Editorial

Asked and answered: is the mortality associated with cardiac surgery related to the anaesthetist and should it be used to measure anaesthetic performance?

Beneficence and non-maleficence are two fundamental principles of medical professionalism [1]. However, they should be considered together since any medical intervention, no matter how beneficial for most, will cause harm to some patients. Cardiac surgery is a perfect example, as it will prolong the lives and alleviate the symptoms of the great majority of patients with surgically treatable heart disease. However, this undoubted beneficence for the vast majority comes at a cost and surgery will result in the deaths of a small minority of patients.

To its credit, the Society of Cardiothoracic Surgeons (STCS) in the UK recognises that surgical performance contributes to patient mortality [2]. As a result of this insight, cardiac surgeons were in the vanguard of surgeons instituting national audits of outcomes and publishing risk-adjusted mortality in the public domain to allow comparison (see http://scts.org/modules/surgeons/default.aspx). Over the years, there have been indications that the anaesthetist (anaesthesiologist) may also influence outcome from cardiac surgery, in particular, mortality [3–5]. In addition, there have been concerns that, like surgeons, anaesthetists who undertake low caseloads may have poorer patient outcomes [6]. In response, the Association of Cardiothoracic Anaesthetists (ACTA) organised a multicentre collaborative study in the UK to investigate any contribution by anaesthetists to the mortality associated with cardiac surgery and, if there was an impact, whether there was any relationship to caseload [7]. Papachristofi and colleagues report the findings in this issue of *Anaesthesia*, and the aims of this editorial are to provide context, identify the strengths and limitations and give a perspective for this important study.

Although cardiac anaesthetists were late in undertaking outcome research [8], Slogoff and Keats reported an observational study in 1985 that examined the predictors of postoperative myocardial infarction in patients undergoing coronary artery bypass grafting (CABG) surgery, identifying tachycardia as an important predictor [3]. Infamously, anaesthesiologist number seven of nine had by far the highest incidences of intra-operative tachycardia, myocardial ischaemia and postoperative myocardial infarction, thus first linking the anaesthetist with the outcome of cardiac surgery.

If I have a hero in cardiac anaesthesia, then it is Arthur S. Keats, as he recognised in 1983 the irrational variance between centres and individuals in cardiac anaesthetic technique [8, 9]. In addition, he was one of the first to investigate the effect of anaesthetic technique on outcome from cardiac surgery using a randomised controlled trial (RCT) [10]. Most importantly, he reported with Slogoff in 1989 that the choice of primary anaesthetic agent (halothane, enflurane, isoflurane and high-dose sufentanil) had no effect on the myocardial outcome of cardiac surgery, thereby leading to fast-track recovery from heart surgery [8]. In 1992, seven years after Slogoff and Keats noted that the anaesthetist might be related to outcome, Merry and colleagues reported a small, single-centre, observational study of 1301 patients that specifically examined the role of the anaesthetist on a composite measure of outcome from cardiac surgery, including mortality, and found a significant association [4]. However, composite

This editorial accompanies an article by Papachristofi *et al*, http://onlinelibrary.wiley.com/doi/10.1111/anae.13291/abstract endpoints are problematic and it is preferable to use a single primary endpoint, such as mortality, if that is available [11]. Most recently in 2015, Glance and colleagues performed a retrospective, multicentre, observational study of 7920 patients and found that the anaesthetist had a significant impact on another composite measure of outcome that also included mortality [5]. Although the study population was six times larger than that of Merry et al., the size was still too small to examine infrequent, but clinically important, adverse outcomes. In contrast to the findings of Glance et al., another recent and larger study of 18 569 (different) patients by Papachristofi and colleagues, using mortality as the sole outcome, found a small association with the surgeon but none with the anaesthetist [6]. However, this was a single-centre study, thus limiting the generalisability of the findings.

In summary, although weak, there is evidence to indicate that the anaesthetist may influence patient composite outcomes from heart surgery, including mortality. Indeed, a biological mechanism for this association may yet lie in the anaesthetist's choice of anaesthetic agent. In contrast to Slogoff and Keats's early, single-centre study, there is moderately strong, but not conclusive, evidence from many RCTs and their meta-analysis as well as a multicentre, observational study of 34 310 patients undergoing CABG surgery, that volatile-based anaesthesia may be associated with a lower mortality than total intravenous anaesthesia [12, 13]. This possible effect is underpinned by the basic science that volatile agents protect the myocardium by preconditioning [13]. Nevertheless, it may still be that, as Slogoff and Keats suggested 30 years ago, outcome from cardiac surgery is influenced by the mis-application of any anaesthetic technique by the anaesthetist [3].

Before considering the implications of Papachristofi et al.'s findings, there are a number of important limitations to their current study that should be noted, including the use of retrospective data, a long study period, a small number of centres and the exclusions of high-risk patients and 24% of the anaesthetists [7]. Although the data were originally collected prospectively and made available to the SCTS and the National Institute for Cardiovascular Outcomes Research for the national audit of outcomes from cardiac surgery, they were not specifically collected to answer the questions posed by this study. The data were then retrospectively examined by the authors and the inherent observational study design leaves it open to bias.

