Clinical outcomes after myocardial revascularization according to operator training status: cohort study of 22 697 patients undergoing percutaneous coronary intervention or coronary artery bypass graft surgery

Daniel A. Jones¹,²,³*, Sean Gallagher¹,³, Krishnaraj Rathod¹,³, Ajay K. Jain¹,³,⁴, Anthony Mathur¹,²,³,⁴, Rakesh Uppal³,⁵, Mark Westwood¹,³, Kit Wong³,⁵, Martin T. Rothman¹,³,⁴, Alex Shipolini³,⁵, Elliot J. Smith¹,³,⁴, Peter G. Mills¹,³,⁴, Adam D. Timmis¹,²,³, Charles J. Knight¹,³,⁴, R. Andrew Archbold¹,³,⁴, and Andrew Wragg¹,²,³,⁴

¹Department of Cardiology, Barts Health NHS Trust, London Chest Hospital, Bonner Road, London E2 9JX UK; ²Department of Clinical Pharmacology, William Harvey Research Institute, Queen Mary University, London, UK; ³NIHR Cardiovascular Biomedical Research Unit, London Chest Hospital, London, UK; ⁴Cardiovascular Training Institute, Barts Health NHS Trust, London, UK; and ⁵Department of Cardiothoracic Surgery, Barts Health NHS Trust, London, UK

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Aims

Myocardial revascularization by either coronary artery bypass graft surgery (CABG) or percutaneous coronary intervention (PCI) carries the risk of serious complications. Observational data suggest that outcomes may be improved by experienced operators, but there are few studies that have analysed the relationship between mortality and primary operator grade. The aim of this study was to investigate the effect of operator grade (trainee vs. consultant) upon outcomes of revascularization procedures.

Methods and results

This was an observational study at a tertiary cardiology centre with accredited training programmes, between 2003 and 2011. A total of 22 697 consecutive patients undergoing either CABG or PCI were included. Associations between operator grade and mortality were assessed by hazard ratios, estimated by Cox regression analyses; 6689 patients underwent CABG, whereas 16 008 underwent PCI. Trainees performed 1968 (29.4%) CABG procedures and 8502 (53.1%) PCI procedures. The proportion of procedures performed by trainees declined over time for both CABG (30.2% in 2003 vs. 26.0% in 2010) and for PCI (58.1% in 2003 vs. 44.5% in 2010). In the unadjusted Cox analysis, consultant operator grade was associated with an increased 5-year mortality after both CABG [HR: 1.26 (95% CI: 1.07–1.47)] and PCI procedures [HR: 1.34 (95% CI: 1.22–1.47)] compared with a trainee operator. However, following multiple adjustment, consultant grade was no longer associated with mortality after either procedure [CABG: HR: 1.02 (95% CI: 0.87–1.20), PCI: HR: 1.08 (95% CI: 0.98–1.20)].

Conclusion

There was no observed detrimental effect on patient outcomes arising from procedures undertaken by trainees working in a structured training environment compared with consultants.

Keywords

PCI • CABG • Training

* Corresponding author. Tel: +44 020 8983 2457, Fax: +44 020 8983 2278, Email: andrew.wragg@bartshealth.nhs.uk.

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Introduction

Myocardial revascularization by either coronary artery bypass graft surgery (CABG) or percutaneous coronary intervention (PCI) carries the risk of serious complications, including myocardial infarction (MI), stroke, and death. Other complications, such as wound infections, bleeding, and renal failure, are less often life-threatening but contribute to increased morbidity and prolonged hospital stays. It is a common perception of both patients and medical staff that complication rates are lower and clinical outcomes better following procedures performed by consultants rather than trainees. Observational data suggest that outcomes after CABG and PCI may be improved if procedures are undertaken in high volume centres by experienced operators, but there are few studies that have analysed the relationship between mortality and primary operator grade. Confirmation of a detrimental influence on clinical outcomes following procedures undertaken by trainees would have serious implications for both patient care and training programmes. We, therefore, sought to investigate the effect of operator grade (trainee vs. consultant) upon outcomes of myocardial revascularization procedures performed in a single centre with longstanding accredited training programmes for both cardiac surgeons and interventional cardiologists. We hypothesized that clinical outcomes would be less favourable following procedures for which the primary operator was a trainee rather than a fully trained, independent consultant operator.

