Training residents in off-pump coronary artery bypass surgery: A 14-year experience

Michele Murzi, MD, Massimo Caputo, MD, Giuseppe Aresu, MD, Simon Duggan, FRCS, and Gianni D. Angelini, FRCS

Objective: Off-pump coronary artery bypass grafting (OPCAB) is an established procedure in many cardiothoracic centers. For it to be widely applicable, however, teaching methods must be developed for surgical trainees. Early clinical outcomes and long-term survival of patients who underwent OPCAB at our institution by trainees supervised and unsupervised were compared with those of patients whose procedures were performed by senior surgeons. To evaluate evolution of training, outcomes were analyzed according to 3 different periods (1996–1999, 2000–2004, 2005–2009) and trainee seniority level.

Methods: This was a retrospective, observational cohort study of prospectively collected data from 5566 consecutive patients who underwent isolated OPCAB performed by trainees (1589, 28.6%; 1111 supervised, 478 unsupervised) and by senior surgeons (3977, 71.4%).

Results: Patients of senior surgeons were more likely to have left ventricular dysfunction ($P = .001$), peripheral vascular disease ($P = .05$), more extensive coronary artery disease ($P = .001$), and higher EuroSCOREs than patients of trainees. In addition, trainees were less likely to have performed urgent operations ($P = .02$) or re-operations ($P = .03$) but more likely to have operated on patients with previous percutaneous coronary intervention ($P = .006$). Early clinical outcomes and long-term survival were similar between groups and not related to trainee seniority, level of supervision by senior surgeon, or period during which training took place.

Conclusions: OPCAB is a safe and reproducible surgical technique that can be taught successfully to cardiothoracic trainees. Clinical outcomes are unrelated to level of supervision or seniority of trainees. (*J Thorac Cardiovasc Surg* 2012;143:1247-53)

Supplemental material is available online.

Residents in cardiothoracic surgery have recently been confronted with the need to gain experience in off-pump coronary artery bypass grafting (OPCAB) as an alternative approach to coronary revascularization. Senior cardiac surgeons are fully aware of the importance of training the next generation of surgeons, but at the same time they have an overriding responsibility to ensure patients' safety and good clinical outcomes. Various academic centers have evaluated the safety of training residents to perform cardiac surgery.¹⁻⁷ Limited information, however, is available on the impact of training in OPCAB for an

extended period and in particular on the effect of seniority level of trainees on clinical outcomes. At our institution, OPCAB has evolved rapidly in the last 14 years, and cardiothoracic trainees have been exposed to this new technique as an integral part of their surgical program.^{3,8-10} The purpose of this study was to compare the performances of trainees, supervised or unsupervised, with those of senior surgeons with respect to early clinical outcome and long-term survival in patients undergoing OPCAB operations. Finally, to evaluate the evolution of training, outcomes were then analyzed according to 3 different time periods (1996–1999, 2000–2004, 2005–2009) and the seniority level of trainees.

MATERIALS AND METHODS

Data Collection

The study was approved by the clinical audit committee of the University Hospitals Bristol Foundation Trust to meet ethical and legal requirements, and individual consent was waived. This was a retrospective, observational, cohort study of prospectively collected data from consecutive patients who underwent isolated OPCAB operations at the Bristol Heart Institute between April 1996 and November 2009. The data collection form was entered into a database (Patient Analysis & Tracking System; Dendrite Clinical Systems, London, UK) and included 5 sections that were filled in consecutively by anesthetists, surgeons, and intensive care unit, high-dependency unit, and ward nurses. The resulting base sample contained detailed clinical information on 5566 patients, of whom 3977 (71.4%) were operated on by senior surgeons and 1589 (28.6%) were operated on by

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Address for reprints: Gianni D. Angelini, FRCS, Bristol Heart Institute, Bristol BS2 8HW, United Kingdom (E-mail: G.D.Angelini@bristol.ac.uk).

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Abbreviation and Acronym

OPCAB = off-pump coronary artery bypass grafting

cardiothoracic trainees (478 [30%] unsupervised). Early clinical outcome and long-term survival were analyzed comparing the operations performed by trainees and senior surgeons. To evaluate the evolution of the training in OPCAB, operations performed by trainees were divided into 3 subgroups according to the periods in which they were carried out (1996–1999, 2000–2004, 2005–2009). Finally, clinical outcomes were evaluated according to the seniority level of trainees in the UK specialist training program in cardiothoracic surgery or equivalent (Calman year 1–6).

Training Program

The Bristol Heart Institute is a regional cardiac surgical center and part of the UK national training program. The UK cardiothoracic training program is conducted over a 6-year period, and admission to it requires successful completion of a 2-year basic surgical training program. Two to three National Training Numbers were allocated to our unit at any time during the study period. In addition, 4 to 6 clinical research or service clinical fellows completed the surgical rota. Seniority level of trainees with official training numbers was defined according to year of training in the UK specialist program in cardiothoracic surgery (Calman year 1–6). For trainees who did not have an official UK training number (research or clinical fellows), the level of experience was retrospectively reviewed and assigned according to equivalent criteria.