The study period was from 2002-12 and, during that decade, much changed in the characteristics of patients presenting for surgery and in the practice of cardiac anaesthesia, for example the increasing adoption of intra-operative transoesphageal echocardiography and the use of anti-thrombotic drugs in patients undergoing CABG. Over time, these changes may have influenced patients' survival, thus disguising any effect of the anaesthetist on mortality. Moreover, only ten of the 36 UK centres took up ACTA's invitation to contribute data to the study. Although unlikely, their willingness to participate may have been because these centres are exemplars of good anaesthetic practice and, if so, the findings may not be generalisable to the remaining 26 UK centres or beyond. Furthermore, almost a quarter of anaesthetists were excluded from the study because, for a variety of reasons, they undertook fewer than 10 cases during the decade. A far more robust study design would have included a similar amount of data from a much shorter time period, from more centres, and would thus have been less affected by changes in background noise, excluded fewer anaesthetists and therefore been more generalisable.

Notwithstanding its limitations, this study is one of the most important pieces of research published in the 30 years of my involvement in cardiac anaesthesia. It is important for cardiac anaesthetists in the UK and, most probably, worldwide, as a fundamental question is asked and answered: do anaesthetists contribute any harm to patients undergoing cardiac surgery as measured by mortality? In addition, with a population sample size of over 110 000 patients and an average of over 580 patients per anaesthetist, it is, by a very long way, the largest study ever to examine this subject [7]. The findings indicate that the overwhelming predictors of mortality are the operative characteristics of the patient, that the surgeon has a small, but significant, impact, and that the anaesthetist makes extremely little – or even no – contribution. The statistical analysis employed had important strengths, but one limitation is that it cannot provide a measure of variance in the estimated proportions. Therefore, although unlikely because of the precision provided by such a large sample size, it is impossible to exclude the possibility that any confidence interval might include zero. Nevertheless, it should be recognised that even if the very small amount of mortality attributed to the anaesthetist (0.25%) was accurate, it is only one sixteenth of the 4% attributed to the surgeon.

Papachristofi and colleagues interpret their finding that anaesthetists have little or no impact on mortality associated with cardiac surgery to reflect good practice by, and training of, cardiac anaesthetists, and conclude that there would be no greater benefit to society by making public the mortality figures of individual anaesthetists. I firmly agree with the last point and would wish to believe the first two points to be the correct interpretation. However, there may be an alternative explanation to performance for the lack of the anaesthetist's influence on mortality.

Surgeons, by the very nature of their work on the heart, can cause irreversible damage to the cardiac structures and myocardium. To facilitate their work, surgeons arrest the heart with cardioplegia and any inadequacy of their technique can also result in damage to the myocardium. Moreover, they can fail to achieve haemostasis before sternal closure, resulting in cardiac tamponade and cardiovascular collapse that can be fatal, unless the sternum is immediately re-opened. So there are a number of mechanisms by which a cardiac surgeon may cause irreversible damage to the heart that may be fatal.

In contrast, other than misadventure, the most likely mechanism by which an anaesthetist might cause the death of a patient undergoing heart surgery is to precipitate cardiovascular collapse by the choice of anaesthetic agents or misapplication of the agents in a way that is unresponsive to vasoconstrictors and positive inotropic drugs. However, in the setting of cardiac surgery, there is immediate recourse to mechanical support of the circulation with cardiopulmonary bypass or intra-aortic balloon pump to salvage the patient with cardiovascular collapse. Having been salvaged by mechanically supported circulation, the patient can then go on to have the underlying cause of their cardiovascular collapse surgically treated, thus preventing its recurrence. So in this interpretation, the findings of Papachristofi et al.'s study are unsurprising.

By establishing that anaesthetists have little or no effect on mortality associated with cardiac surgery, the findings are a deeply reassuring endorsement of the professionalism of cardiac anaesthetists in the UK. Like the National Audit Projects undertaken by the Royal College of Anaesthetists, this study by ACTA is a shining beacon for other anaesthetic bodies to follow, and examine if and how their practice harms their patients. Moreover, similar professional bodies representing cardiac anaesthetists, such as the European Association of Cardiothoracic Anaesthesiology (EACTA) and the Society of Cardiovascular Anesthesiologists (SCA), should consider reproducing the study with improvements to the study design, to confirm whether or not anaesthetists influence mortality associated with cardiac surgery in other geographical areas of the world.

If there is little or no relationship between anaesthetists and mortality, then mortality may not be the most suitable measure of the performance and training of cardiac anaesthetists. There are many other important patient outcomes from cardiac surgery that the anaesthetist may influence [14]. Indeed, some, such as stroke, may be considered worse than dying by some patients. In my unit, there is now a phenomenal incidence of acute kidney injury and, in some patients, this does not resolve. Likewise, delirium is now an everyday occurrence affecting many patients at some time in their postoperative period following cardiac surgery. So there are serious adverse outcomes other than mortality that may be affected by the anaesthetist, and that could be used to measure performance and training. In the UK at least, ACTA should now move on to extending its collaborative, multicentre research to identify and measure such events.

