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ORIGINAL ARTICLE

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Coronary artery bypass surgery in the UK, trends in activity and outcomes from a 15-year complete national series

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Key question

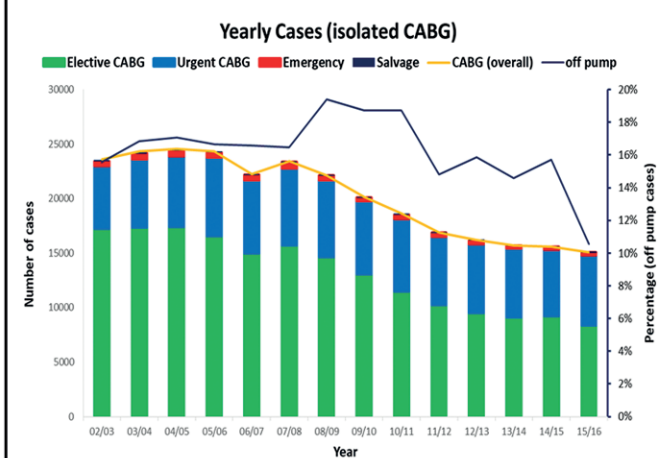
How have the trends in activity and outcomes for coronary artery bypass surgery changed in the UK in the last 15 years?

Key finding(s)

- Consistent decline in caseload and observed mortality (0.6% for elective CABG).
- Three-fold increase in elderly cases.

Take-home message

The demographics and service delivery have changed substantially with challenges for care of the elderly.



Abstract

OBJECTIVES: The aim of this study was to review the UK national trends in activity and outcome in coronary artery bypass graft (CABG) over a 15-year period (2002–2016).

METHODS: Validated data collected (2002–2016) and uploaded to National Institute for Cardiovascular Outcomes Research were used to generate summary data from the National Adult Cardiac Surgery Audit Database for the analysis. Logistic European System of Cardiac

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GENERAL ADULT CARDIAC

Operative Risk Evaluation was used for risk stratification with recalibration applied for governance. Data were analysed by financial year and presented as numerical, categorical, %, mean and standard deviation where appropriate. Mortality was recorded as death in hospital at any time after index CABG operation.

RESULTS: A total of 347 626 CABG procedures (282 883 isolated CABG, 61 109 CABG and valve and 4132 redo CABG) were recorded. Over this period annual activity reduced from 66.6% of workload to 41.7%. The mean age for isolated CABG was 65.7 years. The mean log European System of Cardiac Operative Risk Evaluation was 3.1, 5.9 and 23.2 for elective, urgent and emergency isolated CABG, respectively. There was a decline in the observed mortality for all procedures. Overall mortality for isolated CABG surgery is now 1.0% and only 0.6% for elective operations.

CONCLUSIONS: Quality of care and risk-adjusted mortality rates have consistently improved over the last 15 years despite the increasing risk profile of patients. There have been a consistent decline in overall case volumes and a three-fold increase in elderly cases.

Keywords: Coronary artery • Bypass surgery • Risk-adjusted mortality

ABBREVIATIONS

CABG	Coronary artery bypass graft
EuroSCORE	European System of Cardiac Operative Risk Evaluation
NACSA	National Adult Cardiac Surgery Audit
NHS	National Health Service
NICOR	National Institute for Cardiovascular Outcomes Research
PCI	Percutaneous coronary intervention
SCTS	The Society for Cardiothoracic Surgery in Great Britain and Ireland

INTRODUCTION

Society of Cardiothoracic Surgery (Great Britain and Ireland) (SCTS) was one of the first societies in the world to start reporting cardiac surgical outcome data in 1977 [1]. The data collection process evolved over time to include preoperative, operative and postoperative data [2, 3]. The data are collated by the units across the countries and submitted to National Institute of Cardiovascular Outcomes Research (NICOR). Publication of hospital-specific data started in 2001 followed by named surgeon-specific data for all consultant cardiac surgeons in 2004 following demands for increased transparency and public reporting [4–6].