Definitions

In-hospital mortality included all deaths within 30 days of operation, irrespective of where the death occurred, and all in-hospital deaths after 30 days among patients who had not been discharged after the index operation. Perioperative myocardial infarction, pacing, arrhythmias, and inotropic requirement were recorded and defined as previously reported elsewhere.¹¹ Pulmonary complication included chest infection, ventilation failure, reintubation, and tracheostomy. Postoperative blood loss was defined as total chest tube drainage. Neurologic complications included permanent and transient strokes. Renal complications included acute renal failure, defined as the requirement of hemodialysis or an elevated creatinine level (>200 mmol/L). Infective complication included septicemia and sternal and leg wound infections, defined by positive culture and requirement for antibiotic therapy.¹¹

The completeness of revascularization was identified by comparing the number of distal anastomoses with the number of diseased coronary systems observed on the preoperative angiogram. If the number of distal anastomosis performed equaled the total number of coronary systems with significant disease, the completeness of revascularization index was 1. Patients who had more distal anastomoses performed than the number of vessels with angiographically significant diseases had a completeness of revascularization index greater than 1 and were classified as having a complete revascularization.

A supervised operation performed by a trainee was defined as one in which the senior surgeon was scrubbed in and acted as first assistant. An unsupervised operation was defined as one in which the trainees had reviewed the case and planned the surgical strategy with the senior surgeon who was not scrubbed in at the operating theater but was available, generally in his or her office.

Patient Survival

Patient records were linked to the National Strategic Tracing Service administrative mortality database, which records all the deaths in the United Kingdom. To establish current vital status, patients were matched against

the National Strategic Tracing Service for patient name, National Health Service unique number, date of birth, and post code. Importantly, the cause of death was neither considered nor available in this study; thus the study compared all-cause mortality among the groups.

Anesthetic and Surgical Technique

Anesthetic technique consisted of propofol infusion at 3 mg/(kg · h) combined with alfentanil hydrochloride (INN alfentanil) infusion at 0.5 to 1 μ g/(kg · min). Neuromuscular blockade was achieved by 0.1 to 0.15 mg/kg pancuronium bromide or vecuronium, and the lungs were ventilated to normocapnia with air and oxygen (45% to 50%). Heparin (100 IU/kg) was administered before the start of the first anastomosis to achieve an activated clotting time of 250 to 350 seconds. On completion of all anastomoses, protamine was given to reverse the effect of heparin and return the activated clotting time to preoperative levels.

The method of exposure to perform the anastomoses consisted of a technique that has been previously reported elsewhere.¹² Stabilization was achieved with a reusable stainless steel stabilizer (Abbey Surgical Limited, Mitcham, UK) developed at our institution. Since the beginning of 1999, all anastomoses have been performed with an intracoronary shunt to ensure distal perfusion (Flothru Biovascular Inc, St Paul, Minn). Postoperative management was according to standard protocols as previously detailed elsewhere.¹³

Statistical Analysis

All statistical analysis was performed with SPSS statistical software (version 15.0; BM Corporation, Armonk, NY) and StatsDirect (version 2.7.2; StatsDirect Ltd, Cheshire, UK). Continuous data were expressed as mean $\pm$ SD, and categorical data were expressed as percentages. The Kolmogorov-Smirnov test was used to check for normality of data before further analysis. Differences between the groups were compared with the use of the Student *t* test or with the analysis of variance where appropriate for continuous variables and with the χ^2 test where appropriate for categorical variables. Nonparametric methods were used for variables that were not normally distributed. Stepwise multivariable regression analysis was used to identify independent risk factors for in-hospital mortality, with a significance level of .05 used for both entry and selection. Similarly, multivariable Cox proportional hazard modeling was used to identify independent risk factors for all-cause mortality. Covariates under consideration for all models were all baseline characteristics (as listed in Table 1), the grade of the first operator (senior surgeon and trainees), and the completeness of revascularization. Overall survival was estimated by using the Kaplan-Meier method and was expressed as a percentage. All reported *P* values are 2-sided.

RESULTS

Trainees Versus Senior Surgeons

Between April 1996 and November 2009, a total of 5566 OPCAB procedures were performed at our institution, of which 3977 (71.4%) were done by senior surgeons ($n = 9$) and 1589 (28.6%) were done by trainees ($n = 15$; Table 1). Of the operations performed by the trainees, 478 (30%) were unsupervised. Preoperative patient characteristics are shown in Table 1 and were similar between groups with respect to sex, diabetes mellitus, chronic obstructive pulmonary disease, Canadian Cardiovascular Society class, left main stem stenosis, and intra-aortic balloon pump requirement. Trainees operated on patients with a significantly lower proportion of left ventricular dysfunction ($P = .001$), lower proportion of peripheral vascular disease ($P = .05$), less extensive coronary artery disease ($P = .001$), and thus a lower EuroSCORE ($P = .001$). In addition, trainees

TABLE 1. Patient characteristics for operations performed by senior surgeons and by supervised and unsupervised trainees

