How Safe Is it to Train Residents to Perform Coronary Surgery With Multiple Arterial Grafting? Nineteen Years of Training at a Single Institution

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The learning curve of coronary artery bypass grafting (CABG) with multiple arterial grafting (MAG) is perceived to be associated with increased surgical morbidity and potentially poorer long-term outcomes. We compared short-term outcomes and long-term survival in patients who underwent CABG with MAG performed by attending surgeons or resident trainees at a single institution over a period of 19 years. Using our institutional database, we identified 3039 patients undergoing MAG from 1996-2015. Of those, 958 (32%) were operated by residents and 2081 (68%) by attending surgeons. Propensity score matching and mixed-effects models were used to compare the 2 groups. Operative mortality rate was 0.3% and 0.4% among patients operated by residents and attending surgeons, respectively (P = 0.71), with no significant differences among the groups in postoperative complications. After a mean follow-up time of 11 ± 4 years, survival probability at 5, 10, and 15 years was 95.1% ± 0.7% vs 96.4% ± 0.6%, 87.0% ± 1.1% vs 87.8% ± 1.1%, and 76.6.% ± 1.8% vs 77.6% ± 1.8% in the resident and attending surgeon group, respectively. Resident and attending surgeon cases showed comparable risk of death (hazard ratio [HR] = 1.01; 95% CI: 0.80-1.28; P = 0.92). The equipoise between the 2 groups was confirmed among cases receiving bilateral internal thoracic arteries only (HR = 0.88; 95% CI: 0.54-1.43; P = 0.61), radial artery (HR = 1.22; 95% CI: 0.92-1.61; P = 0.15), or their combination (HR = 0.74; 95% CI: 0.33-1.65; P = 0.47). The present analysis confirms that adequately supervised trainees can perform CABG with MAG without compromising patient safety and long-term survival.

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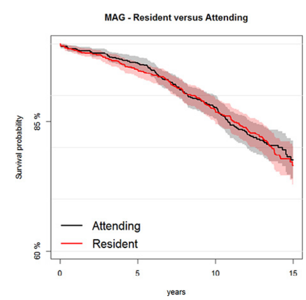
Keywords: Training, Arterial grafts, Survival, Coronary artery bypass graft surgery



Survival in patients undergoing multiple arterial grafting (MAG) operated on by resident vs attending surgeon.

Central Message

A 19-year training experience at a single institution found that adequately supervised trainees can perform CABG with multiple arterial grafting without compromising patient safety and long-term survival.

Perspective Statement

The conflict between trainee education and patient safety, requires surgical training policies to be guided by robust clinical data and high-level evidence. We demonstrated that supervised trainees can effectively perform CABG with multiple arterial grafting without compromising patient safety. These results are expected to promote residents training in multiple arterial grafting.

Despite multiple arterial grafting (MAG) including bilateral internal thoracic arteries (BITA) and radial artery (RA) has been consistently shown to improve survival after coronary artery bypass grafting (CABG), it still remains largely underused.[1-4] It is disconcerting that only 10% of patients undergoing CABG currently receive a second arterial graft in the United States, approximately 4% with BITA and 6% with RA.[5] Moreover, among 1541 procedures performed in the SYNTAX trial and registry, 97.1% included a single arterial conduit, whereas only 22.7% received BITA grafts.[6]

The most commonly cited reason for not performing CABG with MAG, is the learning curve, perceived to be associated with increased surgical morbidity and potentially poorer long-term outcomes.[7,8] This often results in lack of exposure to MAG procedures during cardiothoracic training program.[7] Moreover, the

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current intense professional and public scrutiny of cardiac surgeons' results creates a hostile environment not conducive to trainees' exposure to MAG.

Here, we compared the short- and long-term outcomes of CABG with MAG performed by attending surgeons or resident trainees at the Bristol Heart Institute over a period of 19 years.

METHODS

Study Design

The study was conducted in accordance with the principles of the Declaration of Helsinki. The local audit committee approved the study, and the requirement for individual patient consent was waived. This study was a registry-based analysis involving patients with multivessel coronary artery disease who underwent elective isolated CABG using at least 2 arterial conduits from April 1996 to April 2015, at the Bristol Heart Institute, United Kingdom. We retrospectively analyzed prospectively collected data from the National Institute for Cardiovascular Outcomes Research (NICOR) registry for audit and quality assessment of adult cardiac surgery in the United Kingdom. Reproducible cleaning algorithms were applied to the database, which are regularly updated as required. Briefly, duplicate records and nonadult cardiac surgery entries were removed; transcriptional discrepancies harmonized; and clinical conflicts and extreme values corrected or removed. The data are returned regularly to the local units for validation. Further details and definition of variables are available at http://www.ucl.ac.uk/nicor/audits/adultcardiac/datasets.