The National Adult Cardiac Surgery Audit (NACSA, Surgery Audit) has expanded over the years to include all adult cardiac surgical procedures undertaken in National Health Service (NHS) cardiac surgery centres in the UK (England, Northern Ireland, Scotland and Wales) as well as 5 private hospitals and 1 from the Republic of Ireland. The data are reported on a yearly basis from April to March. The Adult Cardiac Surgery Audit participates within the Clinical Outcomes Publication programme, which publishes information on all hospitals and consultants undertaking adult cardiac surgery. It reports outcomes in the public domain on in-hospital survival along with the total number of procedures performed. This information is published on the Society for Cardiothoracic Surgery website, www.scts.org, and is produced by NICOR (previously published as Blue Books) and the preliminary report for the full cardiac activity for the period 2002–16 was previously published by The Society for Cardiothoracic Surgery in Great Britain and Ireland SCTS) [7].

The primary objective of this national report commissioned on behalf of SCTS was to generate an update about the status of coronary artery bypass graft (CABG) in the UK (hereafter refers to England, Northern Ireland, Scotland, Wales and Republic of Ireland) and identify trends over the years. The secondary objective was to analyse data reporting, quality, and outcomes for CABG. This evaluation was to assist in forecasting future trends and framing recommendations for database management and performance indicators.

PATIENTS AND METHODS

Adult cardiac surgery data submitted by UK NHS hospitals (including additional data from some private hospitals and hospitals in the Republic of Ireland) to NICOR for the period 2002–2016 were used. The dataset has been modified over time to remain contemporary and allow appropriate risk stratification. The summary data were extracted from the NACSA database, which is run by NICOR. No patient identifiable information was used as only the summary data were utilized for the analysis. General Data Protection Regulations were strictly followed for the use of all data. Need for individual consent and ethical approval for use of the summary data was waived. Data were presented as numerical, categorical, %, mean and standard deviation where appropriate. Mortality was recorded as death in hospital at any time after index CABG operation. Trends in activity and outcomes were analysed by financial year.

Data processing

Data processing, validation, and cleaning using reproducible algorithms and principles and other processes of the NACSA database have been previously described [8, 9]. Briefly, data entered locally by surgeons were validated at the unit level by database managers prior to upload via a web portal to NICOR. At this stage, further validation was performed according to logical rules and missing data reports were generated. The data are then forwarded to an academic healthcare informatics department for data cleaning as previously described. Duplicate records are removed, transcriptional discrepancies recoded and clinical and temporal conflicts resolved. The data cleaning is performed by the analyst responsible for the governance analysis in collaboration with surgeons and the audit manager. At this stage, and prior to analysis, data for the last 3 years are returned to each contributing hospital for local validation, and units update their records in the central registry repository where necessary. Basal risk imputation was used for missing data. Missing independent data were mapped to a value providing the smallest possible adjustment for risk and outcome data are mapped to

the worst-case scenario. Record linkages and active governance engagement with units were used to minimize missing data on outcome variables.

Risk adjustment

All mortality data were risk adjusted. Risk-adjusted mortalities were derived from logistic inference models for total hospital mortality based on similar earlier work by Hannan and Racz *et al.* [10, 11]. A hospital's actual measure of performance was compared with its expected performance, assuming the same model for all hospitals but using this hospital's own patient case mix to obtain the expected performance measure. Logistic European System of Cardiac Operative Risk Evaluation (EuroSCORE) was used for risk stratification as previously described with recalibration applied for governance [12–14]. EuroSCORE was found to significantly over-predict the risk of contemporary cardiac surgery and was superseded by EuroSCORE II after 2012 [15, 16]. This over-prediction of risk or 'miscalibration' is caused by a fall in the mortality associated with cardiac surgery despite a concurrent increase in the EuroSCORE-predicted risk over time. Dynamic modelling was applied to correct for a systematic caliberation drift in the cardiac surgical risk modelling over time.

