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Determinants of the length of stay in hospital after cardiac surgery: Association of Cardiothoracic Anaesthetists (ACTA) consecutive cases series study of ten UK specialist centres

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Abstract

Objectives: To determine the relative contributions of patient risk profile, local and individual clinical practice on length of hospital stay after cardiac surgery.

Design: Ten-year audit of prospectively collected consecutive cardiac surgical cases. Case-mix adjusted outcomes were analysed in models that included random effects for centre, surgeon, and anaesthetist.

Setting: UK centres providing adult cardiac surgery.

Participants: 10 of 36 UK specialist centres agreed to provide outcomes for all major cardiac operations over 10 years. After exclusions (duplicates, cases operated by more than one consultant, deaths and procedures for which the EuroSCORE is not appropriate), there were 107,038 cardiac surgical procedures between April 2002 and March 2012, 127 consultant surgeons, and 190 consultant anaesthetists.

Interventions: All cardiac surgical operations for which the EuroSCORE model is appropriate.

Main outcome measure: Length-of-stay up to three months postoperatively.

Results: The principal component of variation in outcomes was patient risk, accounting for 95.43% of the variation for postoperative length-of-stay. The impact of the surgeon and centre was moderate (intra-class correlation coefficients ICC=2.79% and 1.59% respectively), and the impact of the anaesthetist was negligible (ICC=0.19%). Similarly, 96.05% of the variation for prolonged (>11 days) length-of-stay was attributable to the patient, with surgeon and centre less but still influential components (ICC=2.12% and 1.66% respectively, 0.17% only for anaesthetists). Adjustment for year of operation resulted in minor reduction in variation attributable to surgeons (ICC=2.52% for LOS and 2.23% for prolonged LOS).

Conclusions: Patient risk profile is the primary determinant of variation in length of stay, and as a result, current initiatives to reduce hospital stay by modifying consultant performance are unlikely to have a substantial impact. Therefore, the only way to substantially reduce hospital stay after cardiac surgery is by denying surgery to high-risk patients.

Keywords: length-of-stay, hospitalisation, centre, surgeon, anaesthetist, EuroSCORE, cardiac surgery.

INTRODUCTION

According to 2013 records some 36,000 patients undergo cardiac surgery in the UK each year at a high annual cost of around £300 million.[1] Anticipated below-inflation increases in future NHS tariffs have inevitably triggered the search for efficiency savings, particularly improved patient throughput accompanied by shorter hospital stay, which is a key driver of surgical costs.[2, 3] Despite operating on relatively homogeneous patient populations, previous benchmarking exercises have identified considerable centre differences in postoperative models of care and length-of-stay (LOS) after cardiac surgery.[4]

Differences in healthcare providers' practices may also influence hospital stay[5]; nevertheless, the impact of individual surgeons and anaesthetists on LOS has received less attention. For instance, the operating surgeon has been shown to have a significant impact on in-hospital mortality post-cardiac surgery.[5, 6] However, to our knowledge, their impact on postoperative LOS has not been explored. Technically-skilled surgeons with low postoperative morbidity should achieve lower LOS. Similarly, previous studies have suggested differences in anaesthetic practices e.g. the use of "fast-track" anaesthesia protocols may accomplish a similar goal[7, 8]; however the evidence has been inconclusive.[9] These relationships may be confounded by changes in service provision over time, so that careful analysis is required.

Several authors have studied the association between patient-related factors (e.g. disease severity, existence of comorbidities) and prolonged LOS after cardiac surgery.[10-12] There is also controversy as to whether different practices at different centres in the UK directly impact on hospital stay after cardiac surgery.[13] This study aims to quantify the variation in risk-adjusted

postoperative LOS between cardiac centres, surgeons and anaesthetists across the UK, and to investigate changes in these components over time.

Strengths and limitations of this study

- The study comprises more than 100,000 cases from ten of 36 UK specialist centres, amounting to almost a third of the cardiac cases in the UK between 2002 and 2012.
- The study is the first to examine the impact of the operating centre and key providers involved in the delivery of care on the LOS after cardiac surgery.
- Identifying how these external factors influence LOS may contribute to improving the efficiency of care.
- Total hospital LOS may have been underestimated due to failure to include periods of time after inter-hospital transfer.
- The study concerned specialist centres with a likely interest in quality improvements therefore its findings may not be generalisable to smaller, non-specialist centres.

METHODS

Data Source

Cohorts comprising consecutive case series from UK specialist cardiac centres were provided to the Association of Cardiothoracic Anaesthetists. Data collection is mandated by the NHS and recorded prospectively in each centre. Requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority. Previous published work on this dataset examined the impact of the anaesthetist, surgeon and centre on in-hospital mortality.[5]

Study cohort

Details of how the study cohort was derived have been previously published. Briefly, our cohort comprised ten out of 36 UK specialist cardiac centres that provided datasets totalling more than 100,000 cardiac surgical patients (Figure 1). All 36 UK specialist cardiac centres were approached, of which ten agreed to participate and obtained local permissions for data provision within a set timeframe of a month. No centres were excluded. Data from consecutive major cardiac operations were prospectively collected for the 10-year period April 2002 through March 2012. Exclusion criteria were procedures for which the Logistic EuroSCORE was not appropriate, cardiac transplants, pulmonary endarterectomy procedures and very high risk cases that necessitated delivery by at least two consultant surgeons. Patients under 18 years old were also excluded (0.08%). Patients with multiple operations at distinct admissions during the study period were treated as independent episodes.

There was a small amount of missing provider data (n=28, 0.02% and n=1482, 1.3% missing surgeon and anaesthetist entries respectively) which were excluded from the analysis. A small number of cases with missing discharge destination (n=129, 0.11%) or date (n=125, 0.11%) were

excluded. Finally, the EuroSCORE was not recorded for 755 entries (0.66%) which were also excluded. There were three patients with unknown sex, 40 with unknown operative priority status and 5964 with unrecorded operation type, all of whom were included in the analysis (Table 1).

Table 1: Patient and operative characteristics for analysis dataset (n=107,038)

Patient Characteristics	*Category*	*Frequency(Percentage of n=107038)*
Age at admission(years)	[18-36)	1 883 (1.76%)
	[36-56)	15 149 (14.15%)
**Mean:66.20(11.31)*	[56-66)	28 502 (26.63%)
Median:68	[66-76)	39 720 (37.11%)
IQR:(60,74)	[76-86)	20 682 (19.32%)
	[86-96]	1 102 (1.03%)
Gender	Male	78 261 (73.12%)
	Female	28 774 (26.88%)
	Unknown	3 (<0.01%)
EuroSCORE(probability)	[0,0.1)	87 559 (81.80%)
**Mean:0.0690(0.0896)*	[0.1,0.2)	12 515 (11.69%)
Median:0.0400	[0.2,0.3)	3693 (3.45%)
IQR:(0.0208,0.0777)	≥0.3	3271 (3.06%)
Operative Characteristics		
Priority	Elective	74 909 (69.98%)

	Urgent	28 312 (26.45%)
	Emergency	3525 (3.30%)
	Salvage	252 (0.23%)
	Unknown	40 (0.04%)
Operation Type	CABG(isolated)	56 586 (52.87%)
	AVR(isolated)	9719 (9.08%)
	MVR+other	6178 (5.77%)
	CABG+AVR	8594 (8.03%)
	CABG+other procedures	2204 (2.06%)
	CABG+other valve	2860 (2.67%)
	Other procedures	3800 (3.55%)
	AVR+other procedures	2511 (2.34%)
	CABG+AVR+other	1292 (1.21%)
	Valve alone	5788 (5.41%)
	Valve + other	1542 (1.44%)
	Unknown	5964 (5.57%)

**for continuous variables, the mean(SD), median and interquartile range are given.*

Surgeons and anaesthetists with caseloads smaller than 0.1% of the total caseload of their centre were excluded; these professionals, with the exception of one surgeon, had carried out fewer than ten operations and had either retired just after the onset of the study period, were appointed just before the end of the study period or held short-term contracts. Patients who were not discharged after three months of the procedure date were excluded from the analysis as any

patient-related outcomes would likely be unrelated to the procedure itself and more likely be a result of other comorbidities (n=272, 0.24%). Moreover, all cases with immediate discharge (i.e. zero LOS) were excluded as they were either deaths or transfers to other centres (n=441, 0.4%). All remaining cases that resulted in in-hospital death were also excluded from the analysis in order to avoid bias associated with short LOS due to early death considered as a positive outcome and to be consistent with published literature (n=2,971, 2.7%).[10, 12]

The final analysis dataset comprised 107,038 cases (93% of the original case series, n=115,254) treated by 127 surgeons and 190 anaesthetists in 10 centres. The dataset comprised 91% (n=127 of 140) and 76% (n=190 of 250) of the initial surgeon and anaesthetist samples respectively; providers were excluded principally due to low caseload volumes.

Patient involvement

No patients were involved in setting the research question or the outcome measures, developing plans for design or implementation of the study. No patients were asked to advise on interpretation and writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

Variables and Outcome measures

The primary outcome measure was LOS up to three months postoperatively. LOS was defined as the number of days spent in hospital from the day of surgery to hospital discharge. The secondary measure of interest was prolonged LOS, defined as a hospitalisation of more than eleven days following surgery. There is no consensus in the literature on the definition of prolonged LOS after cardiac surgery, and as a result, published studies often adopt the 75th centile of the LOS distribution.[10, 11, 14, 15] In our data set this corresponded to 11 days, and we have chosen it as the cut-off for prolonged stay to ensure consistency with published literature;

we sought the expert advice of our cardiac surgical collaborators to ensure this was relevant to cardiac surgery in the NHS setting.

Since there is no established risk score for prolonged LOS, adjustment for varying patient case-mix risk was achieved using the logistic EuroSCORE.[16] The logistic EuroSCORE is a very well established risk score for in-hospital death with widespread use worldwide and involves 17 cardiac, operation- and patient-related factors. The recently recalibrated version of the score (EuroSCORE II) was not available at the study onset[17]; our analysis included the original logistic EuroSCORE as this was the one used by the participating centres. One centre used the additive EuroSCORE, which is associated with under-prediction in high-risk cases. The proportion of high-risk patients, for which the additive EuroSCORE is known to underperform (additive EuroSCORE≥10%) was very small (0.5%, n=586 of 107,038)[18] and results of sensitivity analysis excluding this centre did not differ from analysis of the full cohort. We considered using patient age, sex and urgency instead of the logistic EuroSCORE to account for patient heterogeneity but EuroSCORE provided better model fit to the data, based on statistical criteria. In addition to variation due to centre, surgeon and anaesthetist, the covariate of interest was the calendar year of operation.

Statistical methods

We investigated the relationship between LOS up to three months postoperatively and potential covariates using mixed effects regression models. Patients were clustered within surgeons and anaesthetists who in turn, were clustered within centres inducing a hierarchy. To reflect this, random effects terms were included for centres, surgeons, and anaesthetists. Logistic EuroSCORE was included as a fixed effect in all models to adjust for varying patient case-mix

risk; year of procedure was included as a continuous fixed effect to investigate changes in outcomes over time.

Since the primary LOS outcome was positively skewed, linear mixed effects models were fitted to the logarithm of the LOS (log(LOS)). Prolonged LOS was modelled as a binary endpoint (≤11 vs > 11 days) using logistic mixed effects models. The following models were implemented for both outcomes of interest.

Initially two three-level random intercept models were fitted in order to establish individual surgeon and anaesthetist effects on the patient outcome, controlling for centre effects and patient case-mix risk. Thereafter, in order to model the effects of surgeons and anaesthetists simultaneously, we fitted a three-level cross-classified model assuming an additive contribution (on the log scale) from each provider (anaesthetist and surgeon), clustered within centres. We further fitted a two-level centre random intercept model, accounting solely for patient heterogeneity, in order to compare its outputs to those of the three-level cross-classified model and assess the impact of provider adjustment on between-centre variation. In order to investigate the effect of time we included the year of operation in the three-level cross-classified model. The methodology used has been described in detail in Papachristofi *et al.*[19]

Finally, in each model we estimated the Intra-Class Correlation Coefficients (ICC)[20] which represent the proportion of the total variation in the outcome that is attributable to each of the anaesthetist, surgeon and centre. The Likelihood Ratio Test was used to determine the significance of the fixed effects terms and the relevant p-values. We implemented all our methods using the statistical software R (version 3.2.2).[21, 22]

RESULTS

Baseline characteristics for the study cohort are summarised in Table 1. Almost three-quarters of the patients were men (73.1%). The mean (SD) age of our cohort was 66.20 (11.31) years. Overall, the median postoperative LOS over the 10-year study period was seven days, with 75% of patients discharged between 6 and 11 days; the corresponding mean LOS was 10.19 (8.36) days, although this is influenced by a small proportion of large values. The mean LOS over time in each centre is depicted in Figure 2, which shows varying patterns across centres; for instance, LOS decreased over time in centre 6 whereas it increased in centre 8. Summaries of each centre's cohorts are given in Table 2. Almost 23% of the study cohort had prolonged LOS over 11 days, which was associated with higher operative risk score compared to patients with LOS of 11 days or less (mean EuroSCORE 11.28% vs 5.42%).

Table 2: Numbers of patients operated on, surgeons and anaesthetists in each centre, between April 2002 and March 2012. Surgeons and anaesthetists who looked after <10 patients/year were excluded. Values are frequency or mean (SD) unless specified as median(IQR).

Centre number	Patients	Surgeons	Anaesthetists	LOS Median (IQR)	LOS Mean (SD)	Logistic EuroSCORE
1	17,889	21	24	8 (6, 11)	10.06 (7.14)	7.52 (9.74)%
2	9,323	13	16	8 (6, 12)	10.96 (9.13)	8.92 (11.26)%
3	6,357	6	8	7 (6, 10)	9.69 (8.59)	7.62 (9.03)%
4	15,008	16	24	7 (6, 10)	9.47 (7.47)	5.77 (7.26)%
5	6,661	10	15	7 (6, 11)	10.08 (8.79)	6.13 (7.96)%

6*	9,637	10	17	7 (6, 9)	9.03 (7.76)	4.29 (3.18)%
7	7,537	13	17	8 (6, 13)	11.41 (9.86)	7.48 (10.61)%
8	7,238	11	13	7 (6, 11)	10.75 (9.08)	6.71 (9.90)%
9	16,506	17	22	7 (6, 11)	10.15 (8.47)	7.47 (9.58)%
10	10,882	10	34	8 (8, 12)	10.95 (8.75)	6.91 (7.84)%

*Additive EuroSCORE was provided by this centre.

The logistic EuroSCORE was significantly associated with LOS in both surgeon and anaesthetist models, additionally adjusted for centre effects (1.230, 95% CI 1.226 to 1.234 and 1.229, 95% CI 1.225 to 1.232 respectively, p-value <0.0001 for both). This amounted to an increase in LOS of about 23% for each 1% increase in logistic EuroSCORE. The logistic EuroSCORE remained significant in the three-level cross-classified model including both surgeon and anaesthetist effects (1.231, 95% CI 1.226 to 1.234, p-value <0.0001). Table 3 shows that 95.43% of the variation in log(LOS) in this analysis was attributable to the EuroSCORE (and remaining patient heterogeneity).

Table 3: Percentage of the variation in post-operative length-of-stay (LOS) and prolonged LOS attributed to each component

Outcome	Centre	Surgeon	Anaesthetist	Patient and other covariates
LOS	1.59%	2.79%	0.19%	95.43%
Prolonged LOS	1.66%	2.12%	0.17%	96.05%

Figures 3a and 3b show the estimated LOS, in days, with its 95% confidence interval (CI) for each surgeon if they operate on a patient of average risk (i.e. mean EuroSCORE estimated at 6.9%), adjusting solely for centre effects, and adjusting for centre and anaesthetist effects

simultaneously. Estimated LOS for 18 out of 127 surgeons, from nine different centres, have 95% CI lying wholly below the average LOS, suggesting shorter hospitalisations for their caseload. Fifteen surgeons from seven centres had higher-than-average estimated LOS. The surgeon random effects variance was modest yet important, with $ICC_{surgeon}$ =0.0287 suggesting 2.87% of the variation in outcome is attributable to the operating surgeon. Adjusting for anaesthetist effects resulted in a minor decrease in the $ICC_{surgeon}$ from 0.0287 to 0.0279. The surgeons with longest and shortest average LOS were distributed across seven centres hence we could not identify a specific centre of extreme performance. This finding, in conjunction with the ICCcentre (1.59%), suggests that LOS is influenced by both surgeon and, to a small extent, by operating centre.

Figures 3c and 3d depict the analogous anaesthetist forest plots, controlling solely for centre effects, and controlling for centre and surgeon effects simultaneously. Between-anaesthetist variability in LOS is smaller than between-surgeon variability (Figure 3c), with associated $ICC_{anaesthetist}$ of 0.58%. Estimated LOS durations for ten out of 190 anaesthetists, from five different centres, have 95% CI lying wholly below the average LOS indicating better performance that average. There were 14 anaesthetists from nine centres whose estimated LOS was higher than average. However, once surgeon effects were adjusted for, anaesthetist variation reduced to $ICC_{anaesthetist}$=0.0019 (0.19%), which is negligible. Figure 3d indicates that there is only one remaining anaesthetist with 95% CI wholly below the average; likewise, the number of anaesthetists with estimated LOS above the average reduced from 14 to four, employed in four different centres. This is unsurprising as, by pure chance, we would expect approximately 5 anaesthetists to lie at the upper end of the spectrum (i.e. if the anaesthetists were normally distributed, 2.5% of 190 (n=4.75) would lie above the 97.5% quantile). The difference in

estimated LOS between the two anaesthetists at the extremes reduced from almost two and a half days to less than one day.

Adjusting only for patient heterogeneity, the proportion of variation attributed to centre where the procedure was undertaken was 1.79% (ICCcentre=0.0179). When surgeon and anaesthetist effects were added, ICCcentre reduced to 1.59%; comparison of Figures 4b and 4a indicates that two centres remained significantly above, and two below, the overall average.

The effect of calendar year of operation on LOS was statistically significant (0.994, 95% CI 0.993 to 0.995, p-value <0.0001). However, this amounted to a decrease of 0.6% in LOS per year, which is unlikely to be clinically important. A calendar year random coefficient model was also fitted (Table S1, Supplementary material) which suggested that changes in LOS through time varied significantly between centres.