Study Population

Patients were eligible for inclusion in the study if they had undergone isolated CABG performed by either attending surgeons or residents using at least 2 arterial conduits in the following configuration: BITA, left internal thoracic artery (LITA) and RA or BITA plus RA with or without additional saphenous vein grafts. In the present series, the RA was considered only in case of target stenosis ≥75% and it was used as a free graft proximally connected to the ascending aorta or as a "y "graft attached to the internal thoracic artery. The internal thoracic artery was used as a pedicle graft that remained proximally connected to its respective subclavian artery (in situ) or as a free graft proximally connected to other internal thoracic artery as a "y" graft. Exclusion criteria were (1) cases performed by nonattending surgeons who had completed their training program; (2) no information available on the primary surgeon status; and (3) LITA not used.

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, 4-6 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 reviewed and assigned according to equivalent criteria. A resident case was retrospectively defined as a case in which the cardiothoracic resident performed the entire surgical procedure. A supervised operation performed by a resident was defined as one in which the attending surgeon was scrubbed in and acted as first assistant. An unsupervised operation was defined as one in which the resident had reviewed the case and planned the surgical strategy with the attending surgeon who was not scrubbed in. The decision to have a resident case was at the discretion of individual attending surgeons. There was no formal agreement on a minimum number of cases to be performed by the residents during their training program. The patients operated on by the resident were selected by assessing their suitability for training taking into account the urgency of the operation and their comorbidities, the quality of the coronary arteries, and the number of grafts required. Training in MAG progressed to gradually increasing levels of complexity including y graft and off-pump MAG (Video 1).

STUDY END POINTS

Short-term outcomes analyzed were re-exploration for bleeding, need for sternal wound reconstruction, postoperative cerebrovascular accident (defined as any confirmed neurologic deficit of abrupt onset that did not resolve within 24 hours), postoperative renal replacement therapy, need for postoperative intra-aortic balloon pump, in-hospital mortality, the occurrence of any of above complications, and length of stay was compared between 2 groups. The incidence of incomplete revascularization, defined as at least 1 diseased primary arterial territory not grafted was also investigated.

Long-term outcome investigated was all-cause mortality. This is considered the most robust and unbiased index in cardiovascular research because no adjudication is required, thus avoiding inaccurate or biased documentation and clinical assessments.[9] Information about postdischarge mortality tracking was available for all patients (100%) and was obtained by linking the institutional database with the National General Register Office.

Pretreatment Variables

The effect of procedure performed by resident vs attending surgeon on outcomes of interest was adjusted for the following pretreatment variables including age, sex, body mass index, New York Heart Association grade III or IV, prior myocardial infarction within 30 days, previous percutaneous coronary intervention, active smoking, diabetes mellitus on oral treatment or on insulin, chronic obstructive pulmonary disease, current smoking, serum creatinine ≥200 mmol/L, previous cerebrovascular accident, peripheral vascular disease, preoperative atrial fibrillation, left main disease, number of vessel diseased, left ventricular ejection fraction between 30% and 49%, left ventricular ejection fraction less than 30%; nonelective admission, emergent or salvage operation, cardiogenic shock, preoperative intra-aortic balloon pump, and eras of surgery. Predicted risk was assessed using Euroscore according to the following definition[10]: low risk as 0-2 points (0.8% expected mortality), medium risk as 3-5 points (3.0% expected mortality), and high risk as > 5 points (11% expected mortality).