RESULTS

Reporting volumes

Analysed summary data over the period 2002–2016 included 347 626 patient records: 282 385 patients with isolated CABG surgery, 61 109 with combined CABG and valve procedures, and 4132 with 'redo' CABG procedures. There has been an 18% expansion in the cardiac surgical consultant workforce contributing to the database and there has been a further 13% increase in the number of reporting units. The mean number of all CABG procedures reported per cardiac unit has, however, decreased from 720 procedures per year to 449 per year (37.6% reduction). Similarly, the average CABG volume reported per surgeon has decreased from 124 procedures per year to 74 per year (40.3% reduction) over this period.

Specific summary reports for CABG

Isolated CABG.

Case volume trends

The overall trends are given in Table 1. There was a 36.1% decrease in reported volumes for isolated CABG (Fig. 1). Ninety percentage of the cases were performed on pump in 2015–2016. This compared with almost 80% in 2008–2010.

The proportion of CABG surgery to the workload of units has also steadily and consistently declined over the years, from 66.6% in 2002–2003 to 41.7% in 2015–2016 (Fig. 2). Among isolated CABG procedures, elective surgery decreased by 51.6% in overall numbers (73.0–53.5% of average unit isolated CABG caseload) whereas urgent surgery increased by 11.4% in overall numbers (24.4–42.6% of average unit isolated CABG caseload) to provide partial compensation only. These changes resulted in a decline in overall numbers. There were no changes in emergency (~2% of isolated CABG) or salvage (~0.2% of isolated CABG) cases. The proportional caseload remained unchanged for patients aged <70 years and for those aged 70–80 years (Fig. 2).

Surgical risk profile

The mean patient age for isolated CABG procedures for the period 2002–2016 was 65.7 years. This did not change much over the years.

The mean logistic EuroSCORE for elective (3.1) and urgent CABG surgery (5.9) remained unchanged. The overall mean logistic EuroSCORE for isolated CABG was 4.6. The mean logistic EuroSCORE for emergency and salvage cases was 23.2 and 35.7, respectively. About 2.2% of patients presented with unstable angina and 17.9% (2016) had a recent myocardial infarction compared with 13.5% (2002). The incidence of ischaemic septal defects and critical preoperative state (defined as cardiorespiratory instability requiring balloon pump, inotropic or vasopressor support, or ventilation) remained stable at around 0.2% and 5.0%, respectively (Fig. 10). Five percentage of patients had poor

Table 1: Overall trends for the period of study (2002–2016) for isolated coronary artery bypass surgery in UK

Year	Cases	Mean age	Logistic EuroSCORE	LOS	Mortality (%)	Overall percentage
2002/2003	23 605	64.38	3.8	7	2.11	66.61
2003/2004	24 335	64.94	4.13	7	2.20	63.98
2004/2005	24 565	65.18	4.16	7	2.20	62.82
2005/2006	24 316	65.36	4.24	7	1.84	59.62
2006/2007	22 233	65.77	4.6	7	2.01	57.29
2007/2008	23 407	65.7	4.64	6	1.59	57.11
2008/2009	22 159	66.03	4.59	6	1.74	53.49
2009/2010	20 156	66.13	4.7	6	1.83	52.11
2010/2011	18 616	66.22	4.76	6	1.75	50.80
2011/2012	16 895	66.01	4.83	6	1.54	45.92
2012/2013	16 210	66.13	5.07	7	1.46	44.37
2013/2014	15 712	66.03	4.98	6	1.60	42.11
2014/2015	15 596	65.92	4.89	6	1.24	41.74
2015/2016	15 078	66.14	4.58	6	1.04	41.69
Overall mean	20 205	65.71	4.57	6	1.73	52.83

EuroSCORE: European System of Cardiac Operative Risk Evaluation.