Methods

We undertook a retrospective observational cohort study of consecutive patients undergoing CABG or PCI at a single, high-volume tertiary cardiac centre between January 2003 and July 2011 to investigate the effect of operator status on outcome.

Operator definition

The primary operator was defined as the surgeon or cardiologist who started the procedure with the intention of undertaking the majority of the procedure. Operator grade was defined as a consultant (fully trained independent operator) or a trainee. Trainees were defined as doctors enrolled in an approved specialty national training programme for cardiology or cardiothoracic surgery. In the UK, doctors are required to complete a 5–6-year training programme in their specialty before they can be deemed competent to practise as an independent clinician/consultant. Doctors would have completed at least 3 years of general training after medical graduation prior to commencing specialist training. The decision to offer revascularization to a patient was always undertaken by a consultant. A consultant also supervised all revascularization procedures and was present within the operating area for all cases. However, the level of supervision varied from case to case depending on the experience of the trainee and the complexity of the case being undertaken.

Inclusion criteria

The surgical cohort comprised patients undergoing first-time isolated CABG. Patients who underwent redo surgery or concomitant valve surgery were excluded. All PCI procedures were included in the analysis (elective, urgent, and emergency procedures).

Data collection

Baseline demographics recorded at the time of the CABG or PCI procedure included age, sex, symptom status, previous MI, PCI or CABG, and history of diabetes mellitus, hypertension, peripheral vascular disease (PVD), previous stroke or transient ischaemic attack, and chronic kidney disease (CKD). Chronic kidney disease was defined as an estimated glomerular filtration rate (eGFR) of <60 ml/min. The following procedural information was collected: urgency of procedure, severity of coronary artery disease, pre-procedural left ventricular function, presence of peri-procedural cardiogenic shock, procedural indication, and primary operator grade. For patients undergoing CABG, the cross-clamp time, cardiopulmonary bypass time, and the number of distal graft anastomoses were also recorded. For patients undergoing PCI, additional data recorded included the arterial access site, procedure time, fluoroscopy time, number of vessels treated, number of stents used, and the use of peri-procedural glycoprotein IIb/IIIa inhibitors.

Procedural urgency was defined as urgent or elective. Urgent status indicated that medical factors required the patient to remain in hospital for their procedure following an acute admission. Elective status was defined by planned admission from home for the procedure. Within the PCI cohort urgent procedures were usually undertaken after acute MI.

Outcomes

The study primary endpoint was long-term all-cause mortality. The United Kingdom Office of National Statistics periodically links the mortality status of patients who have undergone myocardial revascularization to the relevant surgical or PCI component of the national Central Cardiac Audit Database. These databases were used to ascertain the long-term mortality of our patients following myocardial revascularization. Patients were followed up until 19 August 2011. The median follow-up period was 4.0 (inter-quartile range (IQR) 2.1–5.9) years for the CABG cohort and 4.1 (IQR 2.1–5.5) years for the PCI cohort.

In-hospital procedural complications were also recorded. In patients undergoing CABG, major adverse cardiac events (MACEs) were defined as in-hospital death, MI, or stroke, and non-MACEs were defined as post-operative wound infection, re-stentotomy for any reason, and acute kidney injury requiring dialysis. In patients undergoing PCI, MACEs were defined as in-hospital death, MI, stroke, and the need for emergency CABG or repeat PCI, and non-MACEs were defined as procedural coronary arterial complications (including dissection, side-branch occlusion, and perforation) and cardiac tamponade.

Ethics

All data were collected routinely as part of a national cardiac audit project and all patient identifiers were removed prior to analysis. The local Ethics Committee, therefore, advised us that formal ethical approval was not required for this study.