Statistical Analysis

Categorical variables were presented as frequencies and percentages and continuous variables were expressed as mean ± standard deviation. Multiple imputation was used to address missing data (https://cran.r-project.org/package=Amelia). Rubin's method[11] was used to combine results from each of 3 imputed data sets. To control for measured potential confounders in the data set, a propensity score (PS) was generated for each patient from a multivariable logistic regression model based on pretreatment covariates as independent variables with procedure performed by resident vs attending surgeon as a binary dependent variable[12] (Supplementary Table S1). Pairs of patients operated by resident vs attending surgeon were derived using greedy 1:1 matching with a calliper of width of 0.2 standard deviation of the logit of the PS (http://CRAN.Rproject.org/package=nonrandom). The quality of the match was assessed by comparing selected pretreatment variables in PS-matched patients using the standardized mean difference, by which an absolute standardized difference of greater than 10% is suggested to represent meaningful covariate imbalance. To account for the hierarchical clustering of cases by resident and attending pairs, generalized mixed models were used, whereas random intercepts for matching sets were modeled. Generalized linear mixed-effects model was used for short-term outcomes. https://cran.r-project.org/package=lme4 was used for short-term outcomes. Mixed-effects Cox regression was used to investigate the treatment effect on survival (https://CRAN.R-project.org/package=coxme). Time-segmented analysis was used to account for different hazard phases during follow-up.[13] The hazard function was used as a guide to determine approximate time points for the end of the early hazard phase and the beginning of the late phase (http://CRAN.R-project.org/package=muhaz). To account for individual attending surgeon effect on outcomes and resident case selection (certain attending surgeons were more likely to allow residents to perform MAG procedures), a second random effect including attending surgeon identification number was added to the model. The intercept for random effect (excess risk) was estimate by using its standard deviation. Integrated log likelihood test was used to test the random effect. Subgroup analysis was also conducted according to arterial graft configuration adopted (BITA or RA grafting separately). Finally, the effect of procedure performed by resident vs attending on in-hospital mortality and late mortality was investigated according to different stages of cardiothoracic training program early stage (years 1 and 2), intermediate stage (years 3 and 4), and final stage (years 5 and 6). Unsupervised and supervised cases were also compared. A $P < 0.05$ was considered to indicate statistical significance. All statistical analysis was performed using R Statistical Software (version 3.2.3; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Study ppopulation

We identified 3039 patients for the final analysis who underwent isolated CABG with MAG during the study period (Supplementary Figure S1). Of those, 958 (32%) were operated by residents and 2081 (68%) by attending surgeons. A total of 22 attending surgeons were identified during the study period. There was a large variability in number of MAG cases performed by individual attending surgeons and relative rate of resident cases (Supplementary Table S2). Identification of residents performing the procedure was not reported in most cases (735, 76%). Information regarding the stage of training program was available for 340/958(35%) resident cases (early = 21; intermediate = 128; and final = 191). Information regarding the supervision by attending surgeon was available for 395/958 (41%) resident cases with 338 supervised and 57 unsupervised resident cases. Among unsupervised resident cases, 48 were performed by a resident at final stage of training and 3 by a resident at intermediate stage of training.

Patients characteristics distribution before and after PS matching are summarized in Table 1. Overall, attending surgeons operated on patients with a higher burden of comorbidities and more likely to have 3-vessel disease and left main disease. Moreover, resident cases

Table 1. Baseline Characteristics Before and After Propensity Score Matching

	Resident		Attending (All)		SMD	Attending (Matched)		SMD
Overall	958		2081			958		
Age								
<60	541	56.5%	998	48.0%	–17%	522	54.5%	0%
60-69	324	33.8%	762	36.6%		338	35.3%	
70-79	89	9.3%	282	13.6%		92	9.6%	
≥80	4	0.4%	39	1.9%		6	0.6%	
Female								
No	859	89.7%	1843	88.6%	–4%	861	89.9%	1%
Yes	99	10.3%	238	11.4%		97	10.1%	
BMI								
<18.5	3	0.3%	4	0.2%	–8%	3	0.3%	–1%
18.5-24.9	195	20.4%	417	20.0%		198	20.7%	
25-29.9	488	50.9%	1017	48.9%		483	50.4%	
30-34.9	230	24.0%	497	23.9%		216	22.5%	
≥35	42	4.4%	146	7.0%		58	6.1%	
NYHA III-IV								
No	742	77.5%	1618	77.8%	1%	743	77.6%	0%
Yes	216	22.5%	463	22.2%		215	22.4%	
MI within 30 d								
No	844	88.1%	1713	82.3%	16%	846	88.3%	0%
Yes	114	11.9%	368	17.7%		112	11.7%	
PCI								
No	913	95.3%	1978	95.1%	1%	908	94.8%	–2%
Yes	45	4.7%	103	4.9%		50	5.2%	
Smoking								
No	805	84.0%	1744	83.8%	–1%	802	83.7%	–1%
Yes	153	16.0%	337	16.2%		156	16.3%	
DM orally treated								
No	886	92.5%	1912	91.9%	2%	887	92.6%	0%
Yes	72	7.5%	169	8.1%		71	7.4%	
DM on insulin								
No	902	94.2%	1965	94.4%	1%	901	94.1%	0%
Yes	56	5.8%	116	5.6%		57	5.9%	
sCr ≥ 200 mmol/L								
No	953	99.5%	2065	99.2%	–3%	952	99.4%	–1%
Yes	5	0.5%	16	0.8%		6	0.6%	
COPD								
No	919	95.9%	1992	95.7%	1%	912	95.2%	–4%
Yes	39	4.1%	89	4.3%		46	4.8%	
CVA								
No	939	98.0%	2025	97.3%	–5%	940	98.1%	1%
Yes	19	2.0%	56	2.7%		18	1.9%	

