR-1.62 (1.16 to 2.27)  
Stage 2 small vs high volume OR 2.09 (1.06 to 4.1).  
Stage 3 medium vs high volume OR=1.70 (1.13 to 2.57) | Higher mortality in both small and medium volume centres compared to high volume centres for stage 1 but mixed results for stages 2 and 3. Mortality reduced over time independently of volume. |
| Morales, 2010, USA [38]       | Yes            | In hospital                 | Large volume teaching hospitals v rest OR=0.07 (0.02 to 0.24)                           | Ventricular Assist Device – not all cases CHD. Placement of VAD at large volume teaching hospitals reduces risk of mortality when compared to lower volume and non-teaching hospitals. |
| Study                  | Risk Adjusted? | Mortality/survival endpoint | Volume/mortality effect [OR=risk of dying (95%CI)] | Main findings                                                                                                                                 |
|-----------------------|----------------|-----------------------------|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Pasquali, 2012a, United States [39] | Yes            | In hospital                 | Volume as continuous variable p=0.04; As categorical variable lowest vs. highest volume OR = 1.54 [1.02 to 2.32 (p=0.04)] | Norwood procedure. Overall higher volumes associated with lower mortality but variation in individual centre mortality rates that do not reflect this relationship. |
| Petrucci, 2011, United States [40] | Yes            | In hospital                 | Per 10-unit increase in average volume OR = 0.98 [0.85 to 1.13 (p= 0.78)] | Total case volume and Blalock Taussig Shunt Procedure volume included. No relationship between volume and mortality was found.                  |
| Tabbutt, 2012, USA [41] | Yes            | In hospital, 30 days        | Morbidity outcomes - Sepsis – Centre volume P=0.003 Renal failure – centre volume P=0.006, surgeon volume p=0.02 Time to extubation – centre & surgeon volume P<0.001 Length of stay – centre volume P<0.001 | Norwood. Centre and surgeon volume. No relationship between volume and mortality but lower volume centres and surgeon procedures were associated with higher rates of morbidity outcomes and length of stay. |