Finally, increased logistic EuroSCORE was associated with increased odds of prolonged LOS in surgeon only, anaesthetist only and cross-classified models (OR 0.784, 95% CI 0.768 to 0.800; 0.775, 95% CI 0.759 to 0.791; and 0.785, 95% CI 0.769 to 0.801 respectively, p-value <0.0001 for all). The percentage of the variation in prolonged LOS attributable to EuroSCORE (and remaining patient heterogeneity) was 96.05% (Table 3). The variation attributable to the centre, surgeon, and anaesthetist was quantified as 1.66%, 2.12%, and 0. 17% respectively.

We conducted exploratory analysis of the effect of age and logistic EuroSCORE on between-centre variation. Postoperative LOS increased by about 1% for an increase of one year in age (Table S2, Supplementary material). Although small, there was some variation between centres in the age effects, suggesting that part of the between-centre variation could be ascribed to differences in the average age of the treated population. There was some variation between

centres in the case-mix risk treated, which may explain part of the variation in centres' LOS (Table S3, Supplementary material).

DISCUSSION

Our study cohort included 10 of 36 UK cardiothoracic surgical centres, totalling 107,038 heterogeneous patients, equivalent to almost a third of the total cardiac operations performed in the UK during our study period. Patient risk factors accounted for over 95% of the variation in LOS and prolonged LOS in all models. The second most influential factor was the operating surgeon, with centre having a more moderate yet significant effect, whereas anaesthetist-induced variation was minimal.

Comparison with other studies

Our findings are consistent with published literature in other surgical fields suggesting much of the non-patient variation in LOS derives from different provider practices,[11] with the surgeon a more influential component than the anaesthetist. This is to be expected as the surgeon has specific responsibility for the patients' postoperative ward care and discharge. In previously published work using this cohort, similar surgeon and anaesthetist effects were found for in-hospital mortality, with surgeons having a considerable impact (4.00%) and anaesthetists a negligible effect (0.25%).[5] In contrast, there were no centre effects on in-hospital mortality. The centre importantly includes critical care and high dependency services, which may exert a significant effect on LOS, although it is difficult to isolate this aspect from other contributing factors using routinely-collected data.

Potential Explanations and Implications of findings

Our findings suggest that differences in centre infrastructure, policies and possibly geographical location are more likely to affect postoperative LOS than patient survival. We

conducted sensitivity analysis by re-estimating effects including cases of immediate discharge (i.e. zero LOS) and including all remaining cases that resulted in in-hospital death yielding very slightly reduced ICC estimates (1.21%, 2.21% and 0.15% for centre, surgeon and anaesthetist respectively). This reflects the fact that LOS for these patients is partly driven by mortality, resulting in reduced influence of external factors such the centre or surgeon. We further conducted exploratory analysis of factors that may contribute to increased between-centre variation. Our analysis supports the hypothesis that centres in areas with elderly populations are associated with increased LOS, in line with published evidence suggesting older patients are less likely to be discharged home.[8, 11, 12, 23] Likewise, exploratory analysis showed some between-centre variation in case-mix risk treated, which may explain part of the variation in centres' LOS.

The estimated mean LOS per anaesthetist (Figure 3) appears superficially very similar to the estimated probability of in-hospital death vs. anaesthetist previously published (Figure 2[5]). We examined which surgeons were significantly below, or above average both for in-hospital death and LOS but there was no discernible pattern. Interestingly there was one surgeon who was significantly below average both for LOS and in-hospital mortality and one surgeon who was significantly above average for both. There was one surgeon significantly below average for mortality but above average for LOS and one surgeon significantly above average for in-hospital mortality but below average for the LOS.

Figure 4 illustrates a relatively tight distribution of average LOS between centres. It is notable that the two centres (6 and 4) with shortest LOS, had the lowest average EuroSCOREs (4.29 additive and 5.77 logistic respectively). In contrast, centre 10 may have been expected to have a shorter LOS given the relatively low average EuroSCORE (6.9). Geographical location may influence centres' LOS due to the type of populations treated. For instance, centres in less

affluent areas, where access to home care is limited, may be associated with longer LOS. Alternatively, in areas with communities that have an established infrastructure and tradition of caring for relatives, centres may have shorter LOS. Further, in-depth examination of the association of location and socioeconomic status is needed in order to robustly estimate their impact on the LOS.

The small decrease in LOS through time may result from improvements in the delivery of care in recent years, and is consistent with other published literature reporting longer hospitalisations at the beginning of the cohorts studied.[15] Given the numbers of initiatives purporting to reduce LOS after cardiac surgery, the actual 1% per year reduction is modest. Although predicted LOS, for a patient of average risk *decreased* over time in most centres, it *increased* in three (Figure 5); this may be due to changes in management strategies and introduction of more conservative discharge practices in these centres. A potential risk of reducing LOS is an increased risk of hospital readmission due to premature hospital discharge. In April 2011, the Department of Health introduced a policy of non-payment for emergency readmissions to English hospitals. According to the 2011/2012 Payment by Results (PbR) guidance, commissioners will no longer pay for any eligible emergency readmissions to a hospital within 30 days of discharge following planned hospital stay. The potential loss of considerable income may have induced reluctance of early postoperative discharge in some centres.

Limitations

i) Our study is limited by the lack of detailed patient-related information, such as ethnic and social background, rural residency, availability of home carer, access to

transportation and local resources for the provision of social services, which may have a significant effect on postoperative LOS.

ii) We did not have access to centre characteristics, such as proportion of LOS spent in intensive care (ICU), high dependency unit (HDU) or post-surgical ward care. Different models of care, resulting in differing proportions of time in each ward type, could affect total LOS. Similarly characteristics that may influence LOS, such as teaching vs non-teaching hospital status and nurse-bed ratio, were not available.[10, 12]

iii) The logistic EuroSCORE is a predictive risk score for in-hospital mortality and may be less effective at capturing risk of increased LOS. The recalibrated EuroSCORE II, additionally including poor mobility (or, frailty) as a risk factor, may be better at capturing risk of increased LOS.

iv) Total hospital LOS may be underestimated due to failure to include periods of time after inter-hospital transfer.

v) Our cohort included a relatively small number (n=10) of high-volume, specialist centres with a likely interest in quality improvements. Therefore, our results may not generalise to smaller, non-specialist centres and may be prone to underestimation of centre variation. Participating centres may also differ in average case mix or between-provider variability compared to non-participating centres.

Recommendations and Future Research

Analysis of large Electronic Health Records (EHRs) can highlight characteristics of the centre and surgeon that introduce variation in patient outcomes. Future studies of smaller, more detailed databases examining features which may distinguish "long" to "short LOS" centres are required; potential key LOS drivers include teaching hospital status, varying

discharge schemes, management strategies in pre/post-operative care, staffing levels, infrastructure and equipment available, such as operating theatres, medication and medical devices.[10, 12, 24] Likewise, further studies could identify provider practices and techniques that contribute to reduced LOS, such as level of accreditation, caseload volume, previous training and experience.

Delays in hospital discharge are mainly driven by postoperative patient-related complications and differences in centre and surgeon policies and practices; the NHS has previously highlighted that LOS is linked with differences in patient management.[13] It is difficult to separate which result from an internal hospital culture, and which are the result of external local healthcare resources. We used sophisticated statistical methods to establish the degree to which postoperative LOS after cardiac surgery is affected by heterogeneity in patient risk, compared to other factors such as differences in centre policies and provider practice styles. Enhancing our understanding of the relationship between these patient-extraneous factors and postoperative LOS will help centres, providers and commissioners to implement measures to enhance the efficiency of healthcare provision, minimise time in hospital and reduce excess resource use. Health systems, such as the NHS, can benefit considerably as, due to the high throughput, even small LOS reductions may result in large cost savings.[10]

Conclusion

We have shown that patient risk profile is the primary determinant of variation in length of stay, thus current initiatives to reduce LOS by modifying consultant performance or local practice will have limited success. This implies that the only way to substantially reduce hospital stay is by denying surgery to high-risk patients.

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Contributors: OP, LDS and AAK conceived the study. OP and LDS designed the study. OP undertook the statistical analysis and drafted the manuscript. AAK and LDS contributed to the writing of the manuscript. AAK collected the data and coordinated the study. All authors interpreted the data, critically revised the manuscript, and approved the final version. OP and LDS are joint guarantors for the study.

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Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: OP declares partial funding by the Medical Research Council (MRC) and by a Gates Cambridge fellowship outside of the submitted work; AAK reports grants and personal fees from Pharmacosmos and personal fees from Vifor Pharma outside the submitted work; no other financial relationships with any organisations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: No additional data available.

Transparency statement: The lead and senior authors OP and LDS (the manuscript's guarantors) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained. All authors, external and internal, had full access to all of the data (including statistical reports and

tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Ethical approval: The requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority.

Figure legends

Figure 1: Flow diagram showing how the final dataset was derived.

Figure 2: Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

Figure 3: Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 4: Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 5: Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

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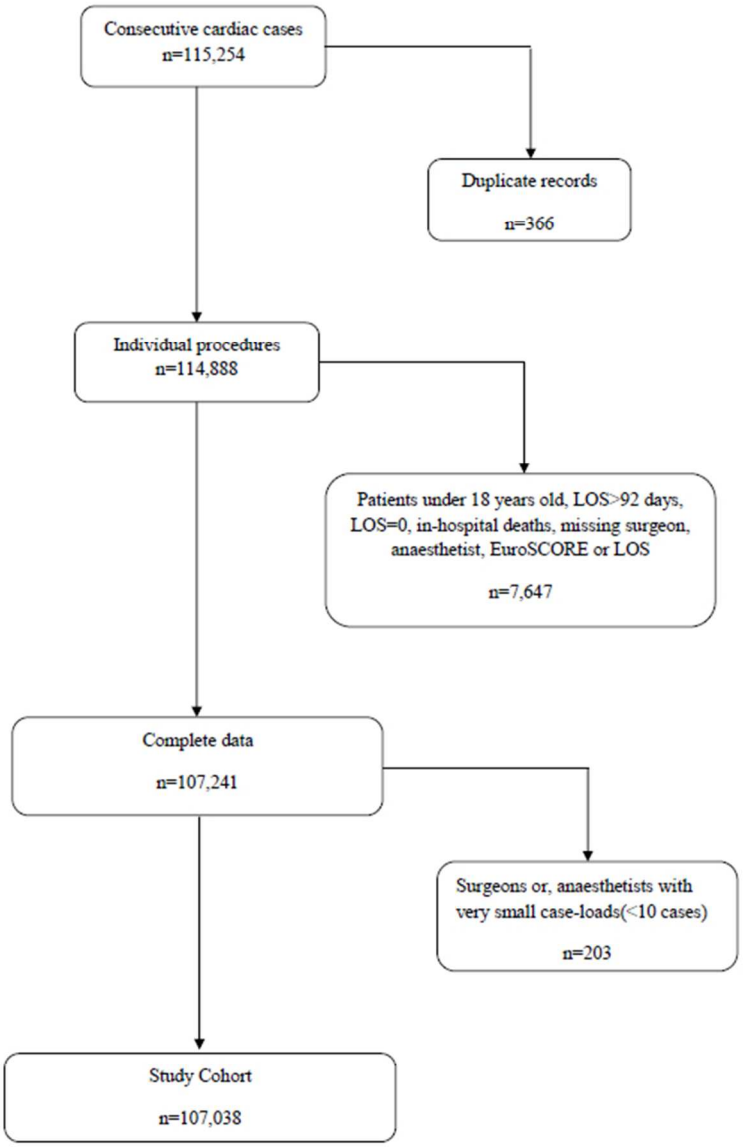
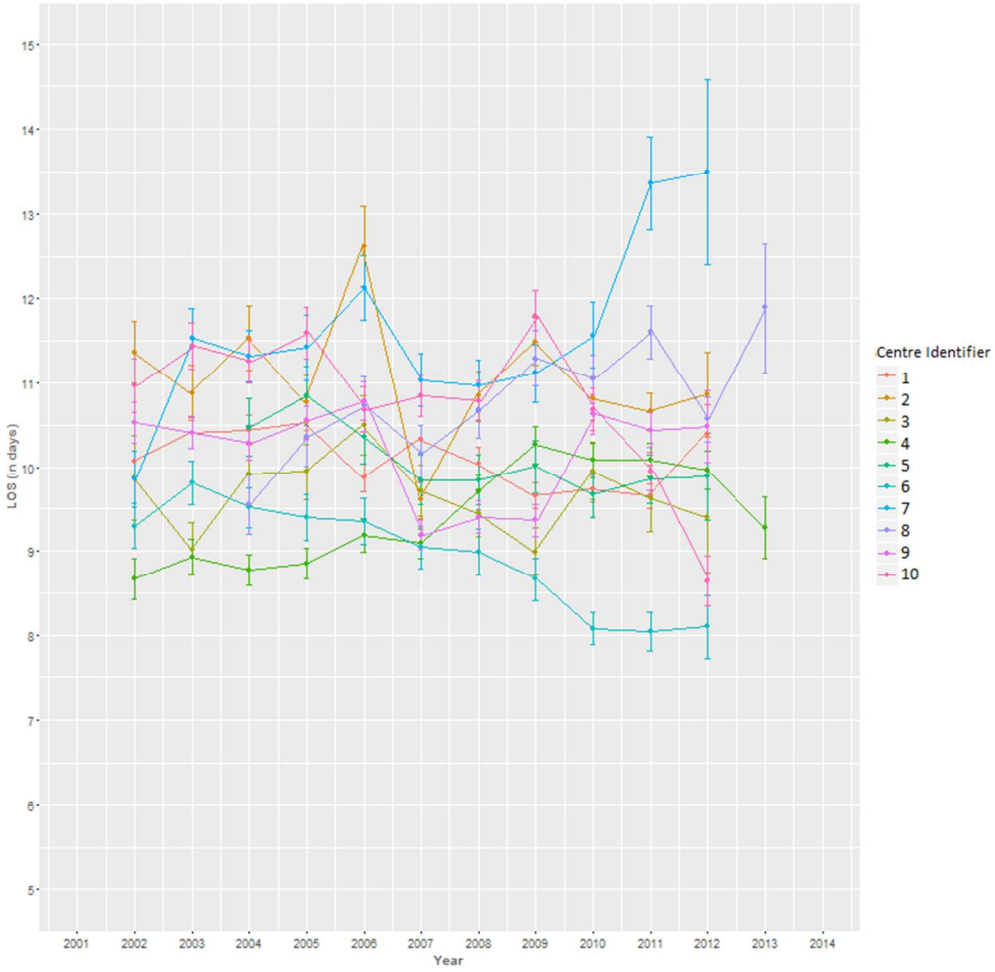


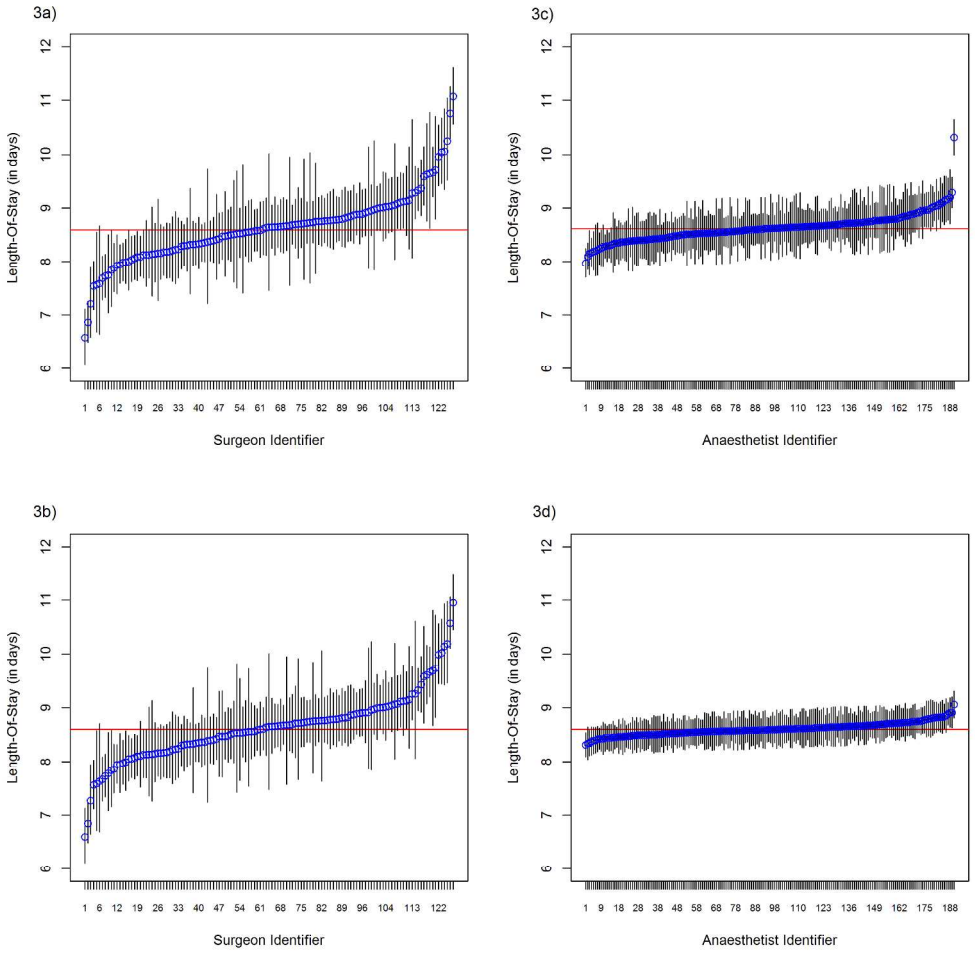
Flow diagram showing how the final dataset was derived.