Table 2: Percentage improvements in the risk-adjusted mortality rates for the years 2002–2003 and 2015–2016

	2002–2003			2015–2016		
	Expected mortality (%)	Observed mortality (%)	Reduction (%)	Expected mortality (%)	Observed mortality (%)	Reduction (%)
Isolated CABG						
Elective	2.9	1.5	48.3	2.8	0.6	78.6
Urgent	5.0	3.1	38.0	5.5	1.3	76.4
Emergency	18.7	11.7	37.4	26.0	6.6	74.6
Overall	3.8	2.1	44.8	4.6	1.0	78.3
CABG + valve	9.9	7.9	20.2	10.6	4.0	62.3
Redo CABG	9.1	7.1	22.0	12.6	7.7	38.9

CABG: coronary artery bypass graft.

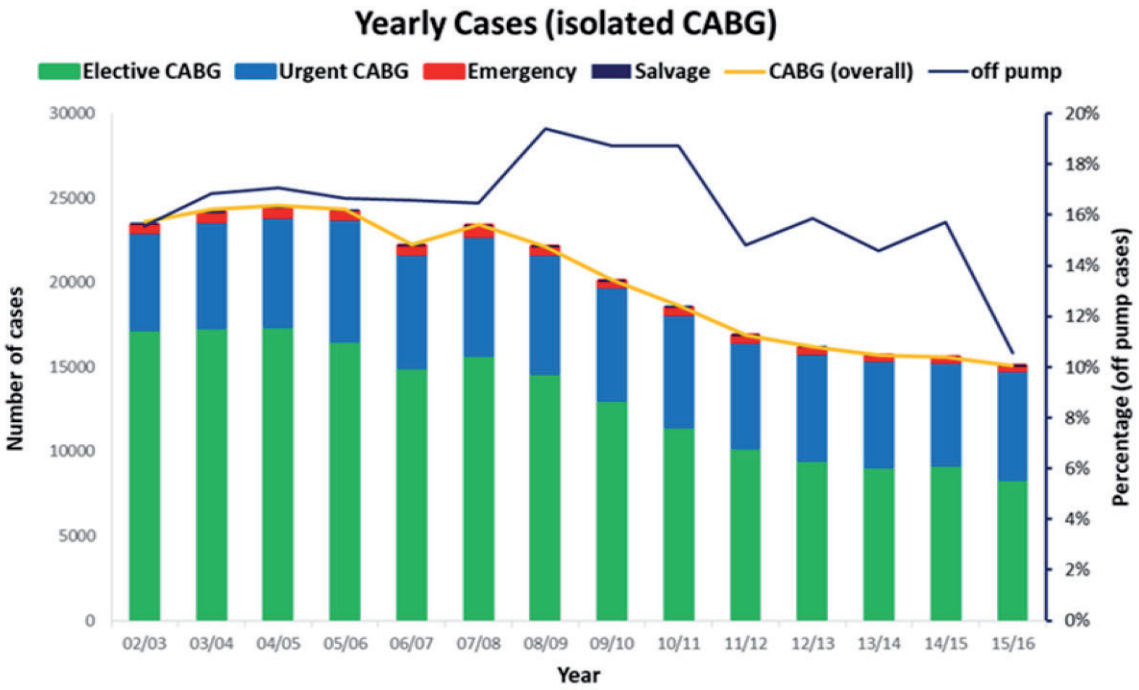

Figure 1: Annual case volumes for isolated coronary artery bypass graft and off-pump coronary artery bypass graft procedures performed in the UK and Ireland for the period 2002–2016.

left ventricular function (ejection fraction <30%) at presentation, and these figures remained largely unchanged over the period reviewed.

Outcomes and quality

Arterial grafting. Use of the left internal thoracic artery remained high at >90% in the latter decade compared with around 80% in 2002–2003. The mean number of grafts used was 3, and this did not change significantly. Use of >1 arterial graft, however, declined from 18.3% to 10.2%. Off-pump CABG also declined from 15.6% to 10.6%. It peaked in 2010–2011, when a fifth of all CABG procedures was performed off pump.