It is not unreasonable to believe that, to maintain competence, a cardiac anaesthetist must undertake a sufficient caseload, and defining what level marks sufficiency would be valuable to inform the profession. Papachristofi et al. also investigated this question and, like their single-centre study, they were unable to find any relationship between anaesthetists' caseloads and mortality [6, 7]. However, if, as I have argued above, mortality is an unsuitable measure of the performance and training of cardiac anaesthetists, then it is also an unsuitable measure to assess adequate caseload. The findings from this study should be another spur for ACTA to identify those patient outcomes that are influenced by anaesthetists and to use these to assess the impact of caseload to answer this important question.

In conclusion, whilst ACTA's multicentre study, reported by Papachristofi et al., has limitations, it also has strengths, and because of the sheer size of its sample population, the multicentre design and the use of a single fundamental outcome of mortality, it provides convincing evidence that the variation in anaesthetist practice contributes little, if anything, to the mortality associated with cardiac surgery. It is a shining example of professionalism by ACTA that could, and should, be reproduced by other professional associations. Nevertheless, having demonstrated non-maleficence as measured by mortality, ACTA should not be complacent, but now move on to examine whether cardiac anaesthetists harm their patients by measuring other outcomes from cardiac surgery that are important to patients and, if so, use these outcomes to measure their performance.

Competing interests

I am a member of ACTA, EACTA and the SCA, and was Chair of the ACTA Committee before Papachristofi et al.'s study was conceived; I had no involvement in the planning, conduct or analysis of the study.

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doi:10.1111/anae.13315

doi:10.1111/anae.13291

Original Article

The contribution of the anaesthetist to risk-adjusted mortality after cardiac surgery*

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Summary

It is widely accepted that the performance of the operating surgeon affects outcomes, and this has led to the publication of surgical results in the public domain. However, the effect of other members of the multidisciplinary team is unknown. We studied the effect of the anaesthetist on mortality after cardiac surgery by analysing data collected prospectively over ten years of consecutive cardiac surgical cases from ten UK centres. Casemix-adjusted outcomes were analysed in models that included random-effects for centre, surgeon and anaesthetist. All cardiac surgical operations for which the EuroSCORE model is appropriate were included, and the primary outcome was in-hospital death up to three months postoperatively. A total of 110 769 cardiac surgical procedures conducted between April 2002 and March 2012 were studied, which included 127 consultant surgeons and 190 consultant anaesthetists. The overwhelming factor associated with outcome was patient risk, accounting for 95.75% of the variation for in-hospital mortality. The impact of the surgeon was moderate (intra-class correlation coefficient 4.00% for mortality), and the impact of the anaesthetist was negligible (0.25%). There was no significant effect of anaesthetist volume above ten cases per year. We conclude that mortality after cardiac surgery is primarily determined by the patient, with small but significant differences between surgeons. Anaesthetists did not appear to affect mortality. These findings do not support public disclosure of cardiac anaesthetists' results, but substantially validate current UK cardiac anaesthetic training and practice. Further research is required to establish the potential effects of very low anaesthetic caseloads and the effect of cardiac anaesthetists on patient morbidity.

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Accepted: 18 September 2015
**Presented in part at the joint meeting of the Association of Cardiothoracic Anaesthetists and the Society of Cardiothoracic Surgeons, April 2015, Manchester, UK.*
[a]See Appendix.
This article is accompanied by an editorial by Alston, http://onlinelibrary.wiley.com/doi/10.1111/anae.13315/abstract.

Introduction

It is accepted that the operating surgeon may affect risk-adjusted mortality following cardiac surgery, and this has led to the publication of surgeon-specific mortality rates in the UK and elsewhere (see http://www.scts.org/patients/hospitals/) [1, 2]. The fact that cardiac surgery is undertaken by teams has inevitably led to the suggestion that other team members – notably the anaesthetist – should be subject to similar scrutiny, and that anaesthetist-specific, risk-adjusted outcomes should be similarly available [3–6].

Objective evaluation of the contribution of individual anaesthetists to postoperative outcome is difficult. A link between the individual anaesthetist and outcomes (myocardial ischaemia and infarction) was suggested 30 years ago in a landmark study by Slogoff and Keats [7]. Merry et al. demonstrated a potential link between patient outcome and individual anaesthetists [8], but the topic received scant attention over the next two decades. Two recent attempts to assess the impact of the anaesthetist on cardiac surgical outcomes have produced conflicting results. A single-centre UK study of 18 662 patients found that the individual anaesthetist had a minimal impact on risk-adjusted mortality [9]. In contrast, a North American retrospective observational study of 7920 patients, based on prospectively collected data from the New York State Cardiac Surgery Reporting System, found evidence of substantial variability in death or major complications between anaesthetists [10]. A possible explanation for the apparent transatlantic differences in the impact of the anaesthetist is the difference in anaesthetic practice. In the UK study centre, anaesthetists' workload was entirely cardiothoracic, largely protocol-driven and cardiac caseload was high. In contrast, in the North American study, many anaesthetists had mixed practices, lower annual cardiac caseloads and greater variation in protocols.