150x211mm (96 x 96 DPI)



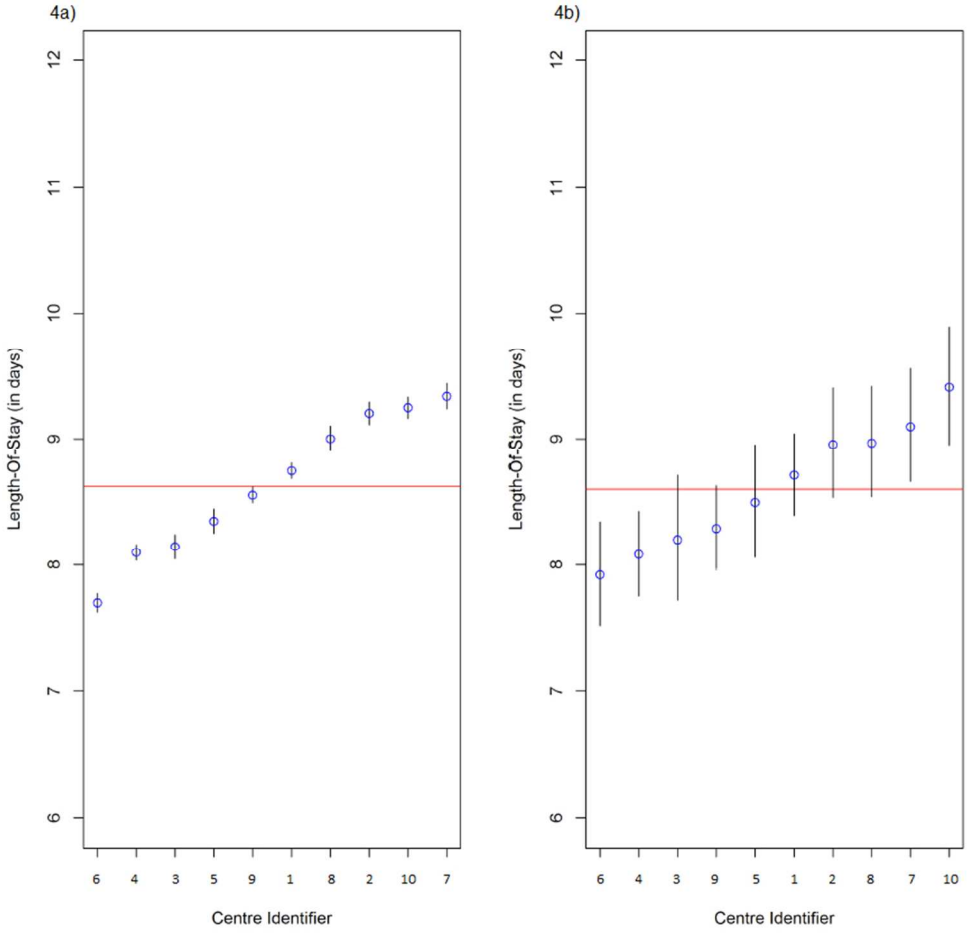
Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

206x206mm (96 x 96 DPI)



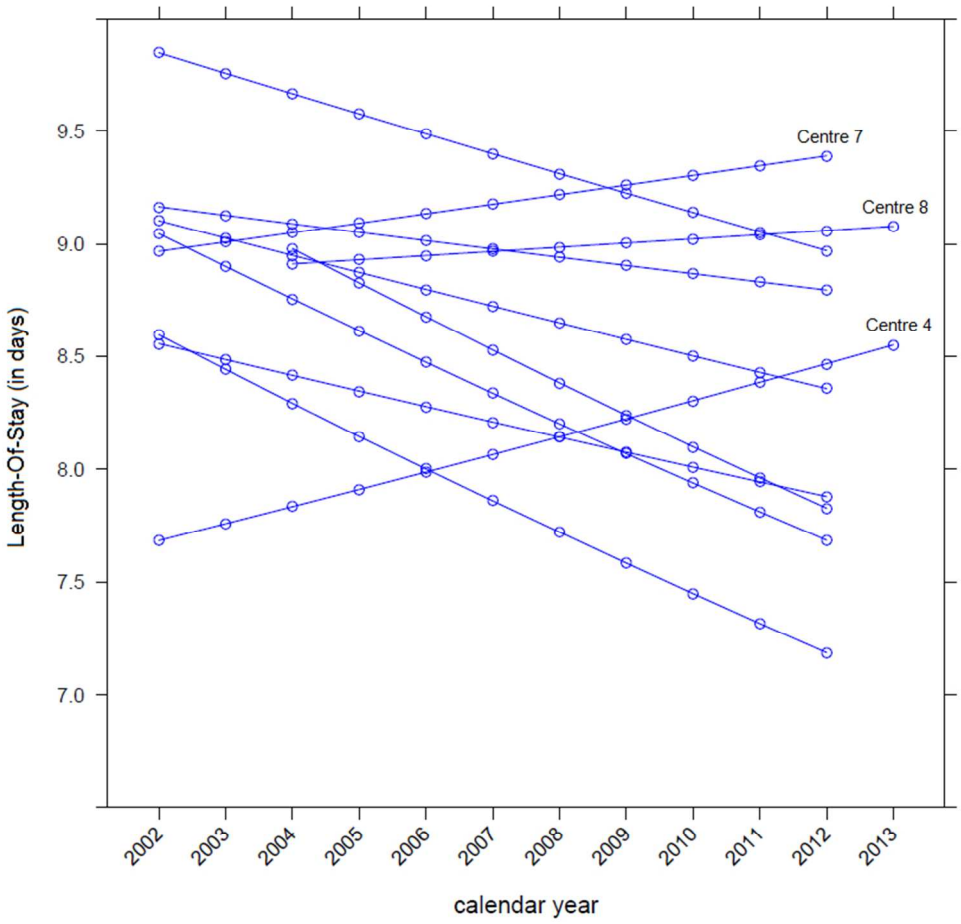
Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

254x254mm (300 x 300 DPI)



Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

236x236mm (96 x 96 DPI)



Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

223x224mm (96 x 96 DPI)

Table S1: Model output for the three-level cross-classified model with centre random "Year of Operation" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.15	(2.20,2.11)	< 0.001
Logistic EuroSCORE	0.208	(0.250,0.211)	< 0.001
Year of Operation	-0.00652	(-0.0127,-0.000346)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00401	0.00582	0.000274
Year of Operation Coefficient	9.51×10^{-5}		

Table S2: Model output for the three-level cross-classified model with Centre random "Age at Operation" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.14	(2.11,2.18)	< 0.001
Age at Operation	0.0102	(0.00898,0.0114)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00237	0.00852	0.000571
Age at Operation Coefficient	3.53×10^{-6}		

Table S3: Model output for the three-level cross-classified model with Centre random "Logistic EuroSCORE" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.16	(2.12, 2.20)	< 0.001
Logistic EuroSCORE	0.210	(0.193,0.226)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00310	0.00601	0.000371
Logistic EuroSCORE Coefficient	6.08×10^{-4}		

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	**Title** **Abstract**	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	**Title** **Abstract** (Design, Setting and Participant sections) N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	**Introduction**: paragraphs 1-3		
Objectives	3	State specific objectives, including any prespecified hypotheses	**Introduction**: paragraph 3		
Methods					
Study Design	4	Present key elements of study design early in the paper	**Methods**: paragraphs 1-2		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	**Methods**: paragraphs 1-2		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the		RECORD 6.1: The methods of study population selection (such as codes or	**Methods**: paragraphs 2-5

		sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	**Methods**: paragraphs 2-5 N/A	algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	**Methods**: Paragraph 1 (Data Source section) and Paragraphs 7-8 (Variables and Outcomes measures section)		
Bias	9	Describe any efforts to address potential sources of bias	**Methods**: paragraphs 4 (Study Cohort section) and		

			8 (Variables and Outcomes measures section)		
Study size	10	Explain how the study size was arrived at	**Methods**: paragraphs 2-5 (Study Cohort section) and Flow diagram (Figure 1)		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section) and paragraphs 9-10 (Statistical Methods section)		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	**Methods**: paragraphs 8 (Variables and Outcomes measures section) and paragraphs 9-12 (Statistical Methods section) **Results**: paragraph 8 **Discussion**: paragraph 3 (Potential explanations and Implications of findings)		
Data access and		..		RECORD 12.1: Authors should	**Methods**:

cleaning methods				describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	paragraphs 1-2 (Data Source and Study Cohort sections) **Methods**: paragraphs 1-5 (Data Source and Study Cohort sections)
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	**Methods**: paragraphs 2-5 (Study Cohort section) Figure 1 – Flow diagram	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	**Methods**: paragraphs 2-5 (Study Cohort section)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and	**Results**: paragraph 1, Tables 1 and 2 **Methods**: paragraphs 2-5 (Study Cohort section)		

		total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	**Results:** paragraph 1		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	**Results:** paragraphs 2-5		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	**Results:** paragraphs 6-8		
Discussion					
Key results	18	Summarise key results with reference to study objectives	**Discussion:** paragraph 1		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	**Discussion:** paragraph 7 (Limitations subsection)	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data,	**Discussion:** paragraphs 7-8 (Limitations and Conclusions and Future research subsection)

				and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	**Discussion:** paragraphs 2-6 (Comparison with other studies and Potential explanations and Implications of findings)		
Generalisability	21	Discuss the generalisability (external validity) of the study results	**Discussion:** paragraphs 2-9		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	**Acknowledgements:** paragraphs 2 and 3		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	**Methods:** paragraph 1 (Data source section) **Acknowledgements**

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

BMJ Open

Effect of individual patient risk, centre, surgeon and anaesthetist on the length of stay in hospital after cardiac surgery: Association of Cardiothoracic Anaesthesia and Critical Care (ACTACC) consecutive cases series study of ten UK specialist centres

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Secondary Subject Heading:	Cardiovascular medicine, Anaesthesia, Surgery
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Effect of individual patient risk, centre, surgeon and anaesthetist on length of stay in hospital after cardiac surgery: Association of Cardiothoracic Anaesthesia and Critical Care (ACTACC) consecutive cases series study of ten UK specialist centres

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Abstract

Objectives: To determine the relative contributions of patient risk profile, local and individual clinical practice on length of hospital stay after cardiac surgery.

Design: Ten-year audit of prospectively collected consecutive cardiac surgical cases. Case-mix adjusted outcomes were analysed in models that included random effects for centre, surgeon, and anaesthetist.

Setting: UK centres providing adult cardiac surgery.

Participants: 10 of 36 UK specialist centres agreed to provide outcomes for all major cardiac operations over 10 years. After exclusions (duplicates, cases operated by more than one consultant, deaths and procedures for which the EuroSCORE risk score for cardiac surgery is not appropriate), there were 107,038 cardiac surgical procedures between April 2002 and March 2012, conducted by 127 consultant surgeons and 190 consultant anaesthetists.

Main outcome measure: Length-of-stay up to three months postoperatively.

Results: The principal component of variation in outcomes was patient risk (i.e. represented by the EuroSCORE and remaining patient heterogeneity), accounting for 95.43% of the variation for postoperative length-of-stay. The impact of the surgeon and centre was moderate (intra-class correlation coefficients ICC=2.79% and 1.59% respectively), and the impact of the anaesthetist was negligible (ICC=0.19%). Similarly, 96.05% of the variation for prolonged (>11 days) length-of-stay was attributable to the patient, with surgeon and centre less but still influential components (ICC=2.12% and 1.66% respectively, 0.17% only for anaesthetists). Adjustment for year of operation resulted in minor reductions in variation attributable to surgeons (ICC=2.52% for LOS and 2.23% for prolonged LOS).

Conclusions: Patient risk profile is the primary determinant of variation in length of stay, and as a result, current initiatives to reduce hospital stay by modifying consultant performance are unlikely to have a substantial impact. Therefore, substantially reducing hospital stay requires shifting away from a one-size-fits-all approach to cardiac surgery, and seeking alternative treatment options personalised to high-risk patients.

Keywords: length-of-stay, hospitalisation, centre, surgeon, anaesthetist, EuroSCORE, cardiac surgery.

Strengths and limitations of this study

- The study comprises more than 100,000 cases from ten of 36 UK specialist centres, amounting to almost a third of the cardiac cases in the UK between 2002 and 2012.
- The study is the first to examine the impact of the operating centre and key providers involved in the delivery of care on the LOS after cardiac surgery.
- Identifying how these external factors influence LOS may contribute to improving the efficiency of care.
- Total hospital LOS may have been underestimated due to lack of information on periods of time after inter-hospital transfer.
- The study concerned specialist centres with a likely interest in quality improvements therefore its findings may not be generalisable to smaller, non-specialist centres.

INTRODUCTION

According to 2013 records some 36,000 patients undergo cardiac surgery in the UK each year at a high annual cost of around £300 million.[1] Anticipated below-inflation increases in future NHS tariffs have inevitably triggered the search for efficiency savings, particularly improved patient throughput accompanied by shorter hospital stay, which is a key driver of surgical costs.[2, 3] Besides financial benefits for the NHS, improving efficiency through length-of-stay (LOS) reductions will also yield benefits for patients as prolonged LOS is directly associated with increased risk of complications and personal financial burden.[2-5] Reductions in LOS could release capacity in the system (e.g. release of occupied beds, nurse/doctor time), allowing the re-allocation of limited NHS resources to other areas in need. Understanding the causes of prolonged LOS may also lead to practices that contribute to the reduction of postoperative complications and other adverse events that have a negative impact on patient quality-of-life.

Despite operating on relatively homogeneous patient populations, previous benchmarking exercises have identified considerable centre differences in postoperative models of care and LOS after cardiac surgery.[6] Differences in healthcare professionals' practices may also influence hospital stay[7]; nevertheless, the impact of individual surgeons and anaesthetists on LOS has received less attention. For instance, the operating surgeon has been shown to have a significant impact on in-hospital mortality post-cardiac surgery.[7, 8] However, to our knowledge, their impact on postoperative LOS has not been explored. Technically-skilled surgeons with low postoperative morbidity should achieve lower LOS.[3, 9-12] Similarly, previous studies have suggested differences in anaesthetic practices e.g. the use of "fast-track" anaesthesia protocols may accomplish a similar goal[13, 14]; however the evidence has been inconclusive.[15] These

relationships may be confounded by changes in service provision over time, so that careful analysis is required.

Several authors have studied the association between patient-related factors (e.g. disease severity, existence of comorbidities) and prolonged LOS after cardiac surgery.[16-18] There is also controversy as to whether different practices at different centres in the UK directly impact on hospital stay after cardiac surgery.[19] This study aims to quantify the variation in risk-adjusted postoperative LOS between cardiac centres, surgeons and anaesthetists across the UK, and to investigate changes in these components over time.

METHODS

Data Source

Cohorts comprising consecutive case series from UK specialist cardiac centres were provided to the Association of Cardiothoracic Anaesthesia and Critical Care. Data collection is mandated by the NHS and recorded prospectively in each centre. Requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority. Previous published work on this dataset examined the impact of the anaesthetist, surgeon and centre on in-hospital mortality.[7]

Study cohort

Details of how the study cohort was derived have been previously published. Briefly, our cohort comprised ten out of 36 UK specialist cardiac centres that provided datasets totalling more than 100,000 cardiac surgical patients (Figure 1). All 36 UK specialist cardiac centres were approached, of which ten agreed to participate and obtained local permissions for data provision within a set timeframe of a month. No centres were excluded. Data from consecutive major cardiac operations were prospectively collected for the 10-year period April 2002 through March 2012. Exclusion criteria were procedures for which the Logistic EuroSCORE (see "Variables and Outcome measures" section for detailed description) was not appropriate, cardiac transplants, pulmonary endarterectomy procedures and very high risk cases that necessitated delivery by at least two consultant surgeons. Patients under 18 years old were also excluded (0.08%). Patients with multiple operations at distinct admissions during the study period were treated as independent episodes.

There was a small amount of missing provider data (n=28, 0.02% and n=1482, 1.3% missing surgeon and anaesthetist entries respectively) which were excluded from the analysis. A small

number of cases with missing discharge destination (n=129, 0.11%) or date (n=125, 0.11%) were excluded. Finally, the EuroSCORE was not recorded for 755 entries (0.66%) which were also excluded. There were three patients with unknown sex, 40 with unknown operative priority status and 5964 with unrecorded operation type, all of whom were included in the analysis (Table 1).

Table 1: Patient and operative characteristics for analysis dataset (n=107,038)

Patient Characteristics	*Category*	*Frequency(Percentage of n=107038)*
Age at admission(years)	[18-36)	1 883 (1.76%)
	[36-56)	15 149 (14.15%)
**Mean:66.20(11.31)*	[56-66)	28 502 (26.63%)
Median:68	[66-76)	39 720 (37.11%)
IQR:(60,74)	[76-86)	20 682 (19.32%)
	[86-96]	1 102 (1.03%)
Gender	Male	78 261 (73.12%)
	Female	28 774 (26.88%)
	Unknown	3 (<0.01%)
EuroSCORE(probability)	[0,0.1)	87 559 (81.80%)
**Mean:0.0690(0.0896)*	[0.1,0.2)	12 515 (11.69%)
Median:0.0400	[0.2,0.3)	3693 (3.45%)
IQR:(0.0208,0.0777)	≥0.3	3271 (3.06%)
Operative Characteristics		

Priority	Elective	74 909 (69.98%)
	Urgent	28 312 (26.45%)
	Emergency	3525 (3.30%)
	Salvage	252 (0.23%)
	Unknown	40 (0.04%)
Operation Type	CABG(isolated)	56 586 (52.87%)
	AVR(isolated)	9719 (9.08%)
	MVR+other	6178 (5.77%)
	CABG+AVR	8594 (8.03%)
	CABG+other procedures	2204 (2.06%)
	CABG+other valve	2860 (2.67%)
	Other procedures	3800 (3.55%)
	AVR+other procedures	2511 (2.34%)
	CABG+AVR+other	1292 (1.21%)
	Valve alone	5788 (5.41%)
	Valve + other	1542 (1.44%)
	Unknown	5964 (5.57%)

**for continuous variables, the mean(SD), median and interquartile range are given. IQR, Interquartile range, CABG, coronary artery bypass grafting; AVR, aortic valve replacement or repair; MVR, mitral valve replacement or repair. Square bracket denotes number inclusive in the interval.*

Surgeons and anaesthetists with caseloads smaller than 0.1% of the total caseload of their centre were excluded; these professionals, with the exception of one surgeon, had carried out

fewer than ten operations and had either retired just after the onset of the study period, were appointed just before the end of the study period or held short-term contracts. Patients who were not discharged after three months of the procedure date were excluded from the analysis as any patient-related outcomes would likely be unrelated to the procedure itself and more likely be a result of other comorbidities (n=272, 0.24%). Moreover, all cases with immediate discharge (i.e. zero LOS) were excluded as they were either deaths or transfers to other centres (n=441, 0.4%). All remaining cases that resulted in in-hospital death were also excluded from the analysis in order to avoid bias associated with short LOS due to early death considered as a positive outcome and to be consistent with published literature (n=2,971, 2.7%).[16, 18]

The final analysis dataset comprised 107,038 cases (93% of the original case series, n=115,254) treated by 127 surgeons and 190 anaesthetists in 10 centres. The dataset comprised 91% (n=127 of 140) and 76% (n=190 of 250) of the initial surgeon and anaesthetist samples respectively; providers were excluded principally due to low caseload volumes.