	Senior surgeons (n = 3977)	Supervised trainees (n = 1111)	Unsupervised trainees (n = 478)	P value
Age (y, mean $\pm$ SD)	65.4 $\pm$ 9	64.6 $\pm$ 9	65.2 $\pm$ 9	.03
Body mass index (kg/m ² , mean $\pm$ SD)	28.2 $\pm$ 5.1	27.9 $\pm$ 4.8	28 $\pm$ 4.1	.3
Female (no.)	749 (18.8%)	196 (17.6%)	97 (20.3%)	.4
Canadian Cardiovascular Society class (mean $\pm$ SD)	2.4 $\pm$ 1.1	2.4 $\pm$ 1.1	2.5 $\pm$ 0.1	.3
New York Heart Association functional class (mean $\pm$ SD)	2 $\pm$ 0.8	2 $\pm$ 0.7	1.9 $\pm$ 0.8	.01
Diabetes mellitus (no.)	831 (20.8%)	214 (19.3%)	106 (22.2%)	.3
Hypertension (no.)	2814 (70.8%)	771 (69.4%)	326 (68.2%)	.4
Cerebrovascular disease (no.)	335 (8.4%)	78 (7%)	28 (5.9%)	.06
Vascular disease (no.)	405 (10.2%)	88 (8%)	43 (9%)	.05
Chronic obstructive pulmonary disease (no.)	427 (10.7%)	127 (11.4%)	54 (11.3%)	.7
History of atrial fibrillation (no.)	135 (3.3%)	33 (3%)	12 (2.5%)	.5
Creatinine (mmol/L, mean $\pm$ SD)	109 $\pm$ 33	110 $\pm$ 36	109 $\pm$ 44	.5
Ejection fraction <30% (no.)	185 (4.6%)	26 (2.3%)	14 (2.9%)	.001
Previous myocardial infarction (no.)	1915 (48.3%)	511 (46.2%)	216 (45.2%)	.2
Previous percutaneous coronary intervention (no.)	253 (6.3%)	100 (9%)	28 (5.9%)	.006
Reoperative surgery (no.)	64 (1.6%)	7 (0.6%)	5 (1%)	.03
Preoperative intra-aortic balloon pump use	14 (0.3%)	3 (0.3%)	4 (0.4%)	.8
Urgent operation (no.)	1828 (45.9%)	461 (41.5%)	224 (46.9%)	.02
EuroSCORE (no.)	3.9 $\pm$ 2.3	3.5 $\pm$ 2	3.6 $\pm$ 2	.001
Left main disease (no.)	918 (25.3%)	240 (21.6%)	117 (24.5%)	.4
Coronary artery disease (vessels, mean $\pm$ SD)	2.5 $\pm$ 0.6	2.4 $\pm$ 0.7	2.3 $\pm$ 0.7	.001

were less likely to have performed urgent operations ($P = .02$) or reoperative surgery ($P = .03$); however, they did operate on more patients with previous percutaneous coronary intervention ($P = .006$). Thirty patients in the senior surgeons group (0.8%), 5 patients in the supervised trainees group (0.5%), and 2 patients (0.4%) in the unsupervised group had to undergo conversion to conventional coronary artery bypass grafting with cardiopulmonary bypass for hemodynamic or electrical instability. Even though the group operated on by trainees received fewer coronary grafts and had a lower completeness of revascularization

index, no difference was noted between the groups in the rate of completeness of revascularization ($P = .7$).

Postoperative morbidity and mortality are shown in Table 2. In-hospital mortalities were 1.3% in the senior surgeons group, 1.2% in the supervised trainees group, and 0.8% in the unsupervised trainees group ($P = .7$). The incidences of respiratory complications, neurologic complications, renal complications, inotropic use, and chest infection were similar among groups. Total blood loss, intubation time, and intensive care unit and hospital stays were similar among groups.

TABLE 2. Operative and postoperative results of operations performed by senior surgeons and by supervised and unsupervised trainees