Statistical analysis

Analyses were performed in order to assess the association of operator grade upon procedural complications and long-term all-cause mortality following CABG and PCI. The CABG and PCI cohorts were analysed separately. Continuous data with a normal distribution are presented as the mean ± standard deviation (SD) and skewed data as the median ± IQR. Categorical variables are summarized using a number (percentage). Continuous variables were compared using Student’s t-test for normally distributed data and using the Mann–Whitney test for non-normally distributed data. Categorical variables were compared using the Pearson χ² test. Long-term survival was described by the Kaplan–Meier method and comparisons in survival between patients operated on by trainees and consultants were made using the log-rank statistic. Associations between variables including operator grade with both
Propensity score analysis
To investigate whether or not any association of operator grade on clinical outcomes was related to procedural risk, we created a propensity score to assess the baseline risk of each patient who underwent CABG and PCI. Separate propensity scores were generated for both the CABG and PCI cohorts. Multiple logistic regression with primary operator grade as the dependent variable was used to develop the propensity score. All potential confounding variables remained in the model regardless of the level of statistical significance on univariate analysis. The regression model was then used to generate the predicted probability of operator grade for each patient (i.e. their ‘propensity score’), which ranged between 0 and 1. The rates of 5-year all-cause mortality in the consultant and trainee groups in each propensity score quintile were compared. Risk ratios (RRs) for mortality were calculated for each propensity score quintile.

Impact of operator grade on clinical outcomes after coronary artery bypass graft surgery

Patient characteristics
Patients operated on by consultants compared with trainees were similar with regard to age and sex distribution, but had a significantly higher frequency of previous MI, left ventricular impairment, multi-vessel coronary disease, CKD, and PVD (Table 1).

Operative characteristics
Consultants’ patients had higher EuroSCOREs, were more commonly urgent, and with a higher frequency of cardiogenic shock compared with trainees’ patients (Table 2). More grafts were placed in consultants’ patients and the average cross-clamp time of the aorta was shorter. However, the overall cardiopulmonary bypass time was similar for patients operated on by trainees and consultants.

Results
During the study period, 24 084 patients underwent myocardial revascularization, 7100 by CABG and 16 984 by PCI; 6689 (94.2%) patients among the CABG group and 16 008 (94.3%) patients among the PCI group had complete datasets and comprised the study cohort (procedures performed by staff grade operators (171 CABG and 188 PCI) were excluded). A similar proportion of procedures were performed by consultants and trainees among included and excluded patients.

Trainees performed 1968 (29.4%) first-time CABG procedures and 8502 (53.1%) PCI procedures during the study period. The proportion of procedures performed by trainees declined over time for both CABG (30.2% in 2003 vs. 26.0% in 2010) and for PCI (58.1% in 2003 vs. 44.5% in 2010).

Table 1  Baseline characteristics of patients undergoing percutaneous coronary intervention and coronary artery bypass graft surgery according to primary operator grade