Expected versus observed mortality. There was a general improvement in in-hospital mortality across all groups (Fig. 3). Observed mortalities were consistently less than half of expected mortalities, and there was improvement for all operative procedures over the period reviewed (Table 1 and 2). Overall mortality for isolated CABG surgery (2016) was 1.0% and only 0.6% for elective operations.

Length of hospital stay. The mean length of stay for isolated CABG patients overall was 6 days (elective: 6 days, urgent: 7 days, emergency: 8 days). This did not change over the period reviewed. For octogenarians, the mean length of stay was 8 days compared with 6 days for patients aged <70 years.

Combined CABG and valve procedures. The mean age for patients undergoing combined CABG and valve procedures was 72.0 years, which was just over 5 years older than for isolated CABG. The proportional number of cases remained fairly constant at 10–12% of overall activity for units over the period, unlike that for isolated CABG. The mean logistic EuroSCORE was 10.3. The length of stay was

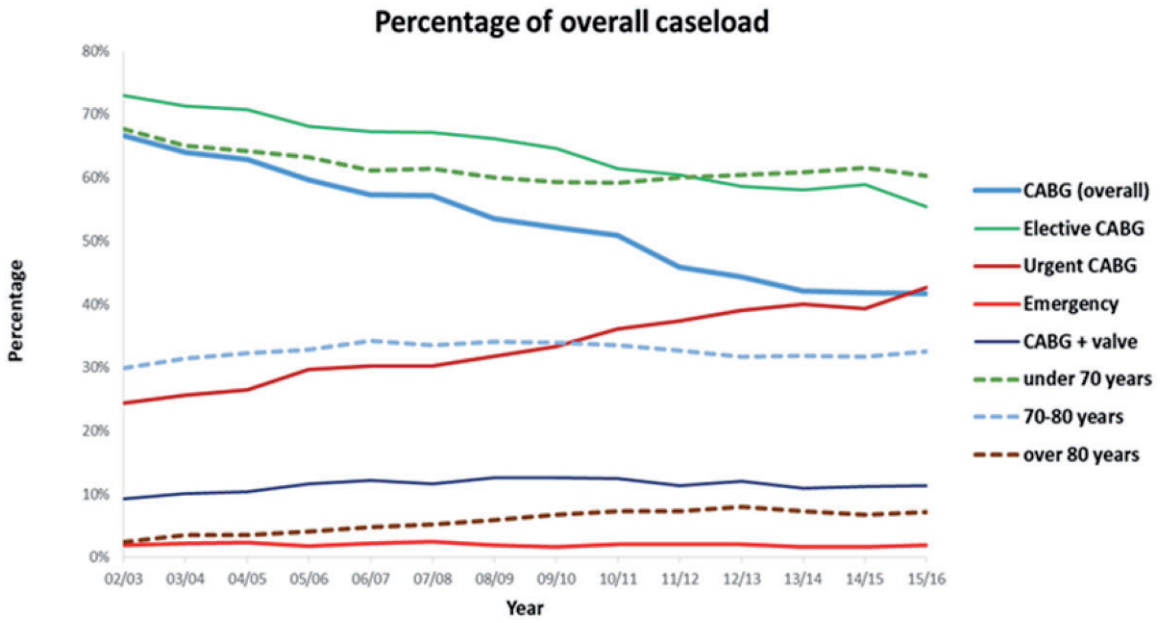

Figure 2: Percentage of unit case volume and age group-specific caseload for the period 2002–2016 in UK and Ireland. Percentages for coronary artery bypass graft (overall) are with reference to entire unit workload and represented as percentages on the *x*-axis.