In surgery, mortality may be inversely related to caseload volume [11, 12]. The analogous impact of anaesthetic caseload volume is unexplored. Cardiothoracic anaesthesia and intensive care has developed into a sub-speciality in its own right, and this has led to a debate as to whether anaesthetists should also undertake a minimum annual caseload.

We were motivated by the hypotheses that there may be variation in cardiac surgical outcomes between anaesthetists as there is between surgeons, and that caseload volume may be associated with patient outcomes. Hence, the aim of our study was to assess the anaesthetists' impact on the variation in outcomes after cardiac surgery and to establish whether caseload volume may affect patient outcome.

Methods

All 36 UK specialist cardiac surgical centres were invited to take part in the study; a time frame of one month was given to respond and to secure relevant permissions. Of the 36 centres, ten volunteered for participation (Bristol University Hospital, Cardiff University Hospital, City Hospital Nottingham, Glenfield Hospital Leicester, Leeds General Infirmary, Liverpool Heart and Chest Hospital, Northern General Hospital Sheffield, Papworth Hospital Cambridge, Royal Victoria Hospital Belfast, and Southampton University Hospital), and obtained the relevant local permissions for data collection within the set time frame. The requirement for formal ethical approval was waived according to the National Research Ethics Service of the NHS Health Research Authority. All centres collected data prospectively as part of NHS requirements and provided these data to the Society of Cardiothoracic Surgeons and National Institute for Cardiovascular Outcomes Research; these datasets were then provided to the Association of Cardiothoracic Anaesthetists (ACTA) in 2014. Data from consecutive major cardiac operations were prospectively collected for the period April 2002 through March 2012 (Fig. 1), with the exception of centre no. 4 (April 2002 through March 2013), and centre no. 8 (April 2004 through August 2013). Cardiac transplants, pulmonary endarterectomy procedures, very high-risk cases that required operation by two or more consultant surgeons, and other procedures for which the logistic EuroSCORE [13] was not suitable, were not studied. Patients under 18 years of age were also not studied.

The primary outcome measure was in-hospital death up to three months postoperatively; patients who were transferred out of the hospital in which they had their surgery to another hospital were considered

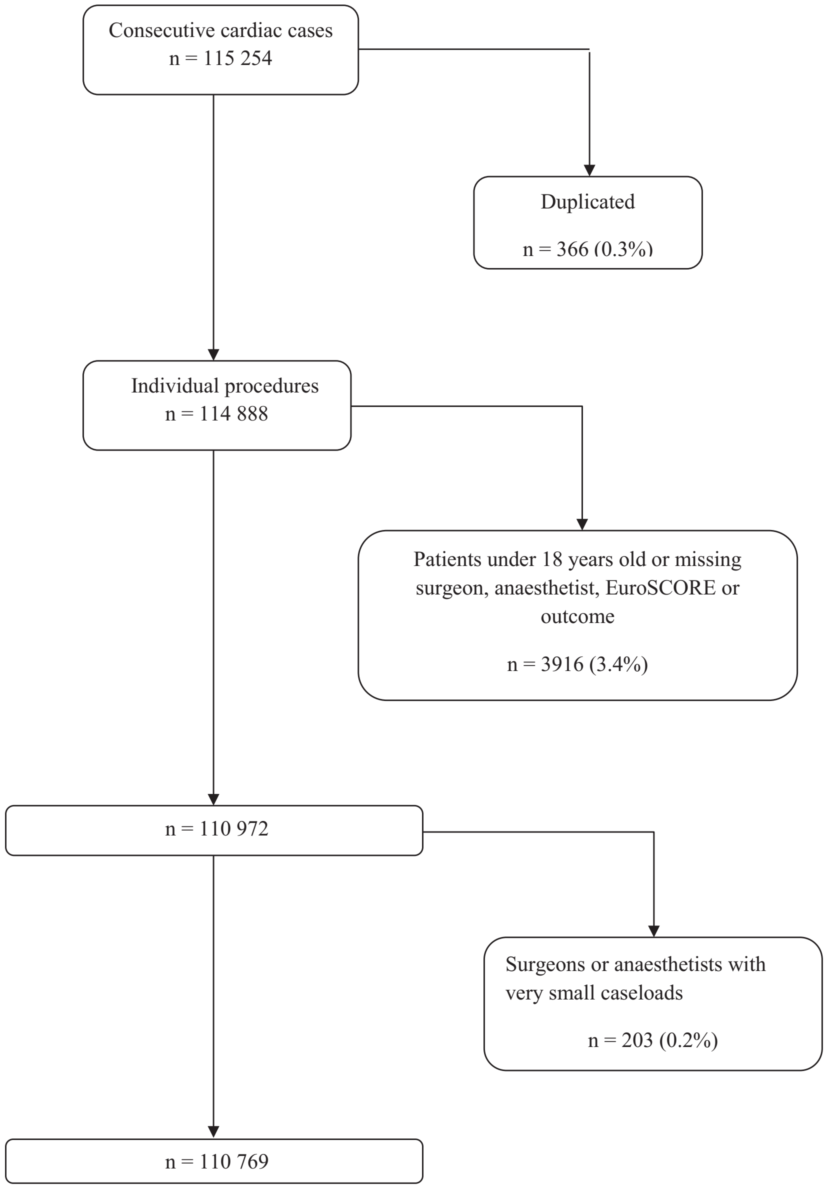

Figure 1 Flow diagram of participants.