(*continued on next page*)

Table 1. Continued

	Resident		Attending (All)		SMD	Attending (Matched)		SMD
PVD								
No	899	93.8%	1933	92.9%	–4%	899	93.8%	0%
Yes	59	6.2%	148	7.1%		59	6.2%	
AF								
No	937	97.8%	2034	97.7%	0%	937	97.8%	0%
Yes	21	2.2%	47	2.3%		21	2.2%	
NVD								
1	21	2.2%	31	1.5%	–13%	21	2.2%	1%
2	320	33.4%	584	28.1%		325	33.9%	
3	617	64.4%	1466	70.4%		612	63.9%	
LMD								
No	754	78.7%	1547	74.3%	–10%	742	77.5%	–3%
Yes	204	21.3%	534	25.7%		216	22.5%	
LVEF 30%-49%								
No	839	87.6%	1700	81.7%	–16%	832	86.8%	–2%
Yes	119	12.4%	381	18.3%		126	13.2%	
LVEF < 30%								
No	953	99.5%	2029	97.5%	–16%	954	99.6%	2%
Yes	5	0.5%	52	2.5%		4	0.4%	
Shock								
No	958	100.0%	2080	100.0%	3%	958	100.0%	0%
Yes	0	0.0%	1	0.0%		0	0.0%	
Preop IABP								
No	957	99.9%	2069	99.4%	–8%	957	99.9%	1%
Yes	1	0.1%	12	0.6%		1	0.1%	
Nonelective								
No	592	61.8%	1176	56.5%	–11%	568	59.3%	–5%
Yes	366	38.2%	905	43.5%		390	40.7%	
Emergent or salvage								
No	957	99.9%	2064	99.2%	–11%	957	99.9%	0%
Yes	1	0.1%	17	0.8%		1	0.1%	
Eras								
1996-1999	254	26.5%	307	14.8%	–41%	238	24.8%	1%
2000-2004	374	39.0%	653	31.4%		383	40.0%	
2005-2009	230	24.0%	797	38.3%		258	26.9%	
2010-2015	100	10.4%	324	15.6%		79	8.2%	
Euroscore								
0-2	590	61.6%	1198	57.6%		620	64.7%	
3-5	321	33.5%	699	33.6%		302	31.5%	
6+	47	4.9%	184	8.8%		36	3.8%	

AF, atrial fibrillation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DM, diabetes mellitus; IABP, intra-aortic balloon pump; LMD, left main disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NVD, number of vessel disease; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; sCr, serum creatinine.

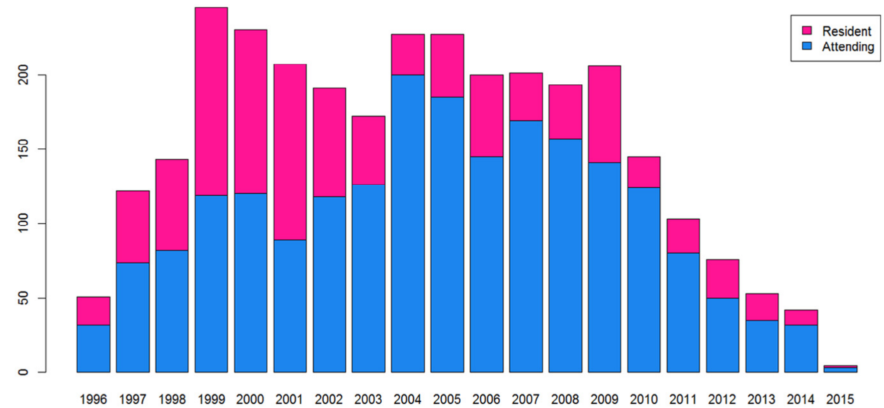

Figure 1. Number of MAG procedures performed by resident and attending surgeon during the study period. (Color version of figure is available online.)