<table>
<thead>
<tr>
<th>Variable</th>
<th>PCI</th>
<th>CABG</th>
<th>P-value</th>
<th>PCI</th>
<th>CABG</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consultant (n = 7505)</td>
<td>Trainee (n = 8502)</td>
<td></td>
<td>Consultant (n = 4722)</td>
<td>Trainee (n = 1968)</td>
<td></td>
</tr>
<tr>
<td>Age (years)* (%)</td>
<td>64.6 ± 12.2</td>
<td>63.8 ± 11.5</td>
<td>0.0115</td>
<td>66.4 ± 10.3</td>
<td>66.7 ± 9.8</td>
<td>0.371</td>
</tr>
<tr>
<td>Male (%)</td>
<td>5573 (74.3)</td>
<td>6247 (73.5)</td>
<td>0.2700</td>
<td>3798 (80.6)</td>
<td>1591 (80.8)</td>
<td>0.724</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>3821 (58.1)</td>
<td>4324 (57.1)</td>
<td>0.9581</td>
<td>3800 (80.5)</td>
<td>1643 (83.5)</td>
<td>0.004</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>1989 (26.5)</td>
<td>2065 (24.2)</td>
<td>0.0014</td>
<td>1591 (33.7)</td>
<td>640 (32.5)</td>
<td>0.369</td>
</tr>
<tr>
<td>Previous MI (%)</td>
<td>1930 (25.7)</td>
<td>1969 (23.1)</td>
<td>0.0002</td>
<td>2357 (49.9)</td>
<td>822 (41.8)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Previous stroke (%)</td>
<td>159 (2.4)</td>
<td>124 (1.6)</td>
<td>0.0019</td>
<td>197 (4.2)</td>
<td>62 (3.2)</td>
<td>0.057</td>
</tr>
<tr>
<td>Previous PCI (%)</td>
<td>1540 (20.5)</td>
<td>1797 (21.1)</td>
<td>0.3241</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Previous CABG (%)</td>
<td>676 (9.0)</td>
<td>559 (6.6)</td>
<td>&lt;0.0001</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>LVEF: &gt;55%</td>
<td>4713 (62.8)</td>
<td>6240 (73.4)</td>
<td>&lt;0.0001</td>
<td>2754 (58.3)</td>
<td>1344 (68.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>30–55%</td>
<td>2191 (29.2)</td>
<td>1930 (22.7)</td>
<td>1543 (32.7)</td>
<td>560 (28.5)</td>
<td>64 (3.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>&lt;30%</td>
<td>601 (8.2)</td>
<td>332 (3.9%)</td>
<td>425 (9.0)</td>
<td>47 (2.4)</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>CKD (eGFR &lt; 60)</td>
<td>267 (3.6)</td>
<td>168 (2.0)</td>
<td>&lt;0.0001</td>
<td>182 (3.8)</td>
<td>47 (2.4)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>PVD</td>
<td>220 (3.3)</td>
<td>230 (3.0)</td>
<td>0.4146</td>
<td>633 (13.4)</td>
<td>202 (10.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Multi-vessel disease (%)</td>
<td>2276 (30.3)</td>
<td>2364 (27.8)</td>
<td>0.0005</td>
<td>4610 (97.6)</td>
<td>1912 (97.2)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft surgery; MI, myocardial infarction; LVEF, left ventricular ejection fraction; CKD (eGFR < 60), chronic kidney disease; PVD, peripheral vascular disease.

*Mean ± SD.
In-hospital clinical outcomes
The rate of in-hospital mortality was 1.4% in patients operated on by consultants compared with 0.8% in patients operated on by trainees (P = 0.055). There were similar rates of in-hospital stroke, re-operation, wound infection, and need for dialysis in the consultant and trainee groups (Table 2).

Long-term mortality following coronary artery bypass graft surgery
Patients operated on by consultants had significantly worse long-term survival than patients operated on by trainees (P = 0.005) (Figure 1A). The 1-year and 5-year mortality rates were 4.6 [95% confidence interval (CI) 2.9–6.7%] and 13.7% (95% CI: 11.3–16.4%), respectively, in the consultant group compared with trainee mortality rates of 3.0 (95% CI: 1.1–6.6%) and 11.7 (95% CI: 8.2–15.8%) in the trainee group.

Predictors of long-term mortality following coronary artery bypass graft surgery
In the unadjusted Cox analysis, consultant operator grade was associated with increased 5-year all-cause mortality [hazard ratio 1.26 (95% CI: 1.07–1.47)] compared with trainee operator status. After multiple adjustment for co-morbidities, however, operator grade was no longer associated with long-term mortality [independent hazard ratio 1.02 (95% CI: 0.87–1.20)] (Figure 2). Incorporation of the propensity score into the model did not change this finding [HR: 1.08 (95% CI: 0.96–1.20)]. The independent predictors of 5-year mortality were age, previous MI, previous stroke, left ventricular impairment, CKD, COPD, and the need for urgent CABG.

Long-term mortality in patients stratified by propensity score and operator grade
Analysis of patients stratified by quintiles of the propensity score showed that the proportion of cases performed by consultants increased progressively from low- to high-risk patients (56.6% in Q1 vs. 82.9% in Q5). As expected, mortality rates also increased from Q1 to Q5. However, there was no significant difference in mortality rates between patients operated on by consultants and by trainees in any quintile. The RR for 5-year mortality associated with consultant procedures compared with trainee procedures across all quintiles of baseline risk was 1.04 (95% CI: 0.86–1.24).