Patient involvement

No patients were involved in setting the research question or the outcome measures, developing plans for design or implementation of the study. No patients were asked to advise on interpretation and writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

Variables and Outcome measures

The primary outcome measure was LOS up to three months postoperatively. LOS was defined as the number of days spent in hospital from the day of surgery to hospital discharge. The secondary measure of interest was prolonged LOS, defined as a hospitalisation of more than eleven days following surgery. There is no consensus in the literature on the definition of

prolonged LOS after cardiac surgery, and as a result, published studies often adopt the 75th centile of the LOS distribution.[16, 17, 20, 21] In our data set this corresponded to 11 days, and we have chosen it as the cut-off for prolonged stay to ensure consistency with published literature; we sought the expert advice of our cardiac surgical collaborators to ensure this was relevant to cardiac surgery in the NHS setting.

Since there is no established risk score for prolonged LOS, adjustment for varying patient case-mix risk was achieved using the logistic EuroSCORE.[22] The logistic EuroSCORE is a very well established risk score for in-hospital death post-cardiac surgery with widespread use worldwide and involves 17 cardiac, operation- and patient-related factors. The recently recalibrated version of the score (EuroSCORE II) was not available at the study onset[23]; our analysis included the original logistic EuroSCORE as this was the one used by the participating centres. One centre used the additive EuroSCORE, which is associated with under-prediction in high-risk cases. The proportion of high-risk patients, for which the additive EuroSCORE is known to underperform (additive EuroSCORE≥10%) was very small (0.5%, n=586 of 107,038)[24] and results of sensitivity analysis excluding this centre did not differ from analysis of the full cohort. We considered using patient age, sex and urgency instead of the logistic EuroSCORE to account for patient heterogeneity but EuroSCORE provided better model fit to the data, based on statistical criteria. In addition to variation due to centre, surgeon and anaesthetist, the covariate of interest was the calendar year of operation.

Statistical methods

We investigated the relationship between LOS up to three months postoperatively and potential covariates using mixed effects regression models. Patients were clustered within surgeons and anaesthetists who in turn, were clustered within centres inducing a hierarchy. To

reflect this, random effects terms were included for centres, surgeons, and anaesthetists. Logistic EuroSCORE was included as a fixed effect in all models to adjust for varying patient case-mix risk; year of procedure was included as a continuous fixed effect to investigate changes in outcomes over time.

Since the primary LOS outcome was positively skewed, linear mixed effects models were fitted to the logarithm of the LOS (log(LOS)). Prolonged LOS was modelled as a binary endpoint (≤11 vs > 11 days) using logistic mixed effects models. The following models were implemented for both outcomes of interest.

Initially two three-level random intercept models were fitted in order to establish individual surgeon and anaesthetist effects on the patient outcome, controlling for centre effects and patient case-mix risk. Thereafter, in order to model the effects of surgeons and anaesthetists simultaneously, we fitted a three-level cross-classified model assuming an additive contribution (on the log scale) from each provider (anaesthetist and surgeon), clustered within centres. We further fitted a two-level centre random intercept model, accounting solely for patient heterogeneity, in order to compare its outputs to those of the three-level cross-classified model and assess the impact of provider adjustment on between-centre variation. In order to investigate the effect of time we included the year of operation in the three-level cross-classified model. The methodology used has been described in detail in Papachristofi *et al.*[25]

Finally, in each model we estimated the Intra-Class Correlation Coefficients (ICC)[26] which represent the proportion of the total variation in the outcome that is attributable to each of the anaesthetist, surgeon and centre. The Likelihood Ratio Test was used to determine the significance of the fixed effects terms and the relevant p-values. We implemented all our methods using the statistical software R (version 3.2.2).[27, 28]

RESULTS

Baseline characteristics for the study cohort are summarised in Table 1. Almost three-quarters of the patients were men (73.1%). The mean (SD) age of our cohort was 66.20 (11.31) years. Overall, the median postoperative LOS over the 10-year study period was seven days, with 75% of patients discharged between 6 and 11 days; the corresponding mean LOS was 10.19 (8.36) days, although this is influenced by a small proportion of large values. The mean LOS over time in each centre is depicted in Figure 2, which shows varying patterns across centres; for instance, LOS decreased over time in centre 6 whereas it increased in centre 8. Summaries of each centre's cohorts are given in Table 2. Almost 23% of the study cohort had prolonged LOS over 11 days, which was associated with higher operative risk score compared to patients with LOS of 11 days or less (mean EuroSCORE 11.28% vs 5.42%); a histogram of the distribution of surgeon caseload volume is provided in the supplementary material (Figure S1).

Table 2: Numbers of patients operated on, surgeons and anaesthetists in each centre, between April 2002 and March 2012. Surgeons and anaesthetists who looked after <10 patients were excluded. Values are frequency or mean (SD) unless specified as median(IQR).

Centre number	Patients	Surgeons	Anaesthetists	LOS Median (IQR)	LOS Mean (SD)	Logistic EuroSCORE
1	17,889	21	24	8 (6, 11)	10.06 (7.14)	7.52 (9.74)%
2	9,323	13	16	8 (6, 12)	10.96 (9.13)	8.92 (11.26)%
3	6,357	6	8	7 (6, 10)	9.69 (8.59)	7.62 (9.03)%
4	15,008	16	24	7 (6, 10)	9.47 (7.47)	5.77 (7.26)%
5	6,661	10	15	7 (6, 11)	10.08	6.13 (7.96)%

					(8.79)	
6*	9,637	10	17	7 (6, 9)	9.03 (7.76)	4.29 (3.18)%
7	7,537	13	17	8 (6, 13)	11.41 (9.86)	7.48 (10.61)%
8	7,238	11	13	7 (6, 11)	10.75 (9.08)	6.71 (9.90)%
9	16,506	17	22	7 (6, 11)	10.15 (8.47)	7.47 (9.58)%
10	10,882	10	34	8 (8, 12)	10.95 (8.75)	6.91 (7.84)%

*Additive EuroSCORE was provided by this centre.

The logistic EuroSCORE was significantly associated with LOS in both surgeon and anaesthetist models, additionally adjusted for centre effects (1.230, 95% CI 1.226 to 1.234 and 1.229, 95% CI 1.225 to 1.232 respectively, p-value <0.0001 for both). This amounted to an increase in LOS of about 23% for each 1% increase in logistic EuroSCORE. The logistic EuroSCORE remained significant in the three-level cross-classified model including both surgeon and anaesthetist effects (1.231, 95% CI 1.226 to 1.234, p-value <0.0001). Table 3 shows that 95.43% of the variation in log(LOS) in this analysis was attributable to the EuroSCORE (and remaining patient heterogeneity).

Table 3: Percentage of the variation in post-operative length-of-stay (LOS) and prolonged LOS attributed to each component

Outcome	Centre	Surgeon	Anaesthetist	Patient and other covariates
LOS	1.59%	2.79%	0.19%	95.43%
Prolonged LOS	1.66%	2.12%	0.17%	96.05%

Figures 3a and 3b show the estimated LOS, in days, with its 95% confidence interval (CI) for each surgeon if they operate on a patient of average risk (i.e. mean EuroSCORE estimated at

6.9%), adjusting solely for centre effects, and adjusting for centre and anaesthetist effects simultaneously. Estimated LOS for 18 out of 127 surgeons, from nine different centres, have 95% CI lying wholly below the average LOS, suggesting shorter hospitalisations for their caseload. Fifteen surgeons from seven centres had higher-than-average estimated LOS. The surgeon random effects variance was modest yet important, with $ICC_{surgeon}$ =0.0287 suggesting 2.87% of the variation in outcome is attributable to the operating surgeon. Adjusting for anaesthetist effects resulted in a minor decrease in the $ICC_{surgeon}$ from 0.0287 to 0.0279. The surgeons with longest and shortest average LOS were distributed across seven centres, hence we could not identify a specific centre of extreme performance. This finding, in conjunction with the ICCcentre (1.59%), suggests that LOS is influenced by both surgeon and, to a small extent, by the operating centre.

Figures 3c and 3d depict the analogous anaesthetist forest plots, controlling solely for centre effects, and controlling for centre and surgeon effects simultaneously. Between-anaesthetist variability in LOS is smaller than between-surgeon variability (Figure 3c), with associated $ICC_{anaesthetist}$ of 0.58%. Estimated LOS durations for ten out of 190 anaesthetists, from five different centres, have 95% CI lying wholly below the average LOS indicating better performance that average. There were 14 anaesthetists from nine centres whose estimated LOS was higher than average. However, once surgeon effects were adjusted for, anaesthetist variation reduced to $ICC_{anaesthetist}$=0.0019 (0.19%), which is negligible. Figure 3d indicates that there is only one remaining anaesthetist with 95% CI wholly below the average; likewise, the number of anaesthetists with estimated LOS above the average reduced from 14 to four, employed in four different centres. This is unsurprising as, by pure chance, we would expect approximately 5 anaesthetists to lie at the upper end of the spectrum (i.e. if the anaesthetists were normally

distributed, 2.5% of 190 (n=4.75) would lie above the 97.5% quantile). The difference in estimated LOS between the two anaesthetists at the extremes reduced from almost two and a half days to less than one day.

Adjusting only for patient heterogeneity, the proportion of variation attributed to centre where the procedure was undertaken was 1.79% (ICCcentre=0.0179). When surgeon and anaesthetist effects were added, ICCcentre reduced to 1.59%; comparison of Figures 4a and 4b indicates that two centres remained significantly above, and two below, the overall average.

The effect of calendar year of operation on LOS was statistically significant (0.994, 95% CI 0.993 to 0.995, p-value <0.0001). However, this amounted to a decrease of 0.6% in LOS per year, which is unlikely to be clinically important. A calendar year random coefficient model was also fitted (Table S1, Supplementary material) which suggested that changes in LOS through time varied significantly between centres, with no national pattern.

Finally, increased logistic EuroSCORE was associated with increased odds of prolonged LOS in surgeon only, anaesthetist only and cross-classified models (OR 0.784, 95% CI 0.768 to 0.800; 0.775, 95% CI 0.759 to 0.791; and 0.785, 95% CI 0.769 to 0.801 respectively, p-value <0.0001 for all). The percentage of the variation in prolonged LOS attributable to EuroSCORE (and remaining patient heterogeneity) was 96.05% (Table 3). The variation attributable to the centre, surgeon, and anaesthetist was quantified as 1.66%, 2.12%, and 0.17% respectively.

We conducted exploratory analysis of the effect of age and logistic EuroSCORE on between-centre variation. Postoperative LOS increased by about 1% for an increase of one year in age (Table S2, Supplementary material). Although small, there was some variation between centres in the age effects, suggesting that part of the between-centre variation could be ascribed to differences in the average age of the treated population. There was some variation between

centres in the case-mix risk treated, which may explain part of the variation in centres' LOS (Table S3, Supplementary material).

DISCUSSION

Our study cohort included 10 of 36 UK cardiothoracic surgical centres, totalling 107,038 heterogeneous patients, equivalent to almost a third of the total cardiac operations performed in the UK during our study period. Patient risk factors accounted for over 95% of the variation in LOS and prolonged LOS in all models. The second most influential factor was the operating surgeon, with centre having a more moderate yet significant effect, whereas anaesthetist-induced variation was minimal.

Comparison with other studies

Our findings are consistent with published literature in other surgical fields suggesting much of the non-patient variation in LOS derives from different provider practices,[17] with the surgeon a more influential component than the anaesthetist. This is to be expected as the surgeon (unlike the anaesthetist) has the oversight of the patients' postoperative ward care and discharge. In previously published work using this cohort, similar surgeon and anaesthetist effects were found for in-hospital mortality, with surgeons having a considerable impact (4.00%) and anaesthetists a negligible effect (0.25%).[7] In contrast, there were no centre effects on in-hospital mortality. The centre importantly includes critical care and high dependency services, which may exert a significant effect on LOS, although it is difficult to isolate this aspect from other contributing factors using routinely-collected data.

Potential Explanations and Implications of findings

Our findings suggest that differences in centre infrastructure, policies and possibly geographical location are more likely to affect postoperative LOS than patient survival. We

conducted sensitivity analysis by re-estimating effects including cases of immediate discharge (i.e. zero LOS) and including all remaining cases that resulted in in-hospital death yielding very slightly reduced ICC estimates (1.21%, 2.21% and 0.15% for centre, surgeon and anaesthetist respectively). This reflects the fact that LOS for these patients is partly driven by mortality, resulting in reduced influence of external factors such the centre or surgeon. We further conducted exploratory analysis of factors that may contribute to increased between-centre variation. Our analysis supports the hypothesis that centres in areas with elderly populations are associated with increased LOS, in line with published evidence suggesting older patients are less likely to be discharged home (Table S2, Supplementary material).[14, 17, 18, 29] Likewise, exploratory analysis showed some between-centre variation in case-mix risk treated, which may explain part of the variation in centres' LOS (Table S3, Supplementary material).

The estimated mean LOS per surgeon (Figure 3) appears superficially very similar to the estimated probability of in-hospital death per surgeon previously published (Figure 2[7]). We examined which surgeons were significantly below, or above average both for in-hospital death and LOS but there was no discernible pattern.

Figure 4 illustrates a relatively tight distribution of average LOS between centres. It is notable that the two centres (6 and 4) with shortest LOS, had the lowest average EuroSCOREs (4.29 additive and 5.77 logistic respectively). In contrast, centre 10 may have been expected to have a shorter LOS given the relatively low average EuroSCORE (6.9). Geographical location may influence centres' LOS due to the type of populations treated. For instance, centres in less affluent areas, where access to home care is limited, may be associated with longer LOS. Alternatively, in areas with communities that have an established infrastructure and tradition of caring for relatives, centres may have shorter LOS. Further, in-depth examination of the

association of location and socioeconomic status is needed in order to robustly estimate their impact on the LOS.

The small decrease in LOS through time may result from improvements in the delivery of care in recent years, and is consistent with other published literature reporting longer hospitalisations at the beginning of the cohorts studied.[21] Given the numbers of initiatives purporting to reduce LOS after cardiac surgery, the actual 1% per year reduction is modest. Although predicted LOS for a patient of average risk *decreased* over time in most centres, it *increased* in three (Figure 5); this may be due to changes in management strategies, introduction of more conservative discharge practices in these centres, or changes in patient-related factors. A potential risk of reducing LOS is an increased risk of hospital readmission due to premature hospital discharge. In April 2011, the Department of Health introduced a policy of non-payment for emergency readmissions to English hospitals. According to the 2011/2012 Payment by Results (PbR) guidance, commissioners will no longer pay for any eligible emergency readmissions to a hospital within 30 days of discharge following planned hospital stay. The potential loss of considerable income may have induced reluctance of early postoperative discharge in some centres.

Limitations

i) Our study is limited by the lack of detailed patient-related information, such as ethnic and social background, rural residency, availability of home carer, access to transportation and local resources for the provision of social services, which may have a significant effect on postoperative LOS.

ii) We did not have access to centre characteristics, such as proportion of LOS spent in intensive care (ICU), high dependency unit (HDU) or post-surgical ward care.

Different models of care, resulting in differing proportions of time in each ward type, could affect total LOS. Similarly characteristics that may influence LOS, such as nurse-bed ratio, were not available.[16, 18]

iii) Information on other healthcare professionals involved in the patients' postoperative care that may contribute to variation in the LOS, such as ICU, HDU and ward staff was not available.

iv) The logistic EuroSCORE is a predictive risk score for in-hospital mortality and may be less effective at capturing risk of increased LOS. The recalibrated EuroSCORE II, additionally including poor mobility (or frailty) as a risk factor, may be better at capturing risk of increased LOS.

v) Total hospital LOS may be underestimated due to lack of information on periods of time after inter-hospital transfer.

vi) Our cohort included a relatively small number (n=10) of high-volume, specialist centres with a likely interest in quality improvements. Therefore, our results may not generalise to smaller, non-specialist centres and may be prone to underestimation of centre variation. Participating centres comprise a limited sample of all eligible centres and as such may also differ in average case mix or between-provider variability compared to non-participating centres. Nevertheless, as cardiac surgery in the UK is only offered in specialist cardiac centres with academic/teaching status, we would expect the participating and non-participating centres to be relatively similar in nature.

Recommendations and Future Research

Analysis of large Electronic Health Records (EHRs) can highlight characteristics of the centre and surgeon that introduce variation in patient outcomes. Future studies of smaller, more detailed databases examining features which may distinguish "long" to "short LOS" centres are required; potential key LOS drivers include varying discharge schemes, management strategies in pre/post-operative care, staffing levels, infrastructure and equipment available, such as operating theatres, medication and medical devices.[16, 18, 30] Likewise, further studies could identify provider practices and techniques that contribute to reduced LOS, such as level of accreditation, caseload volume and previous training and experience.

Delays in hospital discharge are mainly driven by postoperative patient-related complications and differences in centre and surgeon policies and practices; the NHS has previously highlighted that LOS is linked with differences in patient management.[19] It is difficult to separate which result from an internal hospital culture, and which are the result of external local healthcare resources. We used sophisticated statistical methods to establish the degree to which postoperative LOS after cardiac surgery is affected by heterogeneity in patient risk, compared to other factors such as differences in centre policies and provider practice styles. Enhancing our understanding of the relationship between these patient-extraneous factors and postoperative LOS will help centres, providers and commissioners implement measures to enhance the efficiency of healthcare provision, minimise time in hospital and reduce excess resource use. Health systems, such as the NHS, can benefit considerably as, due to the high throughput, even small LOS reductions may result in large cost savings.[16]

Conclusion

We have shown that patient risk profile is the primary determinant of variation in length of stay, thus current initiatives to reduce LOS by modifying consultant performance or local practice will have limited success. This implies that substantially reducing hospital stay requires shifting away from a one-size-fits-all approach to cardiac surgical care, and investing in seeking alternative treatment options personalised to high-risk patients.

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financial relationships with any organisations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: No additional data available.

Transparency statement: The lead and senior authors OP and LDS (the manuscript's guarantors) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained. All authors, external and internal, had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Ethical approval: The requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority.