to have survived. The logistic EuroSCORE was used to adjust for different patient casemix; this is a very well-established risk score, given as a percentage, specifically constructed to be used as a risk predictor for in-hospital death after cardiac operations. It includes 17 cardiac, operation- and patient-related factors and is used for risk assessment in many countries. This is the principal patient covariate we considered and it should be sufficient since all important patient-related factors for in-hospital mortality were included in its construction, with appropriate weighting [13, 14]. Although the original logistic EuroSCORE [13] has been recalibrated (EuroSCORE-2 [14]), the original version was in use during this study and was the version supplied by participating centres. The primary covariate of interest was the caseload volume of anaesthetists and surgeons.

We used logistic random-effects regression analysis [15–17] to analyse the relationship between in-hospital death and potential covariates. The response was death within three months of the procedure. Our analysis reflected the hierarchical nature of the data (patients grouped within surgeons/anaesthetists who are grouped within centres) using 'random-effects' for centres, surgeons, and anaesthetists. The logistic EuroSCORE was included as a fixed effect in all models to standardise for different patient risk-profiles; this was achieved by dividing the scores by 100 to transform them to probabilities and taking their logit transform.

We first fitted two three-level, random intercept models to establish the effects of individual surgeon and anaesthetist on the patient outcome, controlling for centre effects and casemix risk. To investigate the combined effects of surgeon and anaesthetist, we fitted a three-level, cross-classified model assuming an additive, individual contribution from each provider (anaesthetist and surgeon), nested with centres. To investigate the effect of volume on outcome, we refitted the three-level, cross-classified model including the monthly average volume of cases per surgeon and anaesthetist, defined as the total number of operations performed divided by the number of months in active practice. For each model, the intra-class correlation coefficients (ICC) [17] were estimated, interpreted as the proportion of the total variation that can be attributed to each of the anaesthetist, surgeon and centre. The p values determining the significance of the fixed-effect terms were calculated using the likelihood ratio test. Analyses were implemented using R (version 3.0.1, see http://www.r-project.org) [18, 19].

When reporting the results, we have not provided 95% CI. Confidence intervals for the proportion of the variation explained by different components in a hierarchical dataset are extraordinarily difficult to estimate. The technical statistical derivation has not been published (to our knowledge). We can never show that a variance component is zero, or even that a CI includes zero. Software does not normally provide standard errors for the random-effects variance either, and only a likelihood ratio test is recommended to judge the significance of the random-effects terms.

Results

There were missing outcomes of interest, for which records could not be retrieved, in three centres. Since the proportions of missing data from these three centres were very small (0.01%, 0.01% and 1.5% of n = 9900, 18 515 and 7793, respectively), we removed cases with missing outcome from the dataset. In four centres, a small number of missing surgeon entries were found (0.01%, 0.04%, 0.02% and 0.2% of n = 15 461, 7793, 9900 and 6903, respectively), and these were excluded from the analysis. Eight of the ten centres had missing anaesthetist entries, with the largest proportion reaching 3% in centre no. 6 (n = 9900); the percentages in other centres varied from 0.1% to 1.5%. Since the anaesthetist could not be informatively imputed and these percentages were small, these cases were excluded. Finally, missing EuroSCORE entries from five centres (0.03%, 0.7%, 1.2%, 1.9% and 5.0% of n = 6625, 9900, 9633, 7501 and 7793, respectively) were removed from the data.

In all centres, surgeons and anaesthetists who each performed < 0.1% of the cases in their centre were excluded; this was fewer than 10 operations per professional except for one surgeon. These professionals had either retired just after the start of the study period, were appointed just before the end of the study period, or held short-term contracts at their centre.

Final analysis was performed on 110 769 cases after exclusions, 96% of the original case series of 115 254 patients, treated by 127 surgeons and 190 anaesthetists in ten centres. The analysis was done using 91% (127/140) and 76% (190/250) of the original surgeon and anaesthetist samples, respectively, mostly due to the low-volume exclusions. Baseline characteristics for the study cohort are summarised in Table 1. Overall, 3413 of 110 769 patients (3.1%) died in-hospital. In-hospital mortality for the subset of professionals with very small caseloads was comparable with mortality in individual centres (3.45% of n = 203, see Table 2) as well as overall mortality for this dataset. The cases performed in each centre are summarised in Table 2, together with death rates, EuroSCORE and number of surgeons and anaesthetists per centre. For one centre, the additive EuroSCORE was provided, which leads to under-prediction in high-risk patients. Sensitivity analysis excluding this centre did not differ from the analysis including it. The proportion of patients lying above the risk level where the additive EuroSCORE starts to underperform (EuroSCORE ≥ 10%) was very small (0.62%, n = 689 of 110 769) [14, 20]. All centres were high-volume, with only two having fewer than 800 cases per year,

Table 1 Characteristics of cardiac surgical patients and procedure performed (n = 110 769). Values are mean (SD) or number (proportion).