were more likely to be performed during the early years (Fig. 1). Burden of comorbidities gradually increased over the time with a concomitant decrease in number of cases performed by residents (Supplementary Table S3). A similar trend was also observed in non-MAG cases (Supplementary Figure S2). After PS matching, 958 matched pairs were obtained and the 2 groups were comparable for all pretreatment variables including the extension of coronary artery disease (standardized mean difference <10%; Fig. 2).

Intraoperative Data

Intraoperative data in the matched groups is reported in Table 2. Resident cases received the same number of grafts and the incidence of incomplete revascularization was comparable between 2 groups. Rate of off-pump surgery was higher among attending surgeon cases, and x-clamp time and cardiopulmonary bypass time were higher among resident cases. Arterial grafts configuration was also different between 2 groups: BITA usage was higher among resident cases, whereas RA usage was higher among attending surgeon cases.

Operative Outcomes

Table 3 summarizes postoperative outcomes in the matched cohort. No significant differences were observed between the 2 groups. All the 3 deaths in the resident group occurred in patients receiving the RA as

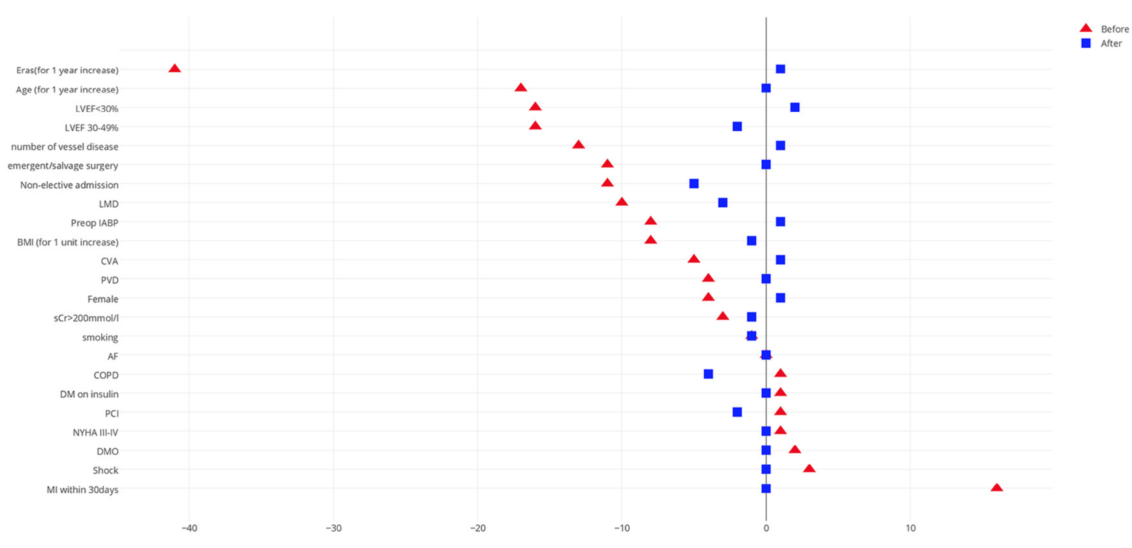

Figure 2. Standardized mean difference before and after matching. AF, atrial fibrillation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DM, diabetes mellitus; DMO, diabetes mellitus orally treated; IABP, intra-aortic balloon pump; LMD, left main disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NVD, number of vessel disease; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; sCr, serum creatinine. (Color version of figure is available online.)