Figure legends

Figure 1: Flow diagram showing how the final dataset was derived.

Figure 2: Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

Figure 3: Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 4: Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 5: Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

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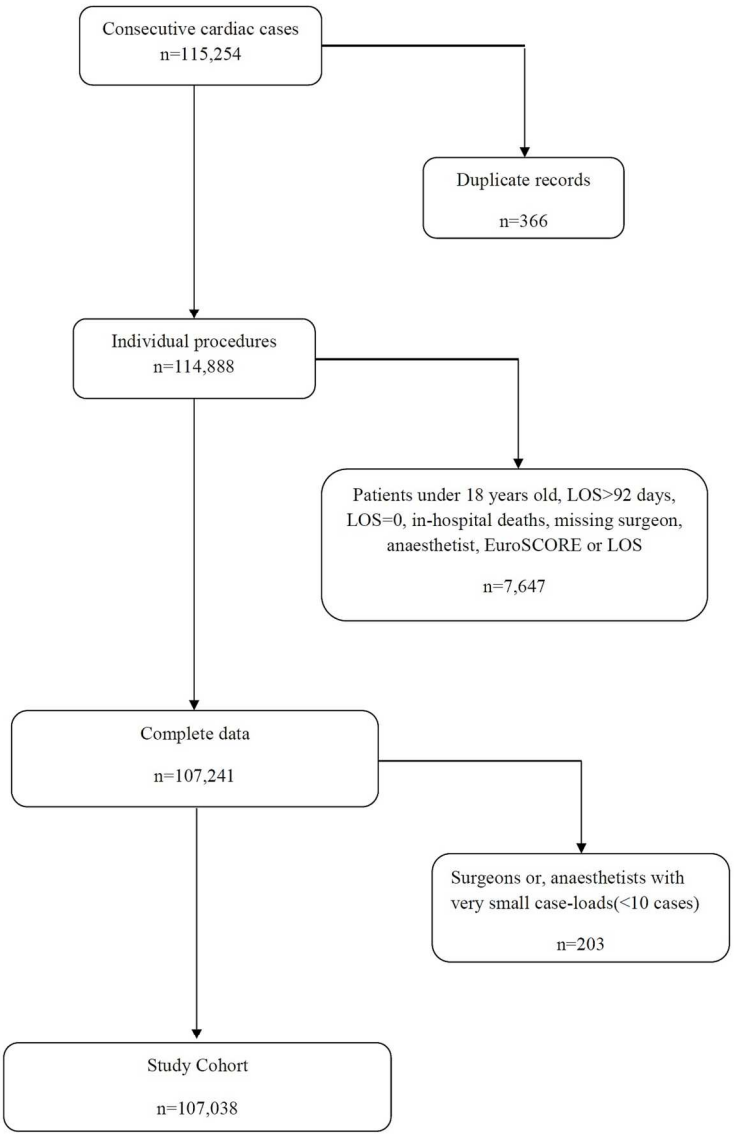
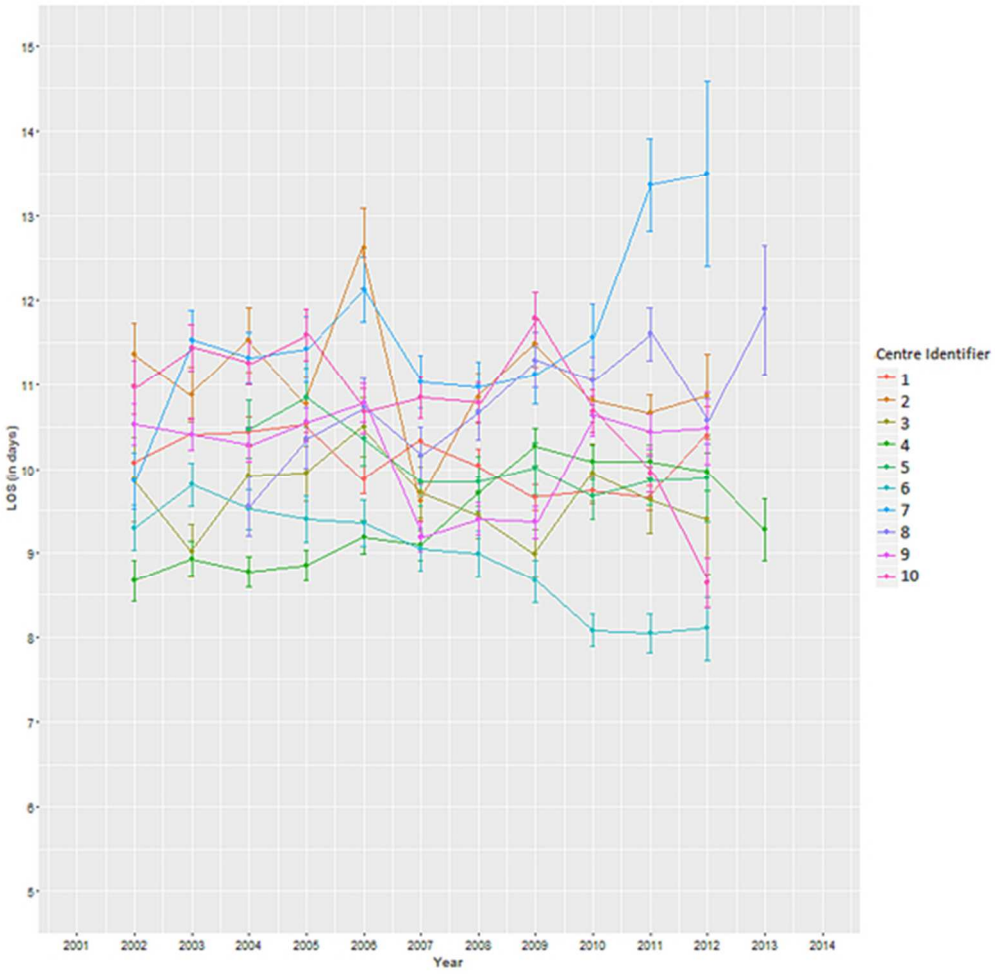


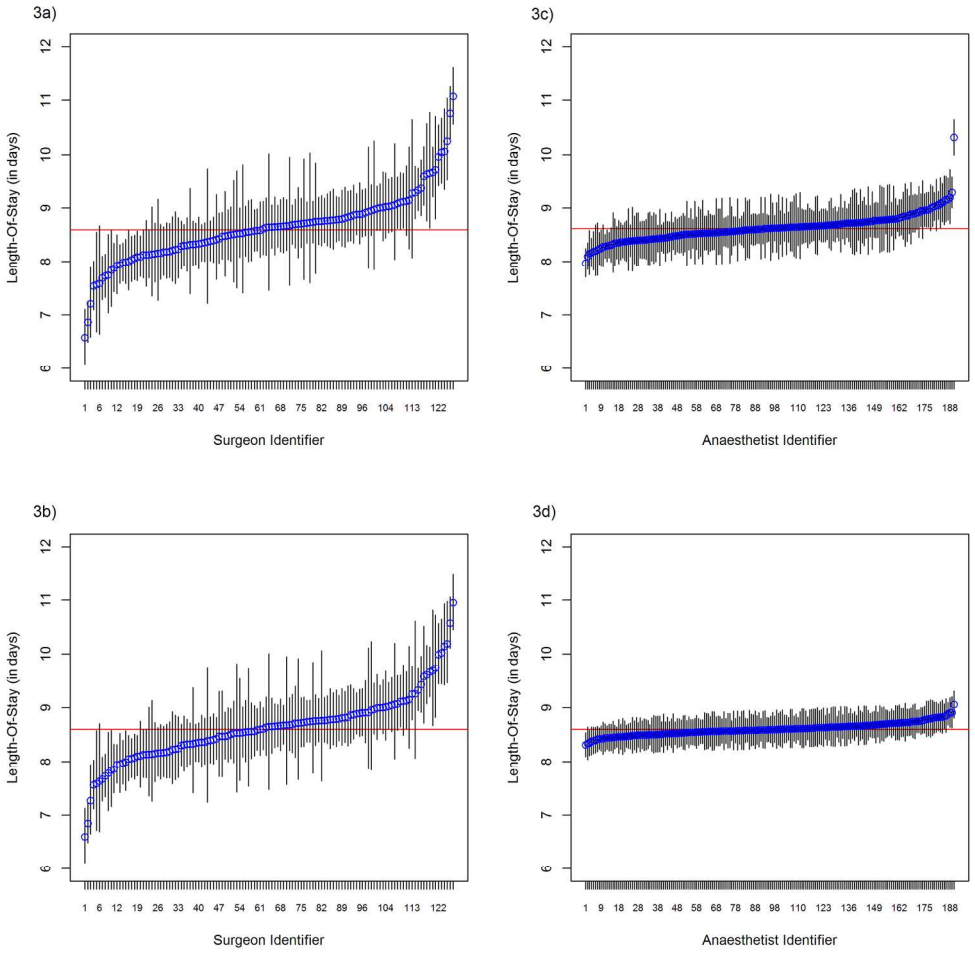
Flow diagram showing how the final dataset was derived.

134x197mm (300 x 300 DPI)



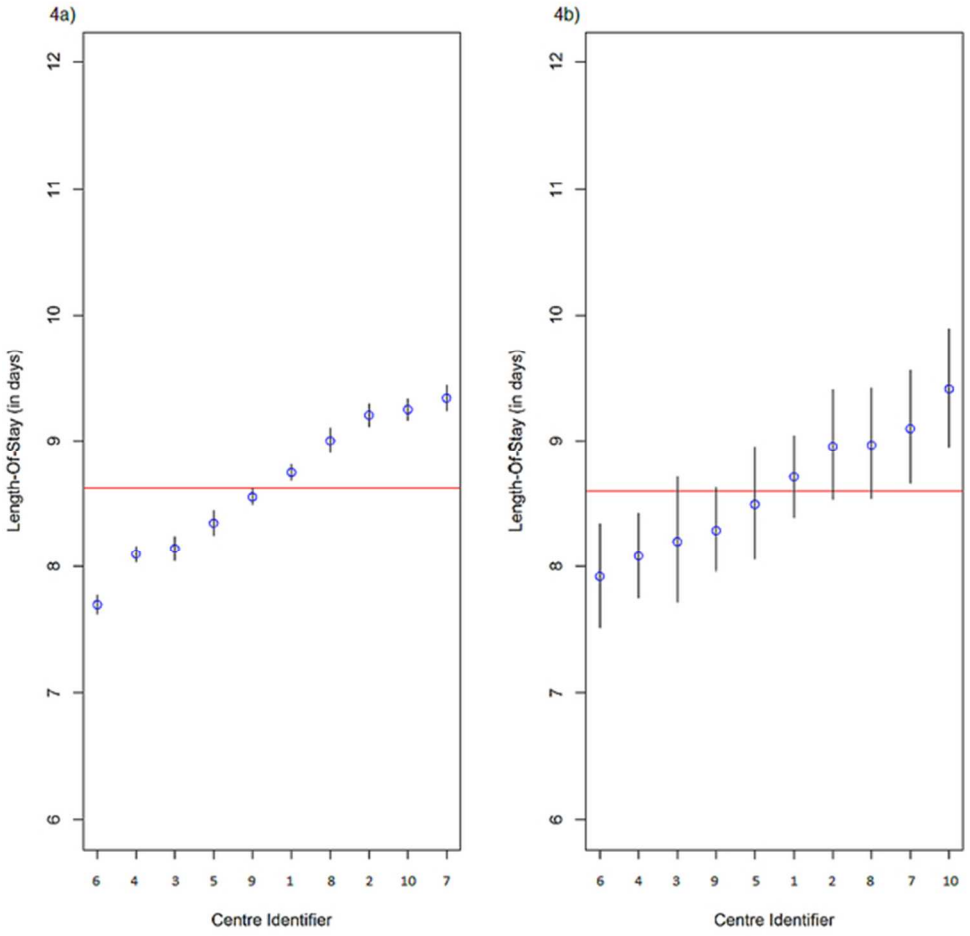
Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

49x49mm (300 x 300 DPI)



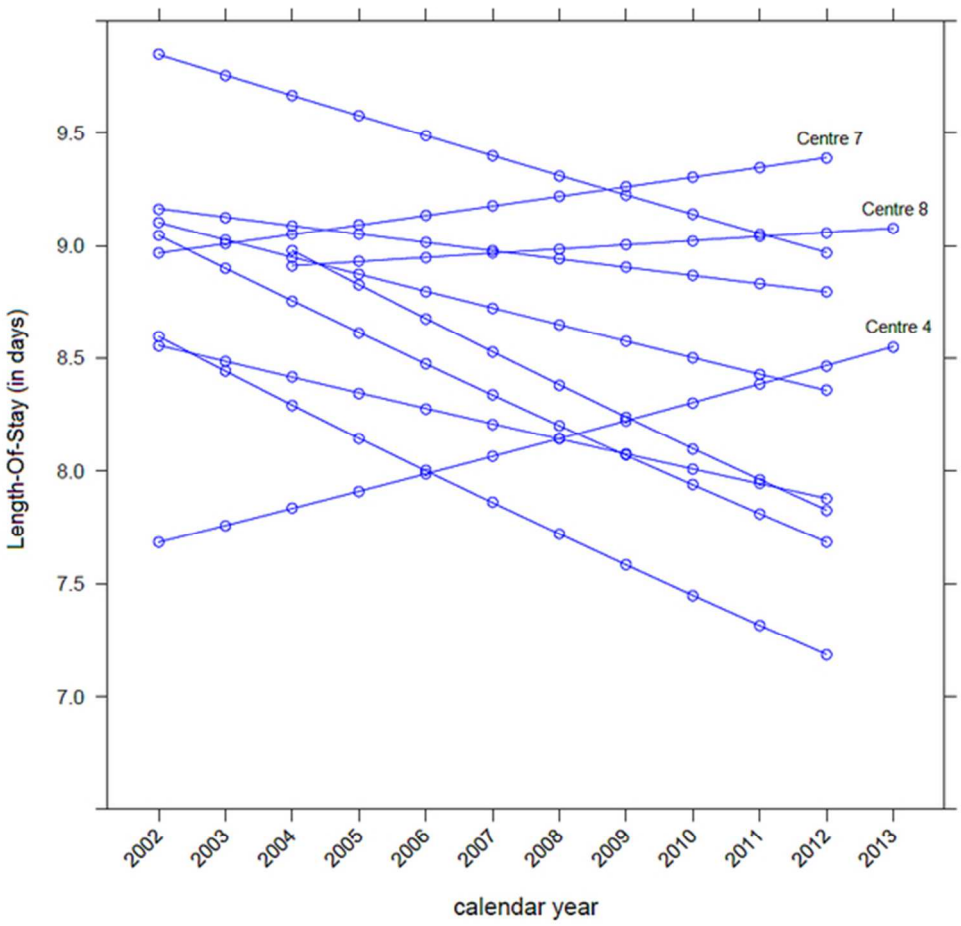
Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

190x190mm (300 x 300 DPI)



Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

56x56mm (300 x 300 DPI)



Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

53x54mm (300 x 300 DPI)

Table S1: Model output for the three-level cross-classified model with centre random "Year of Operation" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.15	(2.20,2.11)	< 0.001
Logistic EuroSCORE	0.208	(0.250,0.211)	< 0.001
Year of Operation	-0.00652	(-0.0127,-0.000346)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00401	0.00582	0.000274
Year of Operation Coefficient	9.51×10^{-5}		

Table S2: Model output for the three-level cross-classified model with Centre random "Age at Operation" coefficient.

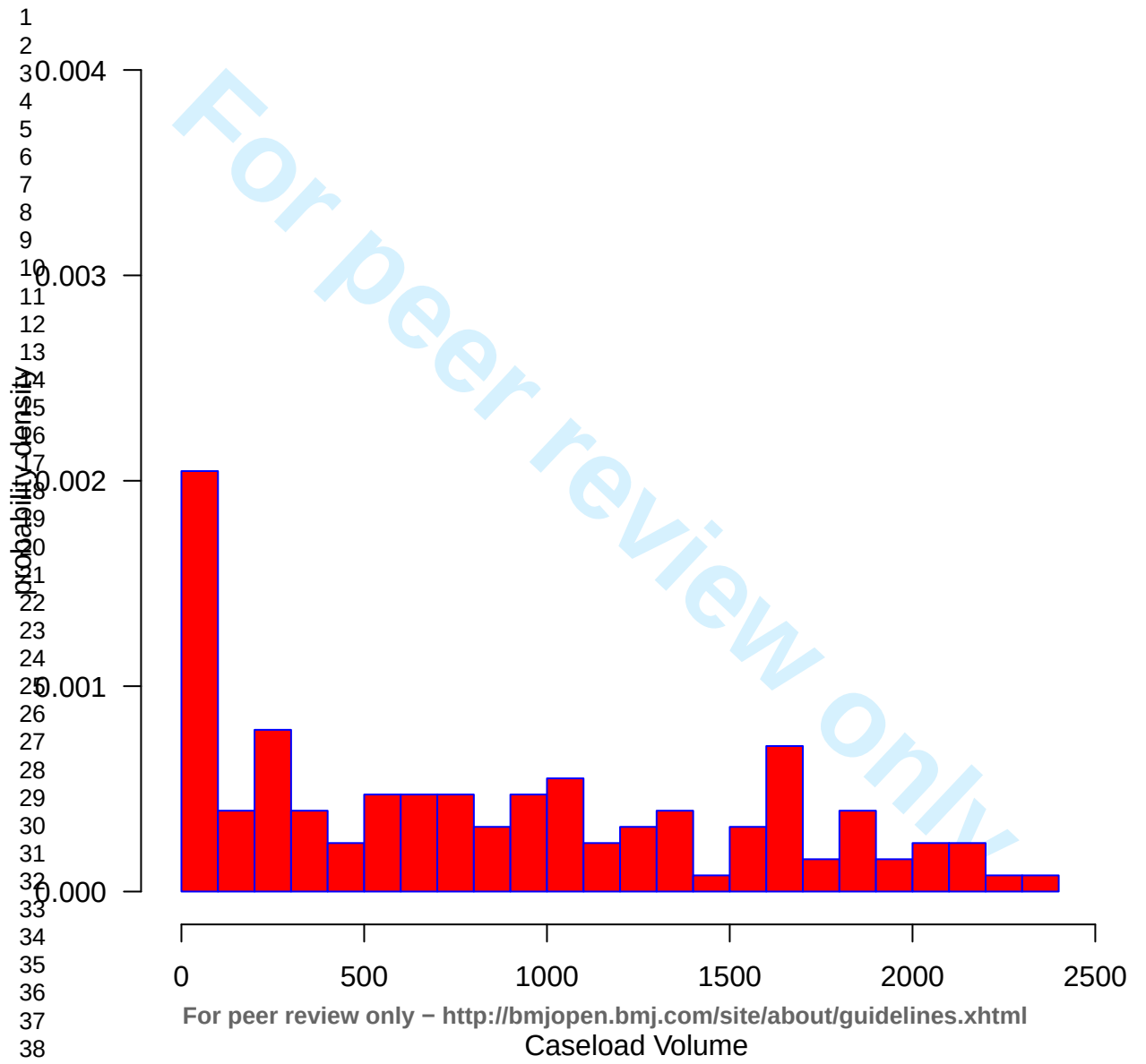
Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.14	(2.11,2.18)	< 0.001
Age at Operation	0.0102	(0.00898,0.0114)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00237	0.00852	0.000571
Age at Operation Coefficient	3.53×10^{-6}		