	Senior surgeons (n = 3977)	Supervised trainees (n = 1111)	Unsupervised trainees (n = 478)	P value
Distal anastomoses (mean $\pm$ SD)	2.5 $\pm$ 0.8	2.4 $\pm$ 0.7	2.3 $\pm$ 0.7	.001
Completeness of revascularization index (mean $\pm$ SD)	1.03 $\pm$ 0.23	1.01 $\pm$ 0.22	1.02 $\pm$ 0.27	.01
Complete revascularization (no.)	3486 (87.6%)	981 (88.3%)	424 (88.7%)	.7
Conversion to cardiopulmonary bypass (no.)	30 (0.8%)	5 (0.4%)	2 (0.3%)	.1
In-hospital mortality (no.)	53 (1.3%)	13 (1.2%)	4 (0.8%)	.7
Reoperation for bleeding (no.)	71 (1.7%)	21 (1.9%)	14 (2.9%)	.2
Blood loss (mL, mean $\pm$ SD)	784 $\pm$ 457	787 $\pm$ 418	825 $\pm$ 477	.2
Perioperative myocardial infarction (no.)	101 (2.5%)	37 (3.2%)	15 (3.1%)	.4
Postoperative Inotropes (no.)	1559 (39.2%)	453 (40.8%)	175 (36.6%)	.3
Postoperative intra-aortic balloon pump (no.)	88 (2.2%)	12 (1%)	9 (1.7%)	.4
Stroke (no.)	8 (0.2%)	5 (0.5%)	0 (0%)	.1
Transient ischemic attack (no.)	15 (0.3%)	2 (0.2%)	0 (0%)	.2
Renal complications (no.)	280 (7%)	68 (6.1%)	37 (7.7%)	.4
Pulmonary complications (no.)	481 (12%)	142 (12.8%)	63 (13.2%)	.7
Intensive care unit stay (d, mean $\pm$ SD)	1.6 $\pm$ 3.6	1.5 $\pm$ 2.7	1.5 $\pm$ 2.2	.5
Hospital stay (d, mean $\pm$ SD)	7.7 $\pm$ 6.5	7.9 $\pm$ 6.5	7.7 $\pm$ 5.3	.8

FIGURE 1. Kaplan-Meier survival curves for operations performed by senior surgeons, supervised trainees, and unsupervised trainees.

In multivariate analysis with logistic regression modeling, trainee as operator (supervised or unsupervised) was not independently associated with in-hospital mortality (odds ratio, 0.73; 95% confidence interval, 0.4–1.3; $P = .3$).

Of the 5566 patients undergoing OPCAB operations, 5496 patients were discharged alive (98.5%). Among these, 5396 (98.7%) were successfully linked to the National Strategic Tracing Service administrative mortality database and were included in the longitudinal analyses (3899 senior surgeons and 1470 trainees performed these cases). Median follow-up was 5.1 ± 3.2 years for the senior surgeons, 5 ± 3.1 years for the supervised trainees group, and 5.2 ± 3.1 for the unsupervised trainees group ($P = .3$). There were 782 late deaths during the study period (14.5%). The Kaplan-Meier event-free survival curves (Figure 1) show no significant difference between the groups at 1, 5, and 10 years: senior surgeons had event-free survivals of 96.5%, 87.9%, and 71.9%, respectively; supervised trainees had event-free survivals of 97.8%, 90.6%, and 73.7%; and unsupervised trainees had event-free survivals of 97.9%, 88.8%, and 76.9% (log-rank $P = .07$).

In the multivariate Cox proportional hazards model, trainee as operator was not associated with long-term survival (hazard ratio, 1.034; 95% confidence interval, 0.867–1.232; $P = .712$). The variables that emerged as independent predictors of late death are shown in Table E1.

Time Period Analysis

The operations performed by trainees during the 3 chosen time periods increased progressively and were 128 (1996–1999), 626 (2000–2004), and 835 (2005–2009; Figure 2). Preoperative characteristics are reported by time period in Table 3. We observed a significant increase in the number of unsupervised operation performed by trainees ($P = .001$), as well as a significant change in the preoperative

FIGURE 2. Breakdown of off-pump coronary artery bypass grafting operations performed by senior surgeons, supervised trainees, and unsupervised trainees (1996–2009).

risk profile of the patients operated on by trainees, with increases in mean age ($P = .001$), New York Heart Association class ($P = .001$), prevalence of diabetes ($P = .007$), prevalence of previous percutaneous coronary intervention ($P = .001$), EuroSCORE ($P < .001$), and extent of coronary artery disease ($P = .001$). There was also a significant progressive increase in the mean number of grafts per patient ($P = .001$). Postoperative mortality and morbidity, however, remained similar during the study period (Table 4).

Seniority Level of Trainees

The number of operations performed and the preoperative characteristics of patients operated on by trainees according to their seniority (Calman year) are reported in Table E2. No significant differences were noted in terms of preoperative characteristics of the patients. Clinical outcomes are shown in Table 5. In-hospital mortality ranged from 0% (year 1) to 2.8% (year 3; $P = .751$). The incidences of respiratory, cardiac, neurologic, pulmonary and renal complications and the duration of hospital stay remained similar across all the Calman year groups.

DISCUSSION

This study summarizes a 14-year experience at a single institution in training cardiothoracic residents to perform OPCAB procedures. There are 2 main findings. (1) Multi-vessel OPCAB is a safe and reproducible technique that can be taught successfully to cardiothoracic surgical trainees. (2) Early clinical outcomes and long-term survival were not related to the trainee's seniority, the level of senior surgeon supervision, or the different time periods of development of OPCAB at our institution.