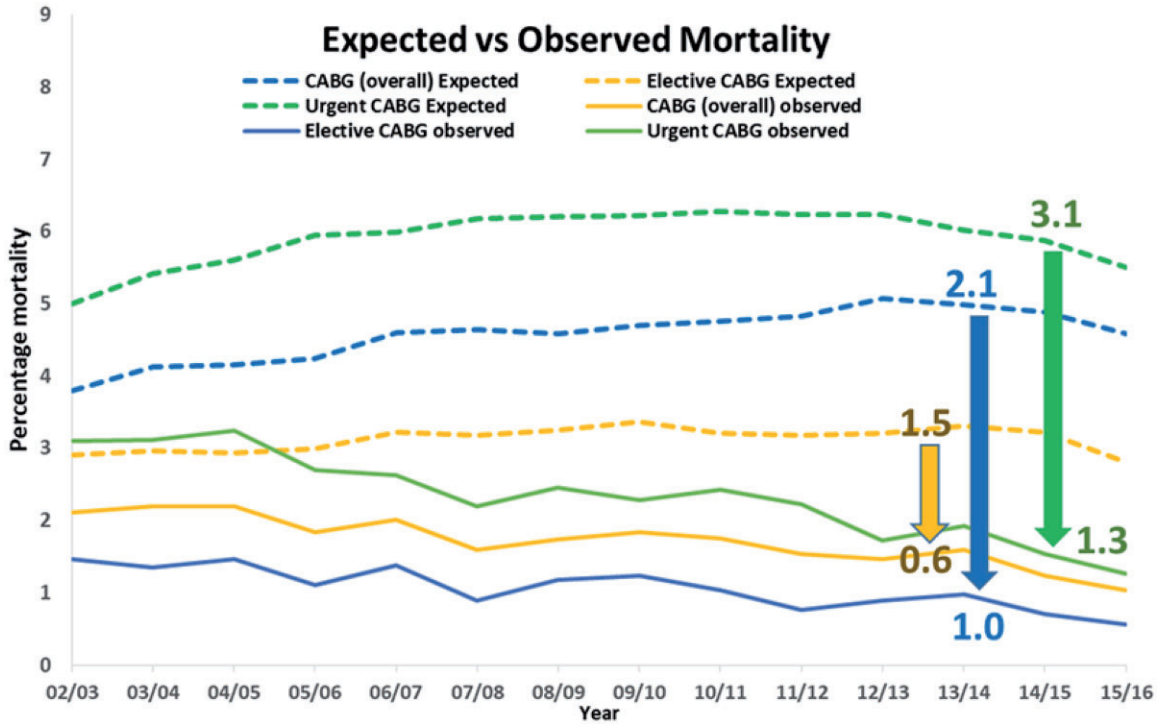

Figure 3: Expected and observed in-hospital risk-adjusted mortality rates for different coronary artery bypass graft procedures for the period 2002–2016 in the UK and Ireland.

more than for other groups at a mean of 9 days over the period.

Octogenarians. The mean age for octogenarians was 82.3 years. Their proportional case numbers increased almost three-fold to 7.2% by 2015–2016. The mean logistic EuroSCORE was 11.8 and the risk profile remained unchanged over the period. The observed mortality rate for octogenarians significantly decreased to less than half over the period (7.9% in 2003 to 3.5% in 2016). However, this is still 5–7 times higher than the observed mortality in other age groups over the same period.

CABG in emergency and salvage cases. The proportional numbers for emergency and salvage cases have remained the same (around 2% and 0.2% respectively). However, the total numbers decreased by a third over the period reviewed, consistent with the declining numbers for isolated CABG. The expected and observed mortality rates for salvage cases remained high but observed mortality improved for emergency cases (from 11.7% in 2002–2003 to 6.6% in 2015–2016) despite a higher predicted mortality rate (18.7% vs 26.0%).