Table S3: Model output for the three-level cross-classified model with Centre random "Logistic EuroSCORE" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.16	(2.12, 2.20)	< 0.001
Logistic EuroSCORE	0.210	(0.193,0.226)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00310	0.00601	0.000371
Logistic EuroSCORE Coefficient	6.08×10^{-4}		



The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	**Title** **Abstract**	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	**Title** **Abstract** (Design, Setting and Participant sections) N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	**Introduction**: paragraphs 1-3		
Objectives	3	State specific objectives, including any prespecified hypotheses	**Introduction**: paragraph 3		
Methods					
Study Design	4	Present key elements of study design early in the paper	**Methods**: paragraphs 1-2		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	**Methods**: paragraphs 1-2		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the		RECORD 6.1: The methods of study population selection (such as codes or	**Methods**: paragraphs 2-5

		sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	**Methods**: paragraphs 2-5 N/A	algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	**Methods**: Paragraph 1 (Data Source section) and Paragraphs 7-8 (Variables and Outcomes measures section)		
Bias	9	Describe any efforts to address potential sources of bias	**Methods**: paragraphs 4 (Study Cohort section) and		

			8 (Variables and Outcomes measures section)		
Study size	10	Explain how the study size was arrived at	**Methods**: paragraphs 2-5 (Study Cohort section) and Flow diagram (Figure 1)		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section) and paragraphs 9-10 (Statistical Methods section)		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	**Methods**: paragraphs 8 (Variables and Outcomes measures section) and paragraphs 9-12 (Statistical Methods section) **Results**: paragraph 8 **Discussion**: paragraph 3 (Potential explanations and Implications of findings)		
Data access and		..		RECORD 12.1: Authors should	**Methods**:

cleaning methods				describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	paragraphs 1-2 (Data Source and Study Cohort sections) **Methods**: paragraphs 1-5 (Data Source and Study Cohort sections)
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	**Methods**: paragraphs 2-5 (Study Cohort section) Figure 1 – Flow diagram	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	**Methods**: paragraphs 2-5 (Study Cohort section)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and	**Results**: paragraph 1, Tables 1 and 2 **Methods**: paragraphs 2-5 (Study Cohort section)		

		total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	**Results:** paragraph 1		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	**Results:** paragraphs 2-5		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	**Results:** paragraphs 6-8		
Discussion					
Key results	18	Summarise key results with reference to study objectives	**Discussion:** paragraph 1		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	**Discussion:** paragraph 7 (Limitations subsection)	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data,	**Discussion:** paragraphs 7-8 (Limitations and Conclusions and Future research subsection)

				and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	**Discussion:** paragraphs 2-6 (Comparison with other studies and Potential explanations and Implications of findings)		
Generalisability	21	Discuss the generalisability (external validity) of the study results	**Discussion:** paragraphs 2-9		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	**Acknowledgements:** paragraphs 2 and 3		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	**Methods:** paragraph 1 (Data source section) **Acknowledgements**

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

BMJ Open

Effect of individual patient risk, centre, surgeon and anaesthetist on length of stay in hospital after cardiac surgery: Association of Cardiothoracic Anaesthesia and Critical Care (ACTACC) consecutive cases series study of ten UK specialist centres

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Effect of individual patient risk, centre, surgeon and anaesthetist on length of stay in hospital after cardiac surgery: Association of Cardiothoracic Anaesthesia and Critical Care (ACTACC) consecutive cases series study of ten UK specialist centres

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Abstract

Objectives: To determine the relative contributions of patient risk profile, local and individual clinical practice on length of hospital stay after cardiac surgery.

Design: Ten-year audit of prospectively collected consecutive cardiac surgical cases. Case-mix adjusted outcomes were analysed in models that included random effects for centre, surgeon, and anaesthetist.

Setting: UK centres providing adult cardiac surgery.

Participants: 10 of 36 UK specialist centres agreed to provide outcomes for all major cardiac operations over 10 years. After exclusions (duplicates, cases operated by more than one consultant, deaths and procedures for which the EuroSCORE risk score for cardiac surgery is not appropriate), there were 107,038 cardiac surgical procedures between April 2002 and March 2012, conducted by 127 consultant surgeons and 190 consultant anaesthetists.

Main outcome measure: Length-of-stay up to three months postoperatively.

Results: The principal component of variation in outcomes was patient risk (i.e. represented by the EuroSCORE and remaining patient heterogeneity), accounting for 95.43% of the variation for postoperative length-of-stay. The impact of the surgeon and centre was moderate (intra-class correlation coefficients ICC=2.79% and 1.59% respectively), and the impact of the anaesthetist was negligible (ICC=0.19%). Similarly, 96.05% of the variation for prolonged (>11 days) length-of-stay was attributable to the patient, with surgeon and centre less but still influential components (ICC=2.12% and 1.66% respectively, 0.17% only for anaesthetists). Adjustment for year of operation resulted in minor reductions in variation attributable to surgeons (ICC=2.52% for LOS and 2.23% for prolonged LOS).

Conclusions: Patient risk profile is the primary determinant of variation in length of stay, and as a result, current initiatives to reduce hospital stay by modifying consultant performance are unlikely to have a substantial impact. Therefore, substantially reducing hospital stay requires shifting away from a one-size-fits-all approach to cardiac surgery, and seeking alternative treatment options personalised to high-risk patients.

Keywords: length-of-stay, hospitalisation, centre, surgeon, anaesthetist, EuroSCORE, cardiac surgery.

Strengths and limitations of this study

- The study comprises more than 100,000 cases from ten of 36 UK specialist centres, amounting to almost a third of the cardiac cases in the UK between 2002 and 2012.
- The study is the first to examine the impact of the operating centre and key providers involved in the delivery of care on the LOS after cardiac surgery.
- Identifying how these external factors influence LOS may contribute to improving the efficiency of care.
- Total hospital LOS may have been underestimated due to lack of information on periods of time after inter-hospital transfer.
- The study concerned specialist centres with a likely interest in quality improvements therefore its findings may not be generalisable to smaller, non-specialist centres.

INTRODUCTION

According to 2013 records some 36,000 patients undergo cardiac surgery in the UK each year at a high annual cost of around £300 million.[1] Anticipated below-inflation increases in future NHS tariffs have inevitably triggered the search for efficiency savings, particularly improved patient throughput accompanied by shorter hospital stay, which is a key driver of surgical costs.[2, 3] Besides financial benefits for the NHS, improving efficiency through length-of-stay (LOS) reductions will also yield benefits for patients as prolonged LOS is directly associated with increased risk of complications and personal financial burden.[2-5] Reductions in LOS could release capacity in the system (e.g. release of occupied beds, nurse/doctor time), allowing the re-allocation of limited NHS resources to other areas in need. Understanding the causes of prolonged LOS may also lead to practices that contribute to the reduction of postoperative complications and other adverse events that have a negative impact on patient quality-of-life.

Despite operating on relatively homogeneous patient populations, previous benchmarking exercises have identified considerable centre differences in postoperative models of care and LOS after cardiac surgery.[6] Differences in healthcare professionals' practices may also influence hospital stay[7]; nevertheless, the impact of individual surgeons and anaesthetists on LOS has received less attention. For instance, the operating surgeon has been shown to have a significant impact on in-hospital mortality post-cardiac surgery.[7, 8] However, to our knowledge, their impact on postoperative LOS has not been explored. Technically-skilled surgeons with low postoperative morbidity should achieve lower LOS.[3, 9-12] Similarly, previous studies have suggested differences in anaesthetic practices e.g. the use of "fast-track" anaesthesia protocols may accomplish a similar goal[13, 14]; however the evidence has been inconclusive.[15] These

relationships may be confounded by changes in service provision over time, so that careful analysis is required.

Several authors have studied the association between patient-related factors (e.g. disease severity, existence of comorbidities) and prolonged LOS after cardiac surgery.[16-18] There is also controversy as to whether different practices at different centres in the UK directly impact on hospital stay after cardiac surgery.[19] This study aims to quantify the variation in risk-adjusted postoperative LOS between cardiac centres, surgeons and anaesthetists across the UK, and to investigate changes in these components over time.

METHODS

Data Source

Cohorts comprising consecutive case series from UK specialist cardiac centres were provided to the Association of Cardiothoracic Anaesthesia and Critical Care. Data collection is mandated by the NHS and recorded prospectively in each centre. Requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority. Previous published work on this dataset examined the impact of the anaesthetist, surgeon and centre on in-hospital mortality.[7]

Study cohort

Details of how the study cohort was derived have been previously published. Briefly, our cohort comprised ten out of 36 UK specialist cardiac centres that provided datasets totalling more than 100,000 cardiac surgical patients (Figure 1). All 36 UK specialist cardiac centres were approached, of which ten agreed to participate and obtained local permissions for data provision within a set timeframe of a month. No centres were excluded. Data from consecutive major cardiac operations were prospectively collected for the 10-year period April 2002 through March 2012. Exclusion criteria were procedures for which the Logistic EuroSCORE (see "Variables and Outcome measures" section for detailed description) was not appropriate, cardiac transplants, pulmonary endarterectomy procedures and very high risk cases that necessitated delivery by at least two consultant surgeons. Patients under 18 years old were also excluded (0.08%). Patients with multiple operations at distinct admissions during the study period were treated as independent episodes.

There was a small amount of missing provider data (n=28, 0.02% and n=1482, 1.3% missing surgeon and anaesthetist entries respectively) which were excluded from the analysis. A small

number of cases with missing discharge destination (n=129, 0.11%) or date (n=125, 0.11%) were excluded. Finally, the EuroSCORE was not recorded for 755 entries (0.66%) which were also excluded. There were three patients with unknown sex, 40 with unknown operative priority status and 5964 with unrecorded operation type, all of whom were included in the analysis (Table 1).

Table 1: Patient and operative characteristics for analysis dataset (n=107,038)

Patient Characteristics	*Category*	*Frequency(Percentage of n=107038)*
Age at admission(years)	[18-36)	1 883 (1.76%)
	[36-56)	15 149 (14.15%)
**Mean:66.20(11.31)*	[56-66)	28 502 (26.63%)
Median:68	[66-76)	39 720 (37.11%)
IQR:(60,74)	[76-86)	20 682 (19.32%)
	[86-96]	1 102 (1.03%)
Gender	Male	78 261 (73.12%)
	Female	28 774 (26.88%)
	Unknown	3 (<0.01%)
EuroSCORE(probability)	[0,0.1)	87 559 (81.80%)
**Mean:0.0690(0.0896)*	[0.1,0.2)	12 515 (11.69%)
Median:0.0400	[0.2,0.3)	3693 (3.45%)
IQR:(0.0208,0.0777)	≥0.3	3271 (3.06%)
Operative Characteristics		

Priority	Elective	74 909 (69.98%)
	Urgent	28 312 (26.45%)
	Emergency	3525 (3.30%)
	Salvage	252 (0.23%)
	Unknown	40 (0.04%)
Operation Type	CABG(isolated)	56 586 (52.87%)
	AVR(isolated)	9719 (9.08%)
	MVR+other	6178 (5.77%)
	CABG+AVR	8594 (8.03%)
	CABG+other procedures	2204 (2.06%)
	CABG+other valve	2860 (2.67%)
	Other procedures	3800 (3.55%)
	AVR+other procedures	2511 (2.34%)
	CABG+AVR+other	1292 (1.21%)
	Valve alone	5788 (5.41%)
	Valve + other	1542 (1.44%)
	Unknown	5964 (5.57%)

**for continuous variables, the mean(SD), median and interquartile range are given. IQR, Interquartile range, CABG, coronary artery bypass grafting; AVR, aortic valve replacement or repair; MVR, mitral valve replacement or repair. Square bracket denotes number inclusive in the interval.*

Surgeons and anaesthetists with caseloads smaller than 0.1% of the total caseload of their centre were excluded; these professionals, with the exception of one surgeon, had carried out

fewer than ten operations and had either retired just after the onset of the study period, were appointed just before the end of the study period or held short-term contracts. Patients who were not discharged after three months of the procedure date were excluded from the analysis as any patient-related outcomes would likely be unrelated to the procedure itself and more likely be a result of other comorbidities (n=272, 0.24%). Moreover, all cases with immediate discharge (i.e. zero LOS) were excluded as they were either deaths or transfers to other centres (n=441, 0.4%). All remaining cases that resulted in in-hospital death were also excluded from the analysis in order to avoid bias associated with short LOS due to early death considered as a positive outcome and to be consistent with published literature (n=2,971, 2.7%).[16, 18]

The final analysis dataset comprised 107,038 cases (93% of the original case series, n=115,254) treated by 127 surgeons and 190 anaesthetists in 10 centres. The dataset comprised 91% (n=127 of 140) and 76% (n=190 of 250) of the initial surgeon and anaesthetist samples respectively; providers were excluded principally due to low caseload volumes.

Patient involvement

No patients were involved in setting the research question or the outcome measures, developing plans for design or implementation of the study. No patients were asked to advise on interpretation and writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

Variables and Outcome measures

The primary outcome measure was LOS up to three months postoperatively. LOS was defined as the number of days spent in hospital from the day of surgery to hospital discharge. The secondary measure of interest was prolonged LOS, defined as a hospitalisation of more than eleven days following surgery. There is no consensus in the literature on the definition of

prolonged LOS after cardiac surgery, and as a result, published studies often adopt the 75th centile of the LOS distribution.[16, 17, 20, 21] In our data set this corresponded to 11 days, and we have chosen it as the cut-off for prolonged stay to ensure consistency with published literature; we sought the expert advice of our cardiac surgical collaborators to ensure this was relevant to cardiac surgery in the NHS setting.

Since there is no established risk score for prolonged LOS, adjustment for varying patient case-mix risk was achieved using the logistic EuroSCORE.[22] The logistic EuroSCORE is a very well established risk score for in-hospital death post-cardiac surgery with widespread use worldwide and involves 17 cardiac, operation- and patient-related factors. The recently recalibrated version of the score (EuroSCORE II) was not available at the study onset[23]; our analysis included the original logistic EuroSCORE as this was the one used by the participating centres. One centre used the additive EuroSCORE, which is associated with under-prediction in high-risk cases. The proportion of high-risk patients, for which the additive EuroSCORE is known to underperform (additive EuroSCORE≥10%) was very small (0.5%, n=586 of 107,038)[24] and results of sensitivity analysis excluding this centre did not differ from analysis of the full cohort. We considered using patient age, sex and urgency instead of the logistic EuroSCORE to account for patient heterogeneity but EuroSCORE provided better model fit to the data, based on statistical criteria. In addition to variation due to centre, surgeon and anaesthetist, the covariate of interest was the calendar year of operation.

Statistical methods

We investigated the relationship between LOS up to three months postoperatively and potential covariates using mixed effects regression models. Patients were clustered within surgeons and anaesthetists who in turn, were clustered within centres inducing a hierarchy. To

reflect this, random effects terms were included for centres, surgeons, and anaesthetists. Logistic EuroSCORE was included as a fixed effect in all models to adjust for varying patient case-mix risk; year of procedure was included as a continuous fixed effect to investigate changes in outcomes over time.

Since the primary LOS outcome was positively skewed, linear mixed effects models were fitted to the logarithm of the LOS (log(LOS)). Prolonged LOS was modelled as a binary endpoint (≤11 vs > 11 days) using logistic mixed effects models. The following models were implemented for both outcomes of interest.

Initially two three-level random intercept models were fitted in order to establish individual surgeon and anaesthetist effects on the patient outcome, controlling for centre effects and patient case-mix risk. Thereafter, in order to model the effects of surgeons and anaesthetists simultaneously, we fitted a three-level cross-classified model assuming an additive contribution (on the log scale) from each provider (anaesthetist and surgeon), clustered within centres. We further fitted a two-level centre random intercept model, accounting solely for patient heterogeneity, in order to compare its outputs to those of the three-level cross-classified model and assess the impact of provider adjustment on between-centre variation. In order to investigate the effect of time we included the year of operation in the three-level cross-classified model. The methodology used has been described in detail in Papachristofi *et al.*[25]

Finally, in each model we estimated the Intra-Class Correlation Coefficients (ICC)[26] which represent the proportion of the total variation in the outcome that is attributable to each of the anaesthetist, surgeon and centre. The Likelihood Ratio Test was used to determine the significance of the fixed effects terms and the relevant p-values. We implemented all our methods using the statistical software R (version 3.2.2).[27, 28]

RESULTS

Baseline characteristics for the study cohort are summarised in Table 1. Almost three-quarters of the patients were men (73.1%). The mean (SD) age of our cohort was 66.20 (11.31) years. Overall, the median postoperative LOS over the 10-year study period was seven days, with 75% of patients discharged between 6 and 11 days; the corresponding mean LOS was 10.19 (8.36) days, although this is influenced by a small proportion of large values. The mean LOS over time in each centre is depicted in Figure 2, which shows varying patterns across centres; for instance, LOS decreased over time in centre 6 whereas it increased in centre 8. Summaries of each centre's cohorts are given in Table 2. Almost 23% of the study cohort had prolonged LOS over 11 days, which was associated with higher operative risk score compared to patients with LOS of 11 days or less (mean EuroSCORE 11.28% vs 5.42%); a histogram of the distribution of surgeon caseload volume is provided in the supplementary material (Figure S1).