The rapid evolution of OPCAB in recent years has resulted in its widespread popularization as an alternative to conventional coronary artery bypass grafting with cardiopulmonary bypass. Residents in cardiothoracic surgery have been confronted with the need to gain experience in this novel approach to myocardial revascularization.¹⁴

TABLE 3. Patient characteristics for operations by trainees broken down by time period

	1996–1999 (n = 128)	2000–2004 (n = 626)	2005–2009 (n = 835)	P value
Age (y, mean $\pm$ SD)	62.5 $\pm$ 9.7	63.8 $\pm$ 9.2	65.8 $\pm$ 9.4	.001
Body mass index (kg/m ² , mean $\pm$ SD)	28.1 $\pm$ 4	27.8 $\pm$ 4	28 $\pm$ 5	.536
Female (no.)	29 (22.6%)	120 (19.1%)	144 (82.7%)	.282
Canadian Cardiovascular Society class (mean $\pm$ SD)	2.9 $\pm$ 0.8	2.6 $\pm$ 1	2.2 $\pm$ 1	.001
New York Heart Association class (mean $\pm$ SD)	1.9 $\pm$ 0.7	2.1 $\pm$ 0.8	2.2 $\pm$ 0.8	.001
Diabetes (no.)	18 (14%)	110 (17.5%)	192 (22.9%)	.007
Hypertension (no.)	68 (53.1%)	391 (62.5%)	638 (76.4%)	.01
Cerebrovascular disease (no.)	7 (5.5%)	30 (4.8%)	69 (8.3%)	.02
Vascular disease (no.)	12 (9.4%)	54 (8.6%)	65 (7.8%)	.7
Chronic obstructive pulmonary disease (no.)	14 (10.9%)	87 (13.9%)	80 (9.6%)	.03
History of atrial fibrillation (no.)	2 (1.6%)	14 (2.2%)	29 (3.5%)	.2
Creatinine (mmol/L, mean $\pm$ SD)	110 $\pm$ 26	113 $\pm$ 49	107 $\pm$ 29	.01
Ejection fraction <30%	8 (6.2%)	19 (3%)	13 (1.5%)	.003
Previous myocardial infarction (no.)	63 (49.2%)	282 (45%)	382 (45.7%)	.643
Previous percutaneous coronary intervention (no.)	5 (3.9%)	29 (4.6%)	94 (11.2%)	.001
Reoperative surgery (no.)	2 (1.6%)	9 (1.4%)	1 (0.1%)	.009
Preoperative intra-aortic balloon pump (no.)	4 (3.1%)	1 (0.2%)	0 (0%)	.001
Urgent operation (no.)	55 (42.9%)	262 (41.8%)	368 (44%)	.721
EuroSCORE (mean $\pm$ SD)	2.2 $\pm$ 1.5	3.4 $\pm$ 2	3.6 $\pm$ 2	.0004
Left main disease (no.)	21 (16.4%)	112 (17.9%)	224 (26.8%)	.001
Coronary artery disease (vessels, mean $\pm$ SD)	2.2 $\pm$ 0.7	2.3 $\pm$ 0.7	2.5 $\pm$ 0.7	.001

Senior surgeons therefore face a dilemma that pits their duty to deliver the highest possible standard of care to their patients against their duty to teach OPCAB to trainees. Studies such as this and others are important to audit trainee performance and to reassure patients that good clinical outcomes are being achieved. Importantly, we are able to show similar early clinical outcomes and long-term survival for patients operated on by trainees, supervised and unsupervised, and by senior surgeons. This is possibly a reflection of the careful patients selection by senior surgeons in allocating cases to be operated on by trainees.

In 2000, a survey from several cardiothoracic training centers in the United States demonstrated that only 22%

of residents had performed 20 or more OPCAB procedures during their training, and only 12% had performed 20 or more complete myocardial revascularizations with OPCAB techniques.¹⁵ We have previously reported our early experience in teaching OPCAB, with no difference in clinical outcome when the surgery was performed by senior surgeons or cardiothoracic trainees.^{3,8-10} We have also provided evidence in the early phase of our program with 4 trainees and the senior surgeon who developed the OPCAB technique at our institution (G.D.A.) that performance monitoring is practical with control charts (eg, cumulative sum charts) and that teaching OPCAB in a residency program is effective, with an average failure rate for

TABLE 4. Postoperative outcomes of patients operated on by trainees broken down by time period

	1996–1999 (n = 128)	2000–2004 (n = 626)	2005–2009 (n = 835)	P value
Distal anastomoses (mean $\pm$ SD)	2.1 $\pm$ 0.8	2.3 $\pm$ 0.7	2.5 $\pm$ 0.7	.001
Completeness of revascularization index (mean $\pm$ SD)	0.7 $\pm$ 0.4	0.9 $\pm$ 0.3	0.9 $\pm$ 0.3	.003
Complete revascularization (no.)	102 (79.6%)	565 (90.2%)	738 (88.3%)	.003
Unsupervised operation (no.)	13 (3.3%)	259 (53.8%)	206 (43.9%)	.001
Conversion to cardiopulmonary bypass (no.)	0 (0%)	2 (0.3%)	5 (0.6%)	.5
In-hospital mortality (no.)	1 (0.8%)	9 (1.4%)	7 (0.8%)	.51
Reoperation for bleeding (no.)	5 (3.9%)	11 (1.8%)	19 (2.3%)	.3
Postoperative myocardial infarction (no.)	3 (2.3%)	18 (2.8%)	30 (3.5%)	.6
Postoperative Inotropes (no.)	50 (39%)	234 (37.3%)	344 (41.1%)	.333
Postoperative intra-aortic balloon pump (no.)	2 (1.5%)	13 (2%)	6 (0.7%)	.077
Stroke (no.)	0 (0%)	4 (0.6%)	4 (0.5%)	.6
Transient ischemic attack (no.)	0 (0%)	1 (0.1%)	1 (0.1%)	.895
Renal complications (no.)	10 (7.8%)	46 (7.3%)	49 (5.8%)	.032
Pulmonary complications (no.)	21 (16.4%)	81 (12.9%)	103 (12.3%)	.44
Intensive care unit stay (d, mean $\pm$ SD)	1.3 $\pm$ 1.0	1.7 $\pm$ 4.2	1.4 $\pm$ 1.3	.06
Hospital stay (d, mean $\pm$ SD)	8 $\pm$ 6	8 $\pm$ 6	7 $\pm$ 5	.835