Impact of operator grade on clinical outcomes after percutaneous coronary intervention
Patient characteristics
Patients who had their procedure performed by a consultant were significantly older, and more frequently had diabetes mellitus, CKD, previous MI, previous stroke, multi-vessel coronary artery disease,
and left ventricular impairment compared with patients who had their procedure performed by a trainee (Table 1).

**Procedural characteristics**
Consultants’ cases were more commonly performed as emergencies due to a greater proportion with STEMI requiring PPCI and rescue PCI compared with trainees’ cases (Table 3). Consultants also treated more patients with cardiogenic shock and previous CABG, performed multi-vessel PCI more often, and used more stents. However, there was no significant difference in fluoroscopy time or radiation dose compared with trainees.

**Figure 1** Kaplan–Meier curves showing the cumulative probability of all-cause mortality according to primary operator after (A) coronary artery bypass graft and (B) percutaneous coronary intervention.
In-hospital clinical outcome
Both MACE (2.4 vs. 1.4%, \(P < 0.0001\)) and non-MACE (6.0 vs. 4.2%, \(P < 0.0001\)) were more common in patients whose PCI was performed by a consultant compared with patients whose procedure was performed by a trainee (Table 3). The higher MACE rate was driven by a higher frequency of peri-procedural MI (0.8 vs. 0.5%, \(P = 0.003\)) and in-hospital death (0.9 vs. 0.3%, \(P < 0.0001\)). There was no significant difference between consultant and trainee groups in rates of stroke, emergency CABG, and repeat PCI.

Long-term mortality following percutaneous coronary intervention
Patients whose PCI was undertaken by a consultant had significantly higher rates of long-term all-cause mortality than patients whose procedure was performed by a trainee at both the 1-year [7.4 (95% CI: 5.3–9.6%) vs. 4.4 (95% CI: 2.6–6.7%), \(P < 0.0001\)] and the 5-year [16.9 (95% CI: 14.7–19.2%) vs. 14.1 (95% CI: 12.1–16.3%), \(P < 0.0001\)] follow-up (Figure 1B). The higher mortality rates were observed after elective cases and following PCI for ACS, with 5-year mortality rates of 14.1% (95% CI: 10.9–17.7%) vs. 11.8% (95% CI: 9.1–14.9%, \(P = 0.004\)) and 19.5% (95% CI: 16.3–22.9%) vs. 16.9% (95% CI:14.0–20.0%, \(P < 0.0001\)), respectively.

Predictors of long-term mortality following percutaneous coronary intervention
In the unadjusted Cox analysis, consultant operator grade was associated with an increased 5-year all-cause mortality (hazard ratio 1.34 (95% CI: 1.22–1.47) compared with a trainee operator. However, following multiple adjustment, consultant operator grade was no longer associated with long-term mortality (hazard ratio 1.08 (95% CI: 0.98–1.20)) (Figure 3). The primary operator status was also not associated with long-term survival after the propensity score was included in the proportional hazard model as a covariate (HR: 1.08 (95% CI: 0.96–1.20)). The independent predictors of long-term mortality were age, diabetes mellitus, previous MI, impaired left ventricular function, CKD, PVD, multi-vessel disease, ACS presentation, cardiogenic shock, and unsuccessful PCI.

Analysis of long-term mortality stratified by propensity score
The proportion of procedures performed by consultants increased progressively from the quintile of lowest risk to the quintile of highest baseline risk (34.9% in Q1 vs. 61.5% in Q5; \(P < 0.0001\)). As expected, 5-year mortality rates also increased from the lowest to the highest quintile of the propensity score with mortality rates of 5.4% in Q1 vs. 18.5% in Q5 for trainees and 6.5% in Q1 vs. 21.5% in Q5 for consultants. However, there was no significant difference in 5-year mortality rates between consultants and trainees among