Table 2. Operative Data in the Matched Cohort

	Resident (*N* = 958)		Attending (*N* = 958)		P_{GLMM}
	n	%	*n*	%	
Number of grafts					
2	350	36.5	346	36.1	0.32
3	471	49.2	449	46.9	
4	128	13.4	151	15.8	
5	9	0.9	12	1.3	
Incomplete revascularization					
No	792	82.7	777	81.1	0.37
Yes	166	17.3	181	18.9	
LAD grafted					
No	20	2.1	23	2.4	0.46
Yes	938	97.9	935	97.6	
RCA grafted					
No	310	32.4	314	32.8	0.84
Yes	648	67.6	644	67.2	
CX grafted					
No	192	20.0	206	21.5	0.42
Yes	766	80.0	752	78.5	
OPCAB					
No	489	51.0	420	43.8	<0.001
Yes	469	49.0	538	56.2	
x-time, min (mean ± sd)	32 ± 27		25 ± 24		<0.001
CPB-time, min (mean ± sd)	54 ± 44		45 ± 41		<0.001
Graft configuration					
BITA	332	34.7%	221	23.1%	<0.001
BITA + RA	91	9.5%	96	10.0%	
RA	535	55.8%	641	66.9%	

CX, circumflex artery; GLMM, generalized linear mixed-effects model; LAD, left anterior descending artery; OPCAB, off-pump coronary artery bypass grafting; RCA, right coronary artery.

additional conduit to the ITA. In 2 cases, off-pump surgery was performed. One death occurred with an unsupervised resident at last stage of training program, the second death occurred with a supervised resident at final stage, and in one case, information on resident status was not available.

Survival

In the matched cohort, mean follow-up time was 11 ± 4 years. Survival probability at 5, 10, and 15 years was 95.1% ± 0.7% vs 96.4% ± 0.6%, 87.0% ± 1.1% vs 87.8% ± 1.1%, and 76.6.% ± 1.8% vs 77.6% ± 1.8% in the resident and attending surgeon group, respectively (Fig. 3). The instantaneous risk of death (the hazard function) was found to have 2 hazard phases. The first was a declining hazard phase from the time of operation throughout nearly the first 30 months (early hazard). It then gave way to an increasing hazard phase beyond 30 months (late hazard, Supplementary Figure S3). Resident and attending surgeon cases showed comparable risk of death during both the early (hazard ratio [HR] = 1.24; 95% CI: 0.64-2.42; $P = 0.50$) and the late phase (HR = 1.01; 95% CI: 0.80-1.28; $P = 0.92$). When the clustering effect due to individual surgeon was added to the model, the 2 groups were still comparable for early phase (HR = 1.22; 95% CI: 0.63-2.38; $P = 0.57$) and late phase (HR = 1. 04; 95% CI: 0.80-1.33; $P = 0.79$). The excess risk for each attending surgeon (the random effect) had a standard deviation of 0.40 and 0.47 for early and late phase ($P = 1$ and $P = 0.003$). Therefore, approximately 15% of attending surgeons had the risk of late death of 1.6 times the normal and a similar fraction had lower risk thus suggesting a modestly large attending surgeon effect.

Table 3. Postoperative Outcomes in the Matched Cohort

	Resident (N = 958)		Attending (N = 958)		P_{GLMM}
	n	%	*n*	%	
Re-exploration for bleeding					
No	937	97.8	935	97.6	0.76
Yes	21	2.2	23	2.4	
SW reconstruction					
No	956	99.8	955	99.7	0.65
Yes	2	0.2	3	0.3	
Postoperative CVA					
No	951	99.3	953	99.5	0.53
Yes	7	0.7	5	0.5	
Postoperative RRT					
No	949	99.1	948	99.0	0.82
Yes	9	0.9	10	1.0	
Postoperative IABP					
No	947	98.9	947	98.9	1
Yes	11	1.1	11	1.1	
In-hospital mortality					
No	955	99.7	954	99.6	0.71
Yes	3	0.3	4	0.4	
Any of earlier complication					
No	911	95.1	908	94.8	0.75
Yes	47	4.9	50	5.2	
Length of stay, d (mean ± sd)	6.9 ± 4.3		7.1 ± 6.3		0.8

CVA, cerebrovascular accident; GLMM, generalized linear mixed-effects model; IABP, intra-aortic balloon pump; RRT, renal replacement therapy; SW, sternal wound.