Table 2: Numbers of patients operated on, surgeons and anaesthetists in each centre, between April 2002 and March 2012. Surgeons and anaesthetists who looked after <10 patients were excluded. Values are frequency or mean (SD) unless specified as median(IQR).

Centre number	Patients	Surgeons	Anaesthetists	LOS Median (IQR)	LOS Mean (SD)	Logistic EuroSCORE
1	17,889	21	24	8 (6, 11)	10.06 (7.14)	7.52 (9.74)%
2	9,323	13	16	8 (6, 12)	10.96 (9.13)	8.92 (11.26)%
3	6,357	6	8	7 (6, 10)	9.69 (8.59)	7.62 (9.03)%
4	15,008	16	24	7 (6, 10)	9.47 (7.47)	5.77 (7.26)%
5	6,661	10	15	7 (6, 11)	10.08	6.13 (7.96)%

					(8.79)	
6*	9,637	10	17	7 (6, 9)	9.03 (7.76)	4.29 (3.18)%
7	7,537	13	17	8 (6, 13)	11.41 (9.86)	7.48 (10.61)%
8	7,238	11	13	7 (6, 11)	10.75 (9.08)	6.71 (9.90)%
9	16,506	17	22	7 (6, 11)	10.15 (8.47)	7.47 (9.58)%
10	10,882	10	34	8 (8, 12)	10.95 (8.75)	6.91 (7.84)%

*Additive EuroSCORE was provided by this centre.

The logistic EuroSCORE was significantly associated with LOS in both surgeon and anaesthetist models, additionally adjusted for centre effects (1.230, 95% CI 1.226 to 1.234 and 1.229, 95% CI 1.225 to 1.232 respectively, p-value <0.0001 for both). This amounted to an increase in LOS of about 23% for each 1% increase in logistic EuroSCORE. The logistic EuroSCORE remained significant in the three-level cross-classified model including both surgeon and anaesthetist effects (1.231, 95% CI 1.226 to 1.234, p-value <0.0001). Table 3 shows that 95.43% of the variation in log(LOS) in this analysis was attributable to the EuroSCORE (and remaining patient heterogeneity).

Table 3: Percentage of the variation in post-operative length-of-stay (LOS) and prolonged LOS attributed to each component

Outcome	Centre	Surgeon	Anaesthetist	Patient and other covariates
LOS	1.59%	2.79%	0.19%	95.43%
Prolonged LOS	1.66%	2.12%	0.17%	96.05%

Figures 3a and 3b show the estimated LOS, in days, with its 95% confidence interval (CI) for each surgeon if they operate on a patient of average risk (i.e. mean EuroSCORE estimated at

6.9%), adjusting solely for centre effects, and adjusting for centre and anaesthetist effects simultaneously. Estimated LOS for 18 out of 127 surgeons, from nine different centres, have 95% CI lying wholly below the average LOS, suggesting shorter hospitalisations for their caseload. Fifteen surgeons from seven centres had higher-than-average estimated LOS. The surgeon random effects variance was modest yet important, with $ICC_{surgeon}$ =0.0287 suggesting 2.87% of the variation in outcome is attributable to the operating surgeon. Adjusting for anaesthetist effects resulted in a minor decrease in the $ICC_{surgeon}$ from 0.0287 to 0.0279. The surgeons with longest and shortest average LOS were distributed across seven centres, hence we could not identify a specific centre of extreme performance. This finding, in conjunction with the ICCcentre (1.59%), suggests that LOS is influenced by both surgeon and, to a small extent, by the operating centre.

Figures 3c and 3d depict the analogous anaesthetist forest plots, controlling solely for centre effects, and controlling for centre and surgeon effects simultaneously. Between-anaesthetist variability in LOS is smaller than between-surgeon variability (Figure 3c), with associated $ICC_{anaesthetist}$ of 0.58%. Estimated LOS durations for ten out of 190 anaesthetists, from five different centres, have 95% CI lying wholly below the average LOS indicating better performance that average. There were 14 anaesthetists from nine centres whose estimated LOS was higher than average. However, once surgeon effects were adjusted for, anaesthetist variation reduced to $ICC_{anaesthetist}$=0.0019 (0.19%), which is negligible. Figure 3d indicates that there is only one remaining anaesthetist with 95% CI wholly below the average; likewise, the number of anaesthetists with estimated LOS above the average reduced from 14 to four, employed in four different centres. This is unsurprising as, by pure chance, we would expect approximately 5 anaesthetists to lie at the upper end of the spectrum (i.e. if the anaesthetists were normally

distributed, 2.5% of 190 (n=4.75) would lie above the 97.5% quantile). The difference in estimated LOS between the two anaesthetists at the extremes reduced from almost two and a half days to less than one day.

Adjusting only for patient heterogeneity, the proportion of variation attributed to centre where the procedure was undertaken was 1.79% (ICCcentre=0.0179). When surgeon and anaesthetist effects were added, ICCcentre reduced to 1.59%; comparison of Figures 4a and 4b indicates that two centres remained significantly above, and two below, the overall average.

The effect of calendar year of operation on LOS was statistically significant (0.994, 95% CI 0.993 to 0.995, p-value <0.0001). However, this amounted to a decrease of 0.6% in LOS per year, which is unlikely to be clinically important. A calendar year random coefficient model was also fitted (Table S1, Supplementary material) which suggested that changes in LOS through time varied significantly between centres, with no national pattern.

Finally, increased logistic EuroSCORE was associated with increased odds of prolonged LOS in surgeon only, anaesthetist only and cross-classified models (OR 0.784, 95% CI 0.768 to 0.800; 0.775, 95% CI 0.759 to 0.791; and 0.785, 95% CI 0.769 to 0.801 respectively, p-value <0.0001 for all). The percentage of the variation in prolonged LOS attributable to EuroSCORE (and remaining patient heterogeneity) was 96.05% (Table 3). The variation attributable to the centre, surgeon, and anaesthetist was quantified as 1.66%, 2.12%, and 0.17% respectively.

We conducted exploratory analysis of the effect of age and logistic EuroSCORE on between-centre variation. Postoperative LOS increased by about 1% for an increase of one year in age (Table S2, Supplementary material). Although small, there was some variation between centres in the age effects, suggesting that part of the between-centre variation could be ascribed to differences in the average age of the treated population. There was some variation between

centres in the case-mix risk treated, which may explain part of the variation in centres' LOS (Table S3, Supplementary material).

DISCUSSION

Our study cohort included 10 of 36 UK cardiothoracic surgical centres, totalling 107,038 heterogeneous patients, equivalent to almost a third of the total cardiac operations performed in the UK during our study period. Patient risk factors accounted for over 95% of the variation in LOS and prolonged LOS in all models. The second most influential factor was the operating surgeon, with centre having a more moderate yet significant effect, whereas anaesthetist-induced variation was minimal.

Comparison with other studies

Our findings are consistent with published literature in other surgical fields suggesting much of the non-patient variation in LOS derives from different provider practices,[17] with the surgeon a more influential component than the anaesthetist. This is to be expected as the surgeon (unlike the anaesthetist) has the oversight of the patients' postoperative ward care and discharge. In previously published work using this cohort, similar surgeon and anaesthetist effects were found for in-hospital mortality, with surgeons having a considerable impact (4.00%) and anaesthetists a negligible effect (0.25%).[7] In contrast, there were no centre effects on in-hospital mortality. The centre importantly includes critical care and high dependency services, which may exert a significant effect on LOS, although it is difficult to isolate this aspect from other contributing factors using routinely-collected data.

Potential Explanations and Implications of findings

Our findings suggest that differences in centre infrastructure, policies and possibly geographical location are more likely to affect postoperative LOS than patient survival. We

conducted sensitivity analysis by re-estimating effects including cases of immediate discharge (i.e. zero LOS) and including all remaining cases that resulted in in-hospital death yielding very slightly reduced ICC estimates (1.21%, 2.21% and 0.15% for centre, surgeon and anaesthetist respectively). This reflects the fact that LOS for these patients is partly driven by mortality, resulting in reduced influence of external factors such the centre or surgeon. We further conducted exploratory analysis of factors that may contribute to increased between-centre variation. Our analysis supports the hypothesis that centres in areas with elderly populations are associated with increased LOS, in line with published evidence suggesting older patients are less likely to be discharged home (Table S2, Supplementary material).[14, 17, 18, 29] Likewise, exploratory analysis showed some between-centre variation in case-mix risk treated, which may explain part of the variation in centres' LOS (Table S3, Supplementary material).

The estimated mean LOS per surgeon (Figure 3) appears superficially very similar to the estimated probability of in-hospital death per surgeon previously published (Figure 2[7]). We examined which surgeons were significantly below, or above average both for in-hospital death and LOS but there was no discernible pattern.

Figure 4 illustrates a relatively tight distribution of average LOS between centres. It is notable that the two centres (6 and 4) with shortest LOS, had the lowest average EuroSCOREs (4.29 additive and 5.77 logistic respectively). In contrast, centre 10 may have been expected to have a shorter LOS given the relatively low average EuroSCORE (6.9). Geographical location may influence centres' LOS due to the type of populations treated. For instance, centres in less affluent areas, where access to home care is limited, may be associated with longer LOS. Alternatively, in areas with communities that have an established infrastructure and tradition of caring for relatives, centres may have shorter LOS. Further, in-depth examination of the

association of location and socioeconomic status is needed in order to robustly estimate their impact on the LOS.

The small decrease in LOS through time may result from improvements in the delivery of care in recent years, and is consistent with other published literature reporting longer hospitalisations at the beginning of the cohorts studied.[21] Given the numbers of initiatives purporting to reduce LOS after cardiac surgery, the actual 1% per year reduction is modest. Although predicted LOS for a patient of average risk *decreased* over time in most centres, it *increased* in three (Figure 5); this may be due to changes in management strategies, introduction of more conservative discharge practices in these centres, or changes in patient-related factors. A potential risk of reducing LOS is an increased risk of hospital readmission due to premature hospital discharge. In April 2011, the Department of Health introduced a policy of non-payment for emergency readmissions to English hospitals. According to the 2011/2012 Payment by Results (PbR) guidance, commissioners will no longer pay for any eligible emergency readmissions to a hospital within 30 days of discharge following planned hospital stay. The potential loss of considerable income may have induced reluctance of early postoperative discharge in some centres.

Limitations

i) Our study is limited by the lack of detailed patient-related information, such as ethnic and social background, rural residency, availability of home carer, access to transportation and local resources for the provision of social services, which may have a significant effect on postoperative LOS.

ii) We did not have access to centre characteristics, such as proportion of LOS spent in intensive care (ICU), high dependency unit (HDU) or post-surgical ward care.

Different models of care, resulting in differing proportions of time in each ward type, could affect total LOS. Similarly characteristics that may influence LOS, such as nurse-bed ratio, were not available.[16, 18]

iii) Information on other healthcare professionals involved in the patients' postoperative care that may contribute to variation in the LOS, such as ICU, HDU and ward staff was not available.

iv) The logistic EuroSCORE is a predictive risk score for in-hospital mortality and may be less effective at capturing risk of increased LOS. The recalibrated EuroSCORE II, additionally including poor mobility (or frailty) as a risk factor, may be better at capturing risk of increased LOS.

v) Total hospital LOS may be underestimated due to lack of information on periods of time after inter-hospital transfer.

vi) Our cohort included a relatively small number (n=10) of high-volume, specialist centres with a likely interest in quality improvements. Therefore, our results may not generalise to smaller, non-specialist centres and may be prone to underestimation of centre variation. Participating centres comprise a limited sample of all eligible centres and as such may also differ in average case mix or between-provider variability compared to non-participating centres. Nevertheless, as cardiac surgery in the UK is only offered in specialist cardiac centres with academic/teaching status, we would expect the participating and non-participating centres to be relatively similar in nature.

Recommendations and Future Research

Analysis of large Electronic Health Records (EHRs) can highlight characteristics of the centre and surgeon that introduce variation in patient outcomes. Future studies of smaller, more detailed databases examining features which may distinguish "long" to "short LOS" centres are required; potential key LOS drivers include varying discharge schemes, management strategies in pre/post-operative care, staffing levels, infrastructure and equipment available, such as operating theatres, medication and medical devices.[16, 18, 30] Likewise, further studies could identify provider practices and techniques that contribute to reduced LOS, such as level of accreditation, caseload volume and previous training and experience.

Delays in hospital discharge are mainly driven by postoperative patient-related complications and differences in centre and surgeon policies and practices; the NHS has previously highlighted that LOS is linked with differences in patient management.[19] It is difficult to separate which result from an internal hospital culture, and which are the result of external local healthcare resources. We used sophisticated statistical methods to establish the degree to which postoperative LOS after cardiac surgery is affected by heterogeneity in patient risk, compared to other factors such as differences in centre policies and provider practice styles. Enhancing our understanding of the relationship between these patient-extraneous factors and postoperative LOS will help centres, providers and commissioners implement measures to enhance the efficiency of healthcare provision, minimise time in hospital and reduce excess resource use. Health systems, such as the NHS, can benefit considerably as, due to the high throughput, even small LOS reductions may result in large cost savings.[16]

Conclusion

We have shown that patient risk profile is the primary determinant of variation in length of stay, thus current initiatives to reduce LOS by modifying consultant performance or local practice will have limited success. This implies that substantially reducing hospital stay requires shifting away from a one-size-fits-all approach to cardiac surgical care, and investing in seeking alternative treatment options personalised to high-risk patients.

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Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: OP declares partial funding by the Medical Research Council (MRC) and by a Gates Cambridge fellowship outside of the submitted work; AAK reports grants and personal fees from Pharmacosmos and personal fees from Vifor Pharma outside the submitted work; no other

financial relationships with any organisations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: No additional data available.

Transparency statement: The lead and senior authors OP and LDS (the manuscript's guarantors) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained. All authors, external and internal, had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Ethical approval: The requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority.

Figure legends

Figure 1: Flow diagram showing how the final dataset was derived.

Figure 2: Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

Figure 3: Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 4: Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

Figure 5: Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

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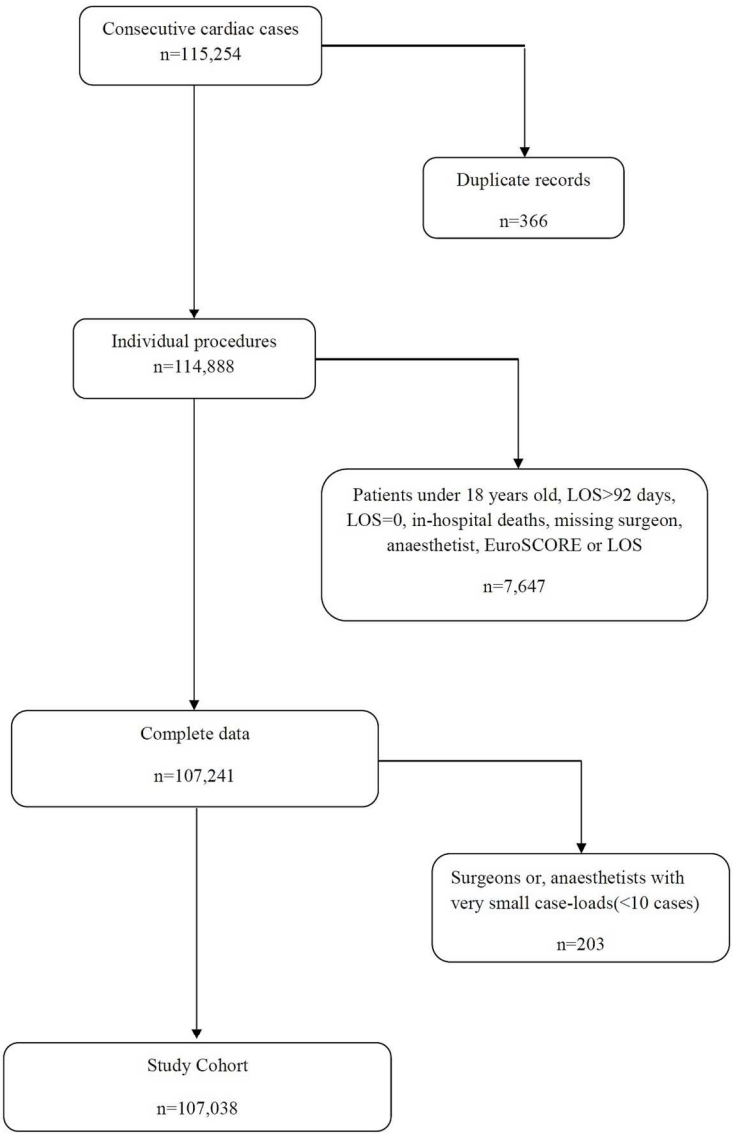

Flow diagram showing how the final dataset was derived.

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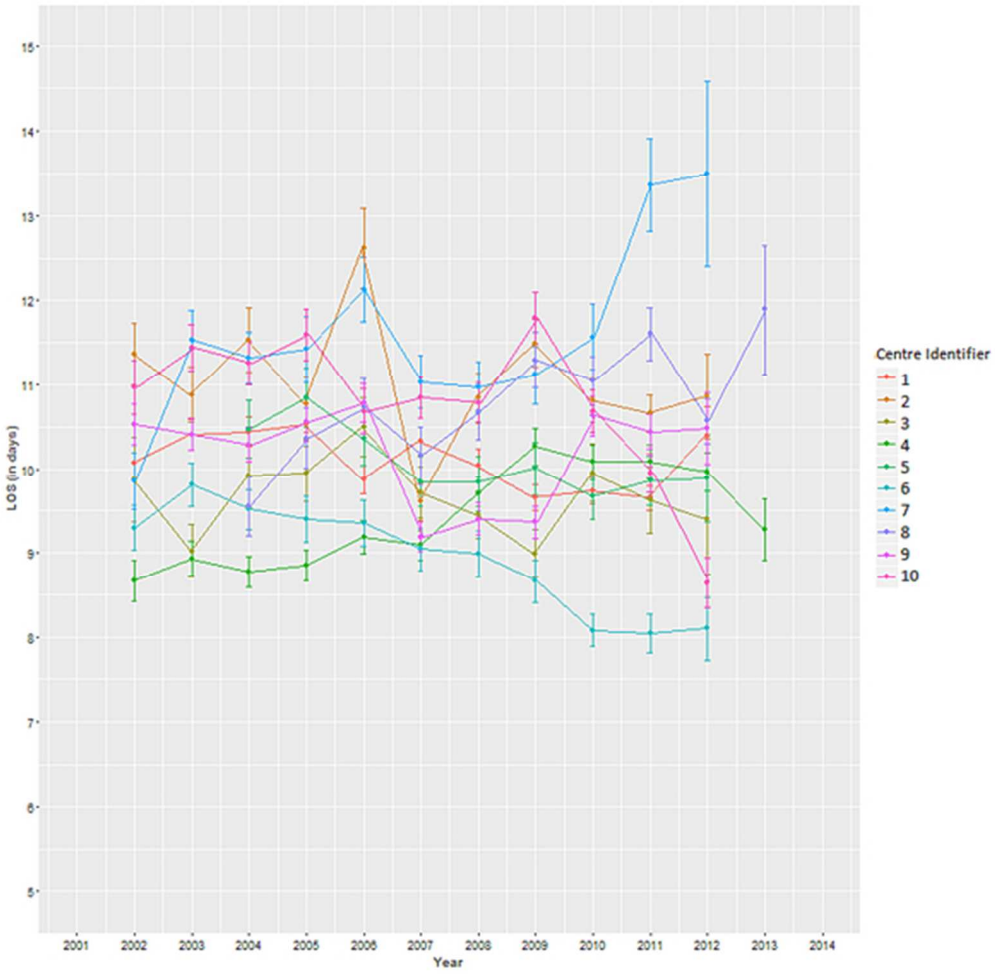

Mean postoperative length of stay (LOS) in hospital and 95% confidence intervals over time for each participating centre.