| Table 3 | Procedural characteristics and in-hospital clinical outcomes after percutaneous coronary intervention according to primary operator grade |
|---------------------------------|---------------------------------|-----------------|
| Consultant (n = 7505)            | Trainee (n = 8502)              | \(P\)-value     |
| Acute coronary syndrome (%)      | 4309 (57.4)                     | <0.0001         |
| Primary PCI (%)                  | 1623 (21.6)                     | <0.0001         |
| Rescue PCI (%)                   | 167 (2.2)                       | <0.0001         |
| NSTEMI (%)                       | 2519 (33.6)                     | 0.076           |
| Elective procedure (%)           | 3196 (42.6)                     | <0.0001         |
| Radial access (%)                | 2116 (28.2)                     | <0.0001         |
| Multi-vessel intervention (%)    | 1283 (17.1)                     | <0.0001         |
| Vessels treated                  | 1.21 ± 0.55                     | <0.0001         |
| Cardiogenic shock (%)            | 185 (2.5)                       | <0.0001         |
| Fluoroscopy time (mins)          | 17.3 ± 55.9                     | 0.6873          |
| Radiation dose (Gycm2)           | 80.2 ± 51.0                     | 0.0860          |
| Number of stents used            | 1.86 ± 1.31                     | <0.0001         |
| Drug-eluting stent procedures (%)| 3858 (51.4)                     | 0.3772          |
| Glycoprotein IIb/IIIa inhibitor use (%) | 3294 (43.9) | <0.0001         |
| In-hospital MACE events (%)      | 179 (2.4)                       | <0.0001         |
| Death (%)                        | 72 (0.9)                        | <0.0001         |
| Recurrent MI (%)                 | 61 (0.8)                        | 0.0031          |
| Repeat PCI (%)                   | 26 (0.4)                        | 0.6724          |
| Emergency CABG (%)               | 12 (0.2)                        | 0.6118          |
| Stroke (%)                       | 8 (0.1)                         | 0.6163          |
| Non-MACE events (%)              | 454 (6.0)                       | <0.0001         |

PCI, percutaneous coronary intervention; NSTEMI, non-ST elevation myocardial infarction; MACE, major adverse cardiac events; MI, myocardial infarction; CABG, coronary artery bypass graft surgery.
patients in any of the five quintiles of baseline risk. The Mantel–Haenszel RR for 5-year all-cause mortality for all five quintiles was 1.07 (95% CI: 0.96–1.20).

**Discussion**

In this cohort study of >22,000 patients, we analysed the relationship between operator status, defined as independent consultant operator or trainee operator, and clinical outcomes following myocardial revascularization procedures. We demonstrated that consultants more commonly undertook CABG and PCI procedures as the first operator for patients at the highest risk of complications and that unadjusted outcomes were worse for patients who were operated on by consultants compared with trainees. However, after accounting for the significantly higher level of baseline risk in consultant cases, due to factors such as worse left ventricular function, more advanced operator or trainee operator, and clinical outcomes following myocardial revascularization procedures. We demonstrated that consultants more commonly undertook CABG and PCI procedures as the first operator for patients at the highest risk of complications and that unadjusted outcomes were worse for patients who were operated on by consultants compared with trainees. However, after accounting for the significantly higher level of baseline risk in consultant cases, due to factors such as worse left ventricular function, more advanced
coronary disease, and more acute presentations, operator status was not associated with a difference in outcome. Specifically, we did not observe a difference in the short- and long-term procedural outcomes for trainees compared with those of consultants.

Our findings are consistent with the results of smaller studies of patients undergoing CABG, which also identified no difference in outcomes for patients operated upon by surgeons of various grades of experience.9–11 Nor were 1-year graft patency rates any worse for less experienced trainees.12 Other studies have investigated whether cardiac surgical outcomes are worse at the beginning of the academic cycle when new trainees start their posts. Although the early part of the academic year may be associated with slightly longer operation times13 and unadjusted data suggest slightly worse clinical outcomes after CABG in the first quarter,14 risk-adjusted outcomes are similar throughout the academic year.13 Studies of patients undergoing vascular surgery have not demonstrated an increased mortality for operations undertaken in academic training hospitals compared with non-training centres.15

There are few, if any, studies relating to the outcome of PCI procedures undertaken by trainees compared with consultants. Observation of operators utilizing PCI simulators showed that trainees have inferior technical abilities compared with experienced operators,16 but it is not known if this translates into worse clinical outcomes, particularly when the trainee is working in a supportive training environment. We found no difference in adjusted 5-year mortality rates between patients whose procedure was performed by a consultant compared with patients whose procedure was performed by a trainee for either PCI or CABG.