TABLE 5. Postoperative outcomes of patients operated on by trainees broken down by trainee seniority (Calman year)

	Year 1 (n = 18)	Year 2 (n = 155)	Year 3 (n = 247)	Year 4 (n = 386)	Year 5 (n = 287)	Year 6 (n = 496)	P value
Distal anastomoses (mean $\pm$ SD)	2.0 $\pm$ 0.7	2.3 $\pm$ 0.7	2.4 $\pm$ 0.7	2.5 $\pm$ 0.7	2.4 $\pm$ 0.7	2.4 $\pm$ 0.7	.341
Completeness of revascularization index (mean $\pm$ SD)	0.91 $\pm$ 0.2	0.99 $\pm$ 0.2	1.0 $\pm$ 0.2	1.0 $\pm$ 0.2	1.0 $\pm$ 0.2	1.0 $\pm$ 0.2	.6
Complete revascularization (no.)	15 (83.3%)	138 (89%)	226 (91.5%)	356 (92.2%)	246 (85.7%)	424 (85.5%)	.01
Conversion to cardiopulmonary bypass (no.)	0 (0%)	2 (1.3%)	2 (0.8%)	2 (0.5%)	1 (0.4%)	0 (0%)	.5
In-hospital mortality (no.)	0 (0%)	2 (1.2%)	3 (1.2%)	2 (0.5%)	5 (1.7%)	5 (1%)	.751
Reoperation for bleeding (no.)	0 (0%)	7 (4.5%)	6 (2.4%)	15 (3.8%)	16 (5.5%)	17 (3.4%)	.439
Perioperative myocardial infarction (no.)	1 (5.5%)	2 (1.2%)	12 (4.8%)	17 (4.4%)	6 (2%)	13 (2.6%)	.167
Postoperative inotropes (no.)	7 (38.8%)	56 (36.1%)	104 (42.1%)	158 (40.9%)	110 (38.3%)	193 (38.9%)	.847
Postoperative intra-aortic balloon pump (no.)	0 (0%)	1 (0.6%)	7 (2.8%)	5 (1.3%)	3 (1%)	5 (1%)	.340
Stroke (no.)	0 (0%)	0 (0%)	1 (0.4%)	3 (0.7%)	0 (0%)	1 (0.2%)	.5
Transient ischemic attack (no.)	0 (0%)	0 (0%)	0 (0%)	1 (0.2%)	1 (0.3%)	0 (0%)	.726
Renal complications (no.)	0 (0%)	11 (7%)	22 (9%)	22 (5.6%)	18 (6.2%)	32 (6.4%)	.544
Pulmonary complications (no.)	2 (11.1%)	19 (12.2%)	30 (12.1%)	46 (11.9%)	40 (13.9%)	68 (13.7%)	.951
Intensive care unit stay (d, mean $\pm$ SD)	1.2 $\pm$ 0.5	1.9 $\pm$ 0.4	2.1 $\pm$ 0.8	1.4 $\pm$ 1.6	1.4 $\pm$ 1.3	1.3 $\pm$ 0.9	.01
Hospital stay (d, mean $\pm$ SD)	10.7 $\pm$ 6.6	10.7 $\pm$ 9	11.5 $\pm$ 13	10.5 $\pm$ 7.7	9.2 $\pm$ 5	10.7 $\pm$ 8.2	.408

OPCAB after adjustment for case mix similar to or better than that for conventional on-pump coronary artery bypass grafting.⁹ During the past 14 years, the number of OPCAB operations performed at our institution has increased significantly, and at the same time, more of these procedures have been undertaken by an increasing number of trainees. The complexity of cases performed by trainees has gradually increased, as has the mean number of grafts per patient, without any increase in procedural morbidity and mortality. At the same time, there has been a significant increase in the number of OPCAB procedures performed without direct supervision, when the consultant was not scrubbed in with the trainee in the operating theater.