Redo CABG. Only 65 redo CABG operations were performed in 2015–2016 (0.2% of overall activity) compared with almost 500 cases in 2002–2003. The surgical risk profile of this referral group has increased substantially (logistic EuroSCORE 9.1 in 2002–2003 but 12.6 in 2015–2016). The observed mortality rate was 6.5% (almost 7 times the current mortality rate for isolated CABG), which was still half of the expected mortality rate in this group.

DISCUSSION

These trends support the view that the number of isolated CABG cases may continue to decline owing to advances in percutaneous coronary interventions (PCIs), improving stent patency rates and broader indications for PCI use in left main stem and triple-vessel disease. At the same time, PCI volumes, which have increased at a rate of 15–20% each year over the last 15 years, could continue to increase. British Cardiovascular Intervention Society data show that the number of PCIs performed each year has more than doubled, from 44 913 in 2002 to 100 483 in 2016 [17]. The PCI rates over this period increased from 759 to 1,530 per million population. The number of PCI centres increased from 64 to 119. In 2016, 6.7 PCIs were performed for each isolated CABG procedure. This compared with only 1.3 PCIs per isolated CABG procedure in 2000.

According to the Office for National Statistics, the population has grown by 9.6% over the period of this review with an annual growth of ∼0.7% per year during the last decade. For the similar future period, there is a projected growth of up to 23% for octogenarians [18]. Based on assumed linear trends from last 14 years, the percentage activity for octogenarians in a typical cardiac unit is likely to rise from the present 7.2% to almost 12% over the next 15 years. Furthermore, the present life expectancy at age 65 (the mean age for isolated CABG patients) is 20.9 years for women and 18.6 years for men (Office for National Statistics, 2017 data). This will present increasing challenges in both the potential provision and the cost of care. For older patients, length of stay is likely to increase, and postoperative recuperation will need reinforcement of referral and peripheral non-surgical rehabilitation centres and social care.

The volume of combined CABG and valve cases has remained steady over the last decade, and this trend might continue in the future. There is a possibility, however, that with rapid expansion of transcatheter valve implantation services, the proportion of older patients will decrease in this subgroup. Similarly, redo CABG cases will continue to decline as most patients are now referred for PCI. There is likely to be a decreasing pool of surgeons who have the experience of redo CABG.

The mortality rates across all groups are some of the lowest in the world despite increasing age, risk profile, and frailty of patients and decreasing experience of the consultant workforce. Further improvements in mortality will probably be very difficult to achieve. Efforts would need to be directed to further reducing morbidity and length of stay and increasing efficiencies elsewhere.

Although this report did not analyse the direct impact of comorbidities such as diabetes, hypertension, smoking and obesity on outcomes, other national databases have reported increasing comorbidities in population groups. Emphasis on preventive strategies can possibly further reduce the length of stay and morbidity of CABG to increase efficiencies and reduce associated healthcare costs.

Quality outcome measures captured in the database need to include postoperative parameters like blood volume usage, length of ventilation, length of stay on the intensive care unit, readmission to the intensive care unit, readmission after hospital discharge, use of antiplatelet agents on day 1 after CABG surgery, antiplatelet drug therapy at discharge and statins at discharge. The surgical and intensive care databases remain separate in UK units, and these need to be merged to capture and report these data points. Historically, morbidity and complications were not as well recorded in the database, and completeness was not good enough over this period to draw valid conclusions. This has recently improved, and the 2018–2019 National Cardiac Audit Programme report specifically reports morbidity and waiting times for CABG surgery.