Age at admission; years	66.4 (11.3)
Logistic EuroSCORE; %	7.36 (9.88)
Male	80 603 (72.8%)
Priority	
Elective	76 540 (69.1%)
Urgent	29 646 (26.8%)
Emergency	4123 (3.7%)
Salvage	419 (0.4%)
Unknown	41 (0.04%)
Operation type	
Isolated CABG	57 644 (52.0%)
Isolated AVR	9956 (9.0%)
MVR	6475 (5.8%)
CABG + AVR	9050 (8.2%)
CABG + other	5466 (5.0%)
Other procedure	16 000 (14.4%)
Unknown	6178 (5.6%)

CABG, coronary artery bypass grafting; AVR, aortic valve replacement or repair; MVR, mitral valve replacement or repair.

the largest high-volume threshold encountered in the literature [21]. All centres exceeded the 400 cases threshold recommended for cardiac operations by the American Heart Association (AHA).

The yearly caseload varied considerably among surgeons and anaesthetists, both between and within centres. Nevertheless, most surgeons (104/127, 81.9%) can be considered high-volume as they performed more than the 75 operations per year recommended by the AHA. Likewise, most anaesthetists (150/190, 79%) anaesthetised for more than 50 operations per year.

The logistic EuroSCORE was a significant covariate in both the three-level surgeon and anaesthetist models for the in-hospital mortality outcome, adjusted for the centre (OR 0.903 (95% CI 0.875–0.931) and 0.896 (95% CI 0.869–0.924), respectively; p value < 0.0001 for both). The logistic EuroSCORE remained significant in the three-level, cross-classified model adjusting for the surgeon and anaesthetist simultaneously (OR 0.903 (95% CI 0.876–0.930; p value < 0.0001). The proportion of the variation in in-hospital death attributed to EuroSCORE (and other unexplained variables) from the three-level, cross-classified model was 95.75% (Table 3).

Figure 2 shows the estimated probability of in-hospital death for each surgeon if they operated on a patient with the mean EuroSCORE (estimated at 7.4%), controlling for the centre effect only, and controlling for both the centre and anaesthetist effects simultaneously. Estimated probabilities of death for eight out of 127 surgeons, from four different centres, have their 95% CI lying wholly below the average probability of death, indicating low mortality. There were 19 surgeons from nine centres whose estimated probability of death was higher than average. The surgeon random-effects variance was moderate but significant with $ICC_{surgeon} = 0.0406$, suggesting that 4.06% of the variation in outcome was attributable to the operating surgeon (Table 3). Adjusting for anaesthetist did not have an effect on the surgeon plots and reduced $ICC_{surgeon}$ slightly from 0.0406 to 0.0400, indicating that the operating anaesthetist's impact on the out-

Table 2 Numbers of patients operated on and surgeons and anaesthetists in each centre, between April 2002 and March 2012. Surgeons and anaesthetists who looked after < 10 patients per year were excluded. Values are number or mean (SD).

Centre no.	Patients	Surgeons	Anaesthetists	Deaths	Mortality	Logistic EuroSCORE
1	18 515	21	24	575	3.11%	8.07 (10.77)%
2	9633	13	16	273	2.83%	9.48 (12.26)%
3	6625	6	8	247	3.73%	8.23 (10.18)%
4	15 461	16	24	449	2.90%	6.16 (8.15)%
5	6907	10	15	220	3.19%	6.61 (9.00)%
6*	9900	10	17	243	2.45%	4.42 (3.35)%
7	7793	13	17	219	2.81%	7.99 (11.47)%
8	7501	11	13	215	2.87%	7.21 (10.91)%
9	17 112	17	22	577	3.37%	7.98 (10.54)%
10	11 322	10	34	395	3.49%	7.28 (8.58)%

*Additive EuroSCORE was provided by this centre (see text).

Table 3 Variation in in-hospital death attributed to each group. Values are proportion.

Centre	Surgeon	Anaesthetist	Patient and other covariates
0%	4.00%	0.25%	95.75%

come is minimal compared with that of the surgeon. After adjusting for surgeon effects, there were no remaining centre effects.

From the centre-anaesthetist model that adjusted for patient risk, the anaesthetist random-effects variance was very small ($ICC_{anaesthetist} = 0.0071$). Figure 2c demonstrates that there is almost no between-anaesthetist variability in the outcome, with only one anaesthetist performing significantly differently from the average. In the cross-classification model adjusting also for surgeon effects, anaesthetist variation reduced to $ICC_{anaesthetist} = 0.0025$ which is negligible (Fig. 2d), with no anaesthetist significantly different from the average. The 'outlying' anaesthetist in Fig. 2c performed 73% of his cases with the 'worst' performing surgeon in his centre; it is thus possible that his results were driven by the surgeon with whom he/she principally worked, thus falsely appearing suboptimal compared with the other anaesthetists. Once we adjusted for the surgeon as well as the anaesthetist in the three-level, cross-classified model, the impact of the surgeon on the anaesthetist's performance was accounted for and the specific anaesthetist was no longer significantly different from average (Fig. 2d). The difference in the probability of in-hospital death between the two anaesthetists at the extremes reduced from about 1.5% to 0.5%.