Resident cases were not associated with higher risk of late death in case of early stage of training (HR = 1.11; 95% CI: 0.27-4.67; P = 0.88), intermediate stage (HR = 0.78; 95% CI: 0.41-1.48; P = 0.45), and final stage (HR = 1.20; 95% CI: 0.72-2.01; P = 0.47; Fig. 4). Finally, the equipoise of survival rates between the 2 groups persisted when we included either supervised (HR = 1.05; 95% CI: 0.70-1.59; P = 0.79) or unsupervised (HR = 0.81; 95% CI: 0.30-2.19; P = 0.68; Fig. 5) cases. The equipoise between the 2 groups for late mortality was confirmed among cases receiving BITA only (HR = 0.88; 95% CI: 0.54-1.43; P = 0.61), LITA plus RA (HR = 1.22; 95% CI: 0.92-1.61; P = 0.15) or the combination of BITA and RA grafting (HR = 0.74; 95% CI: 0.33-1.65; P = 0.47), and among off-pump (HR = 1.13; 95% CI: 0.83-1.55; P = 0.42) and on-pump (HR = 0.96; 95% CI: 0.70-1.37; Fig. 5). Finally, the 2 groups presented similar late survival when the analysis was stratified according to low risk (Euroscore 0-2: HR = 0.96; 95% CI: 0.69-1.34; P = 0.84), intermediate risk (Euroscore 3-5: HR

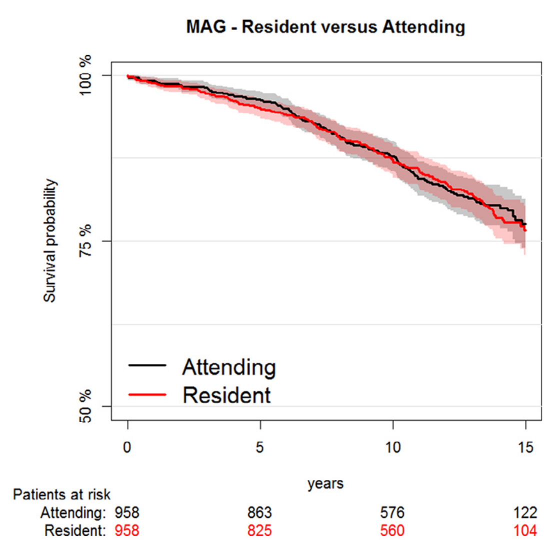

Figure 3. Survival probabilities after MAG performed by residents vs attending surgeons in the matched cohort. (Color version of figure is available online.)

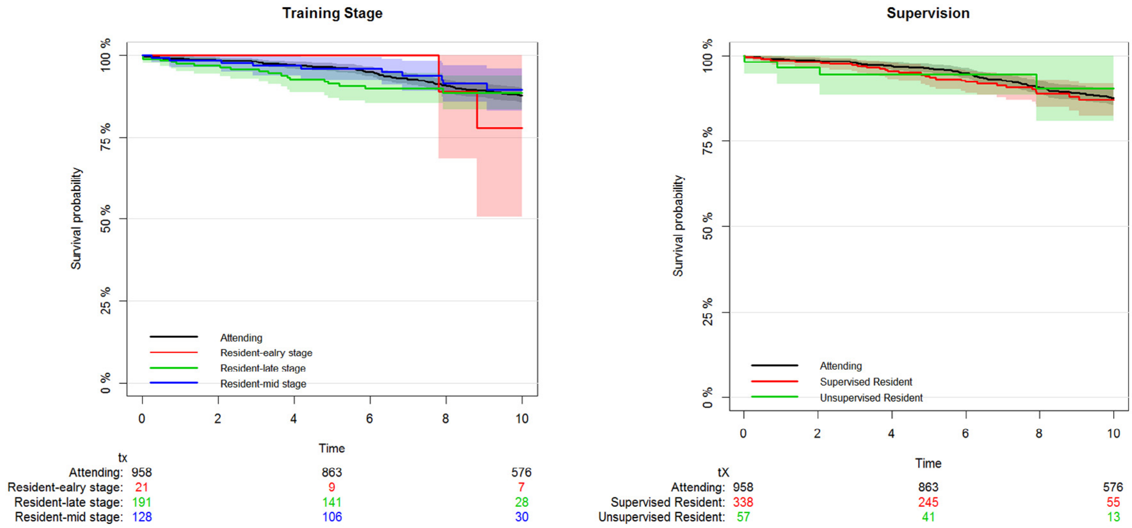

Figure 4. Survival probabilities after MAG performed by residents stratified for stage of training (left) and supervision (right) vs attending surgeons in the matched cohort. (Color version of figure is available online.)

= 0.96; 95% CI: 0.67-1.36; P = 0.82), and high risk (Euroscore 6 plus: HR = 0.94; 95% CI: 0.48-1.83; P = 0.87; Fig. 5).

DISCUSSION

The main finding of this study was that MAG can be safely performed by cardiac surgical residents. Early morbidity was particularly and survival rate up to 15 years were comparable with those observed in patients operated by attending surgeons.