These results are among the best in the world and compare favourably with other databases from Europe, Oceania and North America [19–21]. Other databases have reported similar trends in increasing age and risk profile of patients, decreasing case volumes at the expense of PCI and overall improving mortality. The Society of Thoracic Surgeons Adult Cardiac Surgery Database: 2018 Update on Outcomes and Quality from all 50 states in the US, 10 sites in Canada and 21 participants in 7 other countries reported an operative mortality rate of 2.2% and a mean length of stay of 6.9 days for 156 931 isolated CABG cases in 2016. Similar trends were observed in the North American STS database (2006–2016). CABG patients were increasingly more likely to be diabetic (49% in 2016) and of non-elective status (63% in 2016) and to have undergone a prior PCI (31% in 2016). The frequency of any degree of congestive heart failure increased ∼7% during the interval. Off-pump CABG was used in only 13% of procedures. The SWEDEHEART (Swedish Web-system for Enhancement and Development of Evidence-based care in Heart disease Evaluated According to Recommended Therapies) 2016 annual report from the Swedish Cardiac Surgery Registry similarly showed a decreasing trend in overall case numbers with the lowest volume of cases recorded for 2016 over a period from 1992 to 2016 (40% reduction in overall case volumes) [22]. PCI accounted for 70–90% of all coronary interventions in the SWEDE report after exclusion for diagnostic PCIs and ST elevation myocardial infarction cases. These changes were despite the recommendations and guidelines for surgical revascularization by the European Society of Cardiology/European Association for Cardio-Thoracic Surgery and the American College of Cardiology/Society of Thoracic Surgeons. There was a five-fold increase in the octogenarian population over the period. The reported operative mortality rate was 1.6% with a mean length of stay of 7 days. The 2018 report of the German Society for Thoracic and Cardiovascular Surgery showed similar trends in increasing age and decreasing overall case volumes.

At a national level, a centralized healthcare system (the NHS) with national priorities and funding clearly identified, strong General Practice and Clinical Commissioning networks that are part of the NHS, primary prevention, and patient education for programmes in diabetes, hypertension and hypercholesterolaemia and life style modification, strengthening of perioperative care and rehabilitation community care networks have all contributed to the improvement of these results over the duration of the study. An established framework for multidisciplinary teams (Heart Teams) in cardiac centres has also helped patient selection for better outcomes. Professional UK cardiac societies (British Cardiovascular Iintervention Society, Society of Cardiothoracic Surgery, British Cardiovascular Society) are involved with National Institute of Healthcare and Excellence to set guidelines for best practice. At present, outcomes are measured based on objective standard clinical metrics. Patients receiving care may not directly relate to these. Care pathways need to address this lacuna for quality reporting by addition of 'patient-reported outcomes' at various time intervals in the care pathway [23]. The Care Quality Commission, the independent regulator of health and social care in England, monitors institutions for safety, effectiveness, and care in addition to responsiveness and leadership to maintain the highest levels of service delivery [24]. Patient feedback and 'friends and family' tests have been used extensively to directly gauge the quality of patient care in the NHS. These direct patient-reported outcome measures need to be developed specifically for CABG surgery.

Quality of care and outcomes for patients treated by CABG surgery, as measured by mortality, have improved consistently over the last 15 years despite increasing patient risk profiles. There is a growing trend towards inpatient urgent referrals for surgical revascularization as seen by decreasing elective caseloads and increasing urgent cases. The demographics of patients, the profile of service delivery and training needs are likely to change substantially over the next 15 years. These would present increasing challenges for the cost and delivery of care to increasingly older patients.

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Author contributions

Sunil K. Ohri: Conceptualization; Formal analysis; Investigation; Methodology; Validation; Writing–original draft; Writing–review & editing. **Umberto Benedetto:** Formal analysis; Supervision. **Suvitesh Luthra:** Formal analysis; Investigation; Methodology; Supervision; Writing–original draft; Writing–review & editing. **Stuart W. Grant:** Conceptualization; Formal analysis; Investigation; Methodology; Supervision; Writing–review & editing. **Andrew T. Goodwin:** Conceptualization; Formal analysis; Methodology; Supervision; Writing–review & editing. **Uday Trivedi:** Supervision; Writing–review & editing. **Simon Kendall:** Conceptualization; Supervision; Validation; Writing–review & editing. **David P. Jenkins:** Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Supervision; Validation; Writing–review & editing.

Reviewer information

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