With respect to both surgeons and anaesthetists, there was a weak association between increased volume of cases performed and reduction in mortality, OR 0.99 (95% CI 0.96–1.01; p = 0.277) and 0.99 (95% CI 0.98–1.01; p = 0.217), respectively (see Supporting Information, Appendix S1).

Discussion

Our study cohort of 110 769 patients is the largest study to date of the impact of individual anaesthetists on patient outcome. This study includes data from ten of the 36 UK cardiothoracic surgical centres and incorporates almost a third of all UK cardiac operations

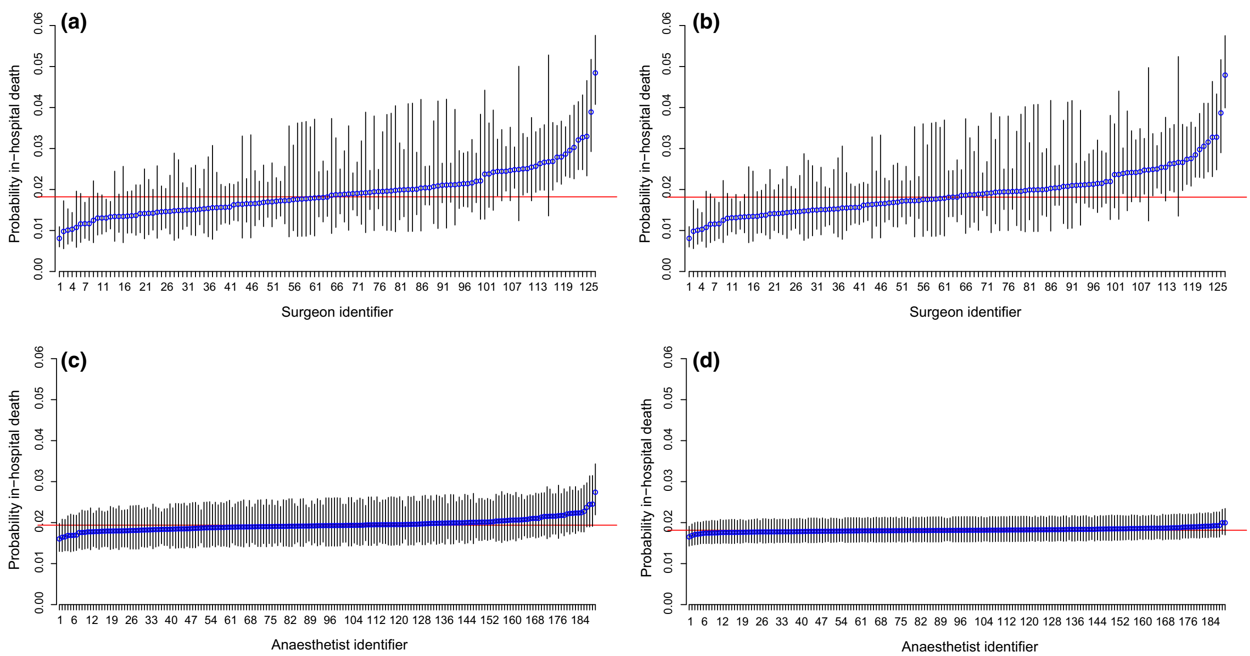

Figure 2 Estimated probability of in-hospital death within three months of surgery for a patient with average EuroSCORE risk: (a) surgeons adjusted for centre only; (b) surgeons adjusted for centre and anaesthetist; (c) anaesthetists adjusted for centre only; (d) anaesthetists adjusted for centre and surgeon. The horizontal line is average probability (1.8%) for the study cohort. Error bars = 95% CI.

undertaken during the one-decade study period. Patient risk accounted for 95.75% of the variation in in-hospital mortality. The second largest effect can be ascribed to the surgeon (Table 3 based on the risk-adjusted model adjusting for centre, surgeon and anaesthetist). Adjusting for the anaesthetist and centre components, the surgeon accounted for 4.00% of the observed variation in-hospital mortality. In comparison, the variation in mortality explained by the individual anaesthetist was minimal (0.25%). There was no remaining variation attributable to the centre.