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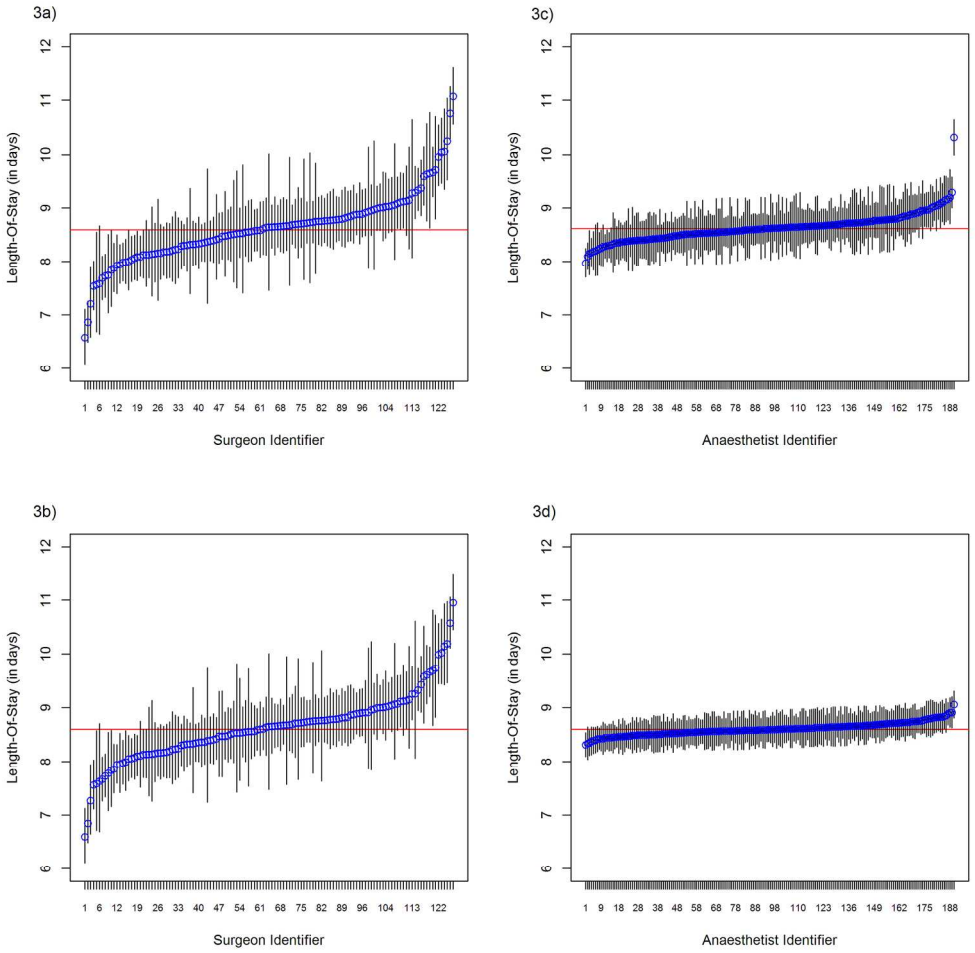

Estimated mean postoperative length of stay (LOS) in hospital and 95% confidence interval for each surgeon (3a, 3b) and anaesthetist (3c, 3d) for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

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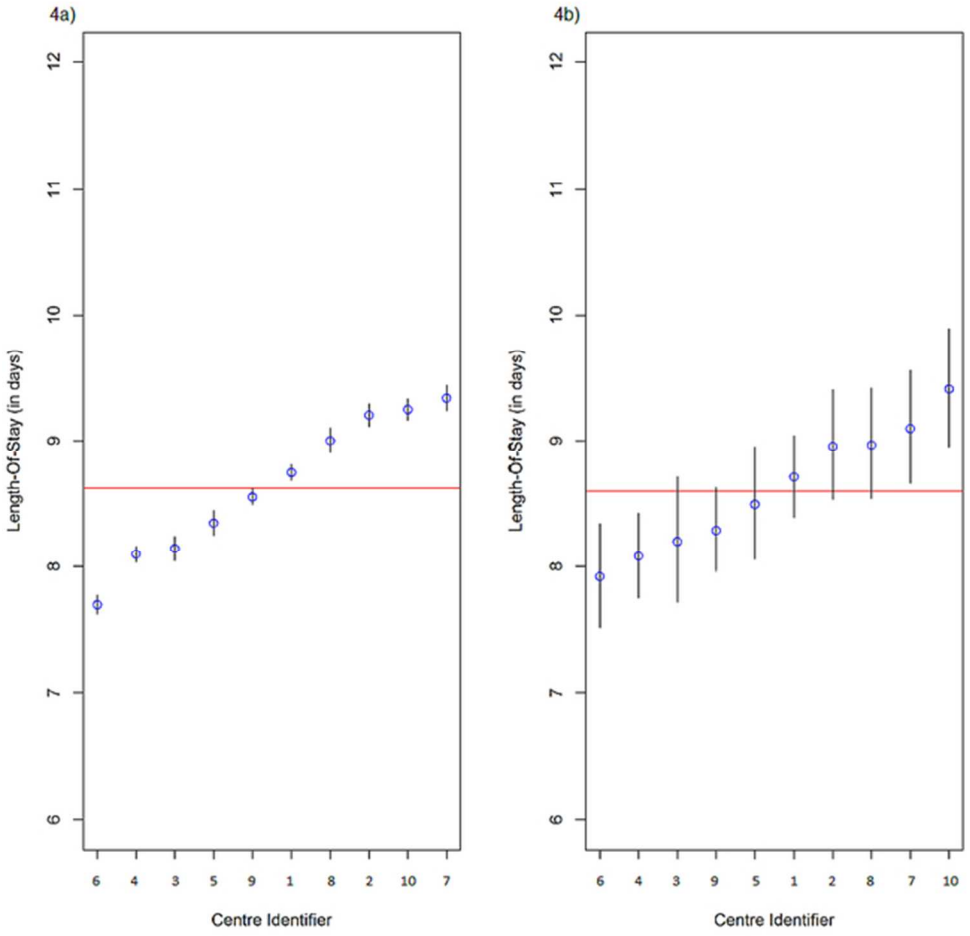

Estimated mean postoperative length of stay in hospital and 95% confidence interval for each centre for a patient with average EuroSCORE risk. Horizontal line is the estimated average LOS for a patient with average EuroSCORE.

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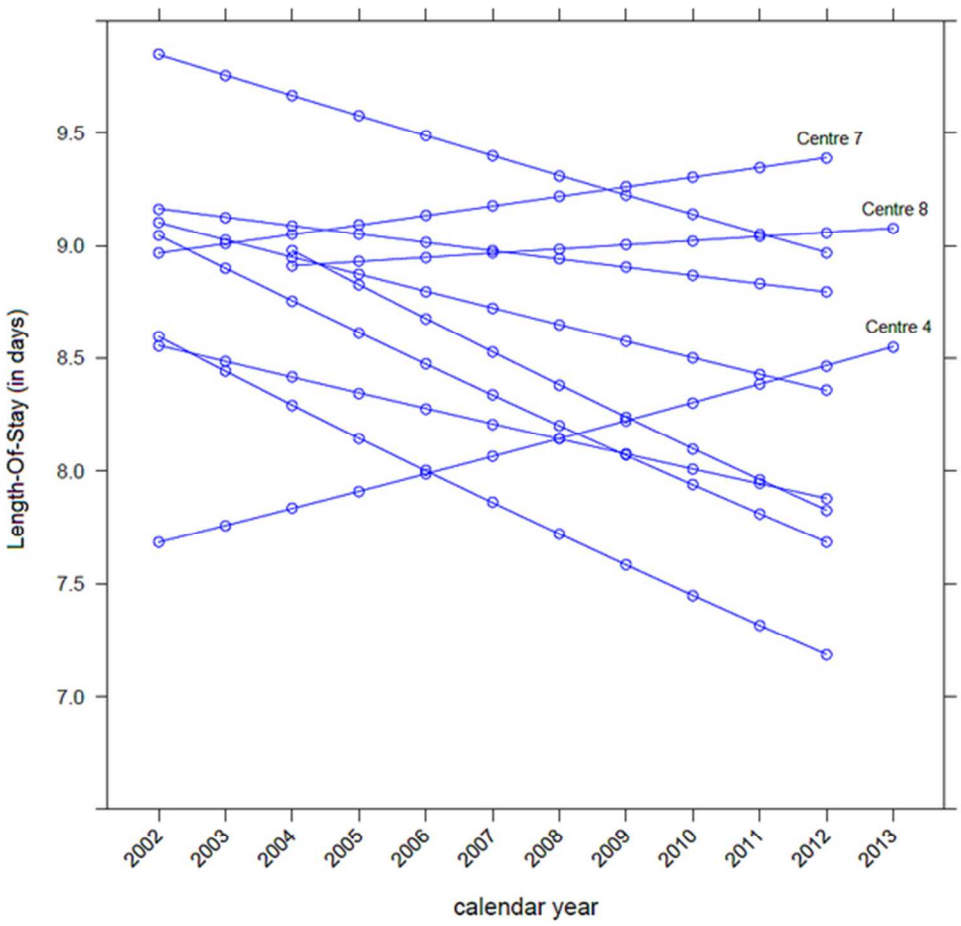


Predicted postoperative length of stay in hospital, for a patient with average EuroSCORE risk, in each centre over time.

53x54mm (300 x 300 DPI)

Table S1: Model output for the three-level cross-classified model with centre random "Year of Operation" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.15	(2.20,2.11)	< 0.001
Logistic EuroSCORE	0.208	(0.250,0.211)	< 0.001
Year of Operation	-0.00652	(-0.0127,-0.000346)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00401	0.00582	0.000274
Year of Operation Coefficient	9.51×10^{-5}		

Table S2: Model output for the three-level cross-classified model with Centre random "Age at Operation" coefficient.

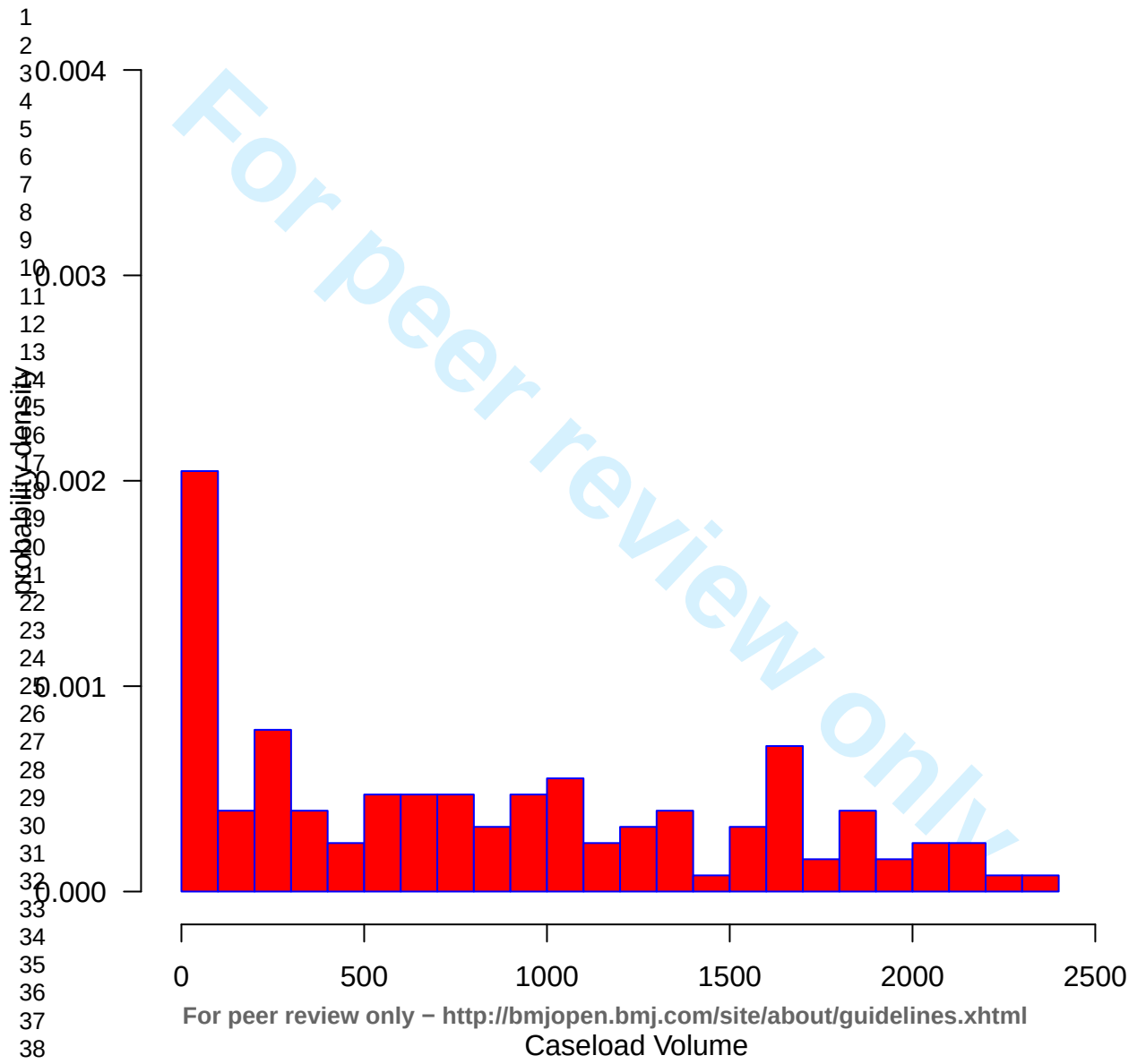
Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.14	(2.11,2.18)	< 0.001
Age at Operation	0.0102	(0.00898,0.0114)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00237	0.00852	0.000571
Age at Operation Coefficient	3.53×10^{-6}		

Table S3: Model output for the three-level cross-classified model with Centre random "Logistic EuroSCORE" coefficient.

Fixed Effects	**Estimate**	**95% Confidence Interval**	**P-value**
Model Intercept	2.16	(2.12, 2.20)	< 0.001
Logistic EuroSCORE	0.210	(0.193,0.226)	< 0.001

Random Effects	**Centre variability**	**Surgeon variability**	**Anaesthetist variability**
Intercept	0.00310	0.00601	0.000371
Logistic EuroSCORE Coefficient	6.08×10^{-4}		



The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	**Title** **Abstract**	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	**Title** **Abstract** (Design, Setting and Participant sections) N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	**Introduction**: paragraphs 1-3		
Objectives	3	State specific objectives, including any prespecified hypotheses	**Introduction**: paragraph 3		
Methods					
Study Design	4	Present key elements of study design early in the paper	**Methods**: paragraphs 1-2		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	**Methods**: paragraphs 1-2		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the		RECORD 6.1: The methods of study population selection (such as codes or	**Methods**: paragraphs 2-5

		sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	**Methods**: paragraphs 2-5 N/A	algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section)
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	**Methods**: Paragraph 1 (Data Source section) and Paragraphs 7-8 (Variables and Outcomes measures section)		
Bias	9	Describe any efforts to address potential sources of bias	**Methods**: paragraphs 4 (Study Cohort section) and		

			8 (Variables and Outcomes measures section)		
Study size	10	Explain how the study size was arrived at	**Methods**: paragraphs 2-5 (Study Cohort section) and Flow diagram (Figure 1)		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	**Methods**: paragraphs 7-8 (Variables and Outcomes measures section) and paragraphs 9-10 (Statistical Methods section)		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	**Methods**: paragraphs 8 (Variables and Outcomes measures section) and paragraphs 9-12 (Statistical Methods section) **Results**: paragraph 8 **Discussion**: paragraph 3 (Potential explanations and Implications of findings)		
Data access and		..		RECORD 12.1: Authors should	**Methods**:

cleaning methods				describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	paragraphs 1-2 (Data Source and Study Cohort sections) **Methods**: paragraphs 1-5 (Data Source and Study Cohort sections)
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	**Methods**: paragraphs 2-5 (Study Cohort section) Figure 1 – Flow diagram	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	**Methods**: paragraphs 2-5 (Study Cohort section)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and	**Results**: paragraph 1, Tables 1 and 2 **Methods**: paragraphs 2-5 (Study Cohort section)		

		total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	**Results:** paragraph 1		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	**Results:** paragraphs 2-5		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	**Results:** paragraphs 6-8		
Discussion					
Key results	18	Summarise key results with reference to study objectives	**Discussion:** paragraph 1		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	**Discussion:** paragraph 7 (Limitations subsection)	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data,	**Discussion:** paragraphs 7-8 (Limitations and Conclusions and Future research subsection)

				and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	**Discussion:** paragraphs 2-6 (Comparison with other studies and Potential explanations and Implications of findings)		
Generalisability	21	Discuss the generalisability (external validity) of the study results	**Discussion:** paragraphs 2-9		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	**Acknowledgements:** paragraphs 2 and 3		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	**Methods:** paragraph 1 (Data source section) **Acknowledgements**

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.