The study has several limitations that are important to consider when interpreting the main findings. It is necessarily observational, for both logistic and ethical reasons. The way in which cases were selected by senior surgeons for trainees is unlikely to be adequately characterized by our data, despite the large number of clinical variables available. Patients operated on by senior surgeons were more likely to have higher risks factors, possibly a reflection of the careful selection process when allocating cases to trainees. One important variable was not documented in the database, namely a shift from trainee to senior surgeon designation as main operator. A change in the designation of trainee to senior surgeon in cases of unexpected findings or intraoperative complications would have led to the performance of trainees being overestimated. We do not believe that this occurred to a significant extent; however, during the early stages of training, the senior surgeons may have intervened in an unplanned manner to perform 1 or more difficult anastomoses or to show the trainee how optimally to position and stabilize the heart. One of the often reported major drawbacks of OPCAB is that the early in-hospital benefits are achieved at the expense of recurrence of angina symptoms and an increased need for revascularization. We have recently

provided evidence in our 7 to 8 years of follow-up of the 2 BHACAS (Beating Heart Against Cardioplegic Arrest Studies) trials of similar graft patency: 89.4% and 89.0% in the on-pump and off-pump groups, respectively, with no difference in cardiac-related events or quality of life.^{16,17} We have not analyzed our data, however, to determine whether OPCAB procedures performed by residents resulted in a higher incidence of recurrent angina or the need for repeated revascularization in these patients. Lack of information on cardiac-related events and the need for repeated revascularization between procedures performed by residents and attending surgeons is a major limitation of this study. Although a resident's experience has not been shown to be associated with adverse outcomes of operations performed in other surgical subspecialties, such as general and eye surgery,^{18,19} the impact of a cardiothoracic trainee's seniority levels in cardiac surgery has seldom been investigated.²⁰ In a recently published article, Bakaeen and colleagues²¹ showed that a resident's level of experience does not influence early and midterm outcomes of on-pump coronary artery bypass grafting, although there was a significant association between lower level of experience and higher cardiopulmonary bypass and crossclamp times.

Cardiothoracic surgical training programs vary greatly in content depending on the particular institution, the interests of its staff referral, and the characteristics of the patients. In the United Kingdom, the training in cardiothoracic surgery spans 6 years, with no specific recommendations for OPCAB. In our institution, trainees are exposed to beating-heart coronary operations from the first year of their training program and start performing conventional coronary artery bypass grafting with cardiopulmonary bypass and OPCAB at the same time. After they have assisted senior surgeons for 40 to 50 OPCAB procedures, trainees are started on simple off-pump cases, requiring only left anterior descending coronary artery or diagonal grafts, before gradually moving

to posterior descending coronary artery grafting. This allows trainees to become progressively acclimated to various techniques of exposure, stabilization, and positioning of shunts before attempting to graft the circumflex system, which remains technically more challenging. By the end of the third year, trainees have performed between 30 and 40 cases as first operator under direct supervision, and proficiency is usually obtained after 80 to 100 OPCAB operations.^{3,9} During this phase, the senior surgeon assesses the level of progression of the individual trainees, because this may vary. This assessment is very much based on the surgeon's judgment, because the simple number of 40 and 80 cases as base for the first stage of training cannot for obvious reason be the only criteria. Every case is considered suitable for training, taking in consideration what has been explained here. Indeed, we have previously reported¹⁰ our experience of trainees operating on high-risk patients, with very few exception such as those with severely impaired left ventricular function or hemodynamic instability. In the last 2 years of training, with the exact timing at the discretion of the supervising surgeon's judgment that a particular trainee has reached a competent level, the trainees are allowed to performed unsupervised operations. The trainee discusses the case and surgical strategy with the senior surgeon, who is generally available in his or her office but not scrubbed in at the operating theater. Trainees rotate on a 6-month period with an individual senior surgeon (all the surgeons performing OPCAB procedures take part in the training program), and although the OPCAB surgical technique is very much standardized across the unit, they are still exposed to and benefit from seeing different surgical approaches.

In the current era of myocardial revascularization, it is essential to expose trainees to OPCAB techniques, which are an integral part of modern coronary surgery. We believe that at present, OPCAB training programs should be limited to institutions that perform large number of these operations per year, with senior surgeons proficient in using the technique. Our primary aim is to encourage the evolution of OPCAB but at the same time maintain a high standard of care. Furthermore, we strive to provide scientific evidence for changes in the training curriculum to transfer our experience to more and more young cardiothoracic surgeons. The future of OPCAB remains bright and expansive. OPCAB is a technique for the many and not the few, both surgeons and patients, but only with structured training and supervision in the right environment.²²

CONCLUSIONS

Multivessel OPCAB is a safe and reproducible surgical technique that can be taught successfully to cardiothoracic surgical trainees. Early clinical outcomes and long-term survival are not related to the trainee's seniority or the level of supervision by the senior surgeons.