Our key findings from a heterogeneous group of ten UK centres were very similar to our previously reported findings from a single, large, specialist cardiothoracic hospital [9]. Surgeons had a small but measurable effect on outcome, whereas no effect was found for the anaesthetist. A literature review identified only one other recent publication assessing the effect of the anaesthetist on cardiac surgical outcomes. In contrast to our findings, Glance et al. reported significant variation in performance between anaesthetists [10]. Different statistical methodology, study design and surgical practices could account for these conflicting findings. Glance et al. used a fixed-effects model, which may not have accounted for the simultaneous effects of the surgeon and the centre. In UK clinical practice, it is usually found that pairings between surgeons and anaesthetists are not random, as they most often are in the USA as reported by Glance et al. As shown by our study, it is possible that part of the variation attributed to the anaesthetist could be explained by the operating surgeon, accounted for in our methodology by using random-effects modelling accounting for all centre, surgeon and anaesthetist groupings simultaneously. The principal advantage of our methodology is that it allows the anaesthetist, surgeon or centre to be treated as a random sample from the whole population; that is, if we had chosen 190 other anaesthetists, the distribution of their results would have been similar, yielding generalisable estimates [22]. In contrast, fixed-effects models restrict results only to the sample of anaesthetists (surgeons or centres) available. Failure to take the dependency between each group's patients into account during analysis may result in bias in the estimated group and covariate effects, and inaccuracy in their respective standard errors and p values [17]. Our approach also allows us to delineate operator average effects from the effect of their caseload volume. Differences in outcome measurements, anaesthetic practice, training and size of surgical centre are additional factors that could explain the differences in findings. Glance et al. used a composite outcome of in-hospital mortality (no measurement period specified) and other major complications on which the anaesthetist may be more influential. No known risk score for this outcome is available, although Glance et al. included several risk factors in their analysis in order to adjust for differences in casemix. Anaesthetic care may be more standardised in UK centres than in the USA, thus allowing less scope for variation in practice to be observed. In the UK, consultants undertaking cardiothoracic anaesthesia have almost invariably undertaken additional sub-speciality training. Although this is also the case for US anaesthetists working in large surgical centres, this may not be the case in many of the smaller US surgical centres.

This study suggests that the standard of cardiac anaesthetic care in the ten UK centres studied is consistently high, but we acknowledge that these findings may not apply elsewhere in the UK or worldwide. Our study has demonstrated a robust mechanism for detecting underperformance, and we recommend that it should be applied to all UK centres with an interest in the monitoring of anaesthetic performance [23].

Perhaps surprisingly, we found no evidence of variation due to the centre. One potential limitation is the possibility that centres that volunteered to participate were different, in terms of patient risk treated or between-provider variability, from those opting not to participate. It is possible that the small number of participating centres and the potential bias due to their self-selection may have resulted in underestimation of the centre variation in our study. Furthermore, any variation in centre performance might be accounted for solely by variation in surgeon performance. Moreover, there is increasing evidence that anaesthetic care may affect patient outcomes such as major postoperative complications (e.g. stroke and myocardial infarction) [24]. A further limitation of our study is that we did not consider such composite outcomes and we underline the need for large studies on these to obtain robust evidence of the relative impact of the anaesthetist. The study was conducted in UK specialist cardiothoracic centres, where anaesthetic practices are often protocol-driven; this limits the potential for variation in the standard of care. Therefore, the findings may not apply outside of the UK where practice may differ. There was a small percentage (< 3.4%) of missing data in our dataset, which occurred mostly at the start and end of the recorded series. Blocks of missing data at the end of series are likely to have been due to delays between completed hospital episodes and data entry on to hospital electronic data systems. Moreover, in some centres, the consistent recording of the logistic EuroSCORE was not in place from the start of the series (in 2002), resulting to some missing data. In both these cases, missing data can be described as due to administrative reasons and assumed to be missing completely at random. Finally, in centre 6, one of the participating surgeons omitted to record the specific anaesthetist with whom he was principally working, resulting in missing anaesthetist data; hence, we excluded these records from further analysis. A sensitivity analysis including this surgeon and imputing his missing anaesthetist entries did not alter the results. Professionals with very small caseloads were excluded from analysis to avoid problems with model fit due zero events. However, as the exclusion of low-volume professionals resulted in few exclusions (0.2%) and, since mortality in this subset was comparable with that of the full dataset (3.45% and 3.1%), it is unlikely that this induced bias in the results.

This study was embarked upon by ACTA primarily to answer two questions: (i) should individual anaesthetists' outcomes be published on the Internet? and (ii) what is the safe minimum annual caseload? Based on our findings, the answer to the first question is a resounding 'no' in the UK. Publication of these results appears unnecessary and may have unintended consequences, such as avoidance of high-risk cases, already observed in cardiac surgical practice [25].

The second question is currently more difficult to answer. Our study suggests that performance is consistent in anaesthetists who complete at least ten cases per year and the second question is partially unresolved. Separate subgroup analysis of the combined outcomes of our very low-volume UK colleagues is probably required to answer this question. Although there was a weak association between higher monthly case volume and survival, our results suggest that caseload may be less important than previously thought. Increased morbidity (rather than death) associated with low annual case volumes may be an additional reason for Glance's et al.'s apparent conflicting findings.

In conclusion, in the ten UK specialist centres studied, the overwhelming factor associated with in-hospital mortality was the patients' risk profile, with the individual surgeon having a small but statistically significant contribution to variation in mortality. The impact of the individual anaesthetist was minimal. The operating centre did not have an effect on the outcome. We propose that this study substantially validates current UK specialist training and practice in cardiothoracic anaesthesia as fit for purpose, at least as far as it affects patient mortality. We recommend that further study to examine the effect of cardiac anaesthetists on patient morbidity be carried out.

Acknowledgements

This study was completed as part of a PhD project undertaken by OP, who was funded by a Medical Research Council Studentship Grant and by a Gates Cambridge Fellowship. AK is Editor-in-Chief of *Anaesthesia* and this manuscript has undergone additional external review as a result.

Competing interests

No other competing interests declared.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Model outputs and construction of Table 3.