Our findings may not be applicable to other procedures or to other training environments. In orthopaedic surgery, for example, long-term outcomes may be worse in patients undergoing hip replacement surgery when the primary surgeon is a trainee compared with a consultant.17 Complication rates may be higher when day case anaesthesia is undertaken by a trainee.18 However, these studies used procedural complications and/or procedural failure as their endpoints rather than mortality. The availability of a consultant who can identify potential problems, provide advice to the trainee and, if necessary, take over the procedure when problems arise mitigates the risk of complicated procedures that begin as ‘trainee cases’, translating into a poor final outcome for the patient.

In an idealized training environment, the risk profile of cases assigned primarily to trainees would be low and outcomes better than those higher risk cases that mandated a senior primary operator. Our analysis of patients by the propensity score demonstrated that consultants undertook the majority of revascularization procedures for patients who were at the highest risk of adverse procedural outcomes, a finding that patients and healthcare providers would expect. However, it is appropriate for more experienced trainees to undertake some procedures on higher risk patients. In our cohort, trainees undertook 17.1% of CABG procedures and 38.5% of PCI procedures among patients in the quintile of highest risk estimated by the propensity score. However, there was no significant difference in 5-year mortality rates between patients operated on by consultants and by trainees in any quintile of risk for either CABG or PCI.

Implications for training and clinical practice
Trainees at our institution performed 29.4% of first-time isolated CABG operations and 53.1% of all PCI procedures during the study period with no apparent detrimental effect on patient outcomes. Our training programmes for cardiothoracic surgery and for cardiology are both well established. All training cases are supervised by a consultant, and the majority is performed under direct supervision. Our data do not show that the operator status is unimportant; rather they demonstrate that in a well-structured training environment, with careful and appropriate patient selection, outcomes are not compromised by trainees undertaking revascularization procedures. Cases undertaken by trainees require detailed pre-procedural discussion and planning. A consultant assisting a trainee will not only monitor the technical quality, but will also focus on strategic aspects of the procedure. This might include suggesting alternative equipment or techniques, ensuring good technical results, and optimization of post-procedure care. One might speculate that the ideal combination to undertake invasive procedures is a trainee supported by a consultant; a trainee in the assistant role being more likely to focus on the technical aspects of the procedure and less likely to offer potentially helpful advice to a consultant as the primary operator. Our results show that with appropriate supervision and case selection, trainees can perform myocardial revascularization procedures without an adverse impact on clinical outcomes.

Limitations
This was an observational study; the patients in the consultant and the trainee groups were not randomly assigned. There were significant differences between the groups in baseline and procedural characteristics and in surgical risk. We expect that these differences were due in large part to the selection of cases by consultants to be performed by trainees. Multivariate analyses were performed in order to assess the impact of trainee as first operator status on clinical outcomes, but it is possible that factors that influenced the relationship between operator status and clinical outcomes were not measured. We were not able to differentiate between procedures that were completed by a trainee and those that were commenced by a trainee but subsequently ‘taken over’ by a consultant due to technical complexity or procedural complications. Furthermore, the degree of trainee supervision was not assessed.

Conclusion
Five-year mortality rates after myocardial revascularization procedures were significantly higher for patients whose procedure was undertaken by a consultant compared with a trainee. This adverse prognosis was explained by the more complex case mix among consultants and once the differences in baseline and procedural risk were accounted for, operator grade had no impact upon patient outcomes. There was no observed detrimental effect on patient outcomes arising from procedures undertaken by trainees working in a structured training environment compared with consultants.
Clinical outcomes after myocardial revascularization

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