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TABLE E1. Multivariate Cox proportional hazards model for independent predictors of long-term mortality

Variable	HR	95% CI	<i>P</i> value
Age (y)	1.046	1.034–1.058	.001
Preoperative New York Heart Association class	1.184	1.070–1.310	.001
Diabetes	1.700	1.439–2.007	.001
Chronic obstructive pulmonary disease	1.499	1.228–1.829	.001
Vascular disease	1.659	1.354–2.031	.001
History of atrial fibrillation	1.733	1.296–2.17	.001
EuroSCORE	1.066	1.025–1.208	.001
Incomplete revascularization	1.279	1.049–1.560	.015
Trainee operator	1.034	0.867–1.232	.712

HR, Hazard ratio; CI, confidence interval.

TABLE E2. Characteristics of patients operated on by trainees broken down by seniority (Calman year)

	Year 1 (n = 18)	Year 2 (n = 155)	Year 3 (n = 247)	Year 4 (n = 386)	Year 5 (n = 287)	Year 6 (n = 496)	<i>P</i> value
Age (y, mean $\pm$ SD)	67.7 $\pm$ 7.6	66.1 $\pm$ 8.3	65.8 $\pm$ 9.5	67.6 $\pm$ 8.3	66.7 $\pm$ 8.1	66.7 $\pm$ 9	.314
Body mass index (kg/m ² , mean $\pm$ SD)	26.6 $\pm$ 3.4	28.2 $\pm$ 4.7	28 $\pm$ 4.2	27.9 $\pm$ 4.4	27.9 $\pm$ 4.2	28.1 $\pm$ 4	.917
Female (no.)	4 (22.2%)	36 (23%)	39 (15.7%)	62 (16%)	53 (18.4%)	99 (19.9%)	.316
Canadian Cardiovascular Society class (mean $\pm$ SD)	2.07 $\pm$ 0.9	2.1 $\pm$ 0.7	2.1 $\pm$ 0.8	1.9 $\pm$ 0.8	2 $\pm$ 0.7	2 $\pm$ 0.8	.614
Diabetes (no.)	3 (16.6%)	29 (18.7%)	43 (17.4%)	85 (22%)	57 (19.8%)	103 (20.7%)	.782
New York Heart Association class (no.)	2 $\pm$ 0.9	2.1 $\pm$ 0.7	2.1 $\pm$ 0.8	1.9 $\pm$ 0.8	2 $\pm$ 0.7	2 $\pm$ 0.8	.238
Hypertension (no.)	12 (66.7%)	102 (65.8%)	163 (66%)	276 (61.5%)	196 (68.3%)	348 (70.2%)	.6
Cerebrovascular disease (no.)	2 (11.1%)	9 (5.8%)	11 (4.5%)	33 (8.5%)	15 (5.2%)	36 (7.3%)	.3
Vascular disease (no.)	1 (5.5%)	10 (6.5%)	23 (9.3%)	36 (9.3%)	20 (7%)	41 (8.2%)	.798
Chronic obstructive pulmonary disease (no.)	2 (11.1%)	20 (12.9%)	27 (10.9%)	38 (9.8%)	41 (14.2%)	53 (10.6%)	.557
History of atrial fibrillation (no.)	1 (5.5%)	4 (2.5%)	5 (2%)	17 (4.4%)	9 (3%)	9 (1.8%)	.257
Creatinine (mmol/L, mean $\pm$ SD)	109 $\pm$ 24	109 $\pm$ 51	117 $\pm$ 41	112 $\pm$ 52	106 $\pm$ 22	109 $\pm$ 39	.105
Ejection fraction <30% (no.)	0 (0%)	2 (1.29%)	5 (2%)	9 (2.33%)	8 (2.7%)	16 (3.2%)	.7
Previous myocardial infarction (no.)	7 (38.9%)	70 (45.2%)	111 (44.9%)	169 (44.1%)	137 (47.9%)	233 (47%)	.9
Previous percutaneous coronary intervention (no.)	3 (16.6%)	11 (7%)	19 (7.6%)	33 (8.5%)	24 (8.3%)	38 (7.6%)	.8
Reoperative surgery (no.)	1 (5.6%)	0 (0%)	4 (1.6%)	4 (1%)	1 (0.3%)	1 (0.4%)	.05
Preoperative intra-aortic balloon pump (no.)	0 (0%)	0 (0%)	0 (0%)	1 (0.3%)	0 (0%)	4 (0.8%)	.3
Urgent operation (no.)	6 (33.3%)	62 (40%)	98 (39.6%)	170 (44%)	136 (47.3%)	213 (42.9%)	.442
EuroSCORE (mean $\pm$ SD)	2.8 $\pm$ 1.8	3 $\pm$ 2	3.4 $\pm$ 1.9	3.6 $\pm$ 2.1	3.5 $\pm$ 1.8	3.5 $\pm$ 1.9	.077
Left main disease (no.)	4 (28.5%)	26 (23.2%)	32 (13.2%)	100 (27.6%)	66 (26.5%)	129 (26.6%)	.002
Coronary artery disease (vessels, mean $\pm$ SD)	2.2 $\pm$ 0.8	2.4 $\pm$ 0.7	2.4 $\pm$ 0.7	2.5 $\pm$ 0.7	2.5 $\pm$ 0.7	2.5 $\pm$ 0.6	.162