Although the use of additional arterial grafts has been shown to be associated with better outcomes including prolonged survival,[1-4] CABG with MAG remains underused.[5,6] The learning curve has been cited as the most common reason for not performing MAG,[6] questioning whether this procedure should be at all part of a cardiothoracic training program. Performing MAG is undoubtedly technically demanding and patient's safety should always be a concern when training young surgeons. The effect of training on

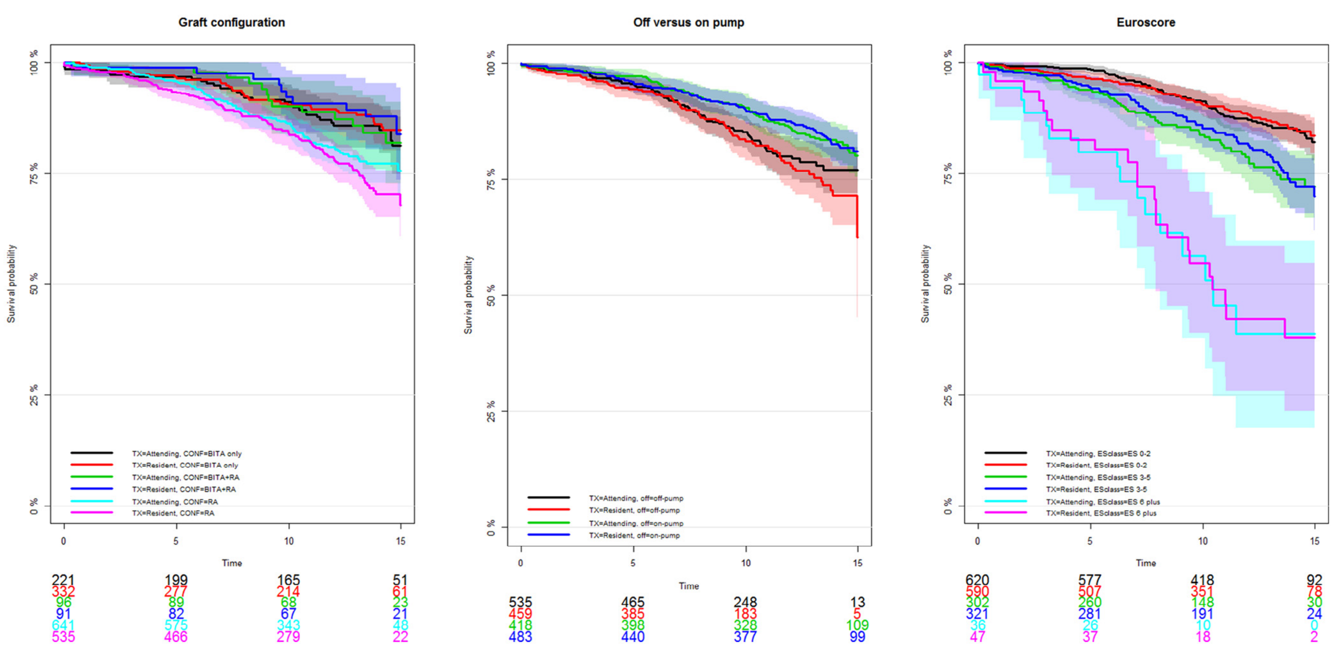

Figure 5. Survival probabilities after MAG performed by residents vs attending surgeons in the matched sample stratified for graft configuration (left), off-pump vs on-pump (central), and Euroscore (right). ES, Euroscore. (Color version of figure is available online.)

clinical outcome after cardiac surgery has been the subject of previous publications.[14-17] However, to the best of our knowledge, this is the first study that compared outcomes in patients undergoing CABG with MAG performed by residents vs attending surgeons, and we found that the 2 groups had comparable short-term outcomes and long-term survival. We noticed that residents were more likely to use BITA, whereas the use of RA was more common among cases performed by attending surgeons. This difference may be partially explained by the better quality of coronary anatomy of resident cases more suitable for BITA grafting. Unfortunately, information regarding the quality of native coronary arteries was not available in this retrospective study. However, our subgroup analysis confirmed the equipoise between residents and attending surgeons in performing MAG regardless the graft selection. MAG performed by resident was also shown to be safe during both on-pump and off-pump procedures. Finally, stage of training program did not significantly affect late survival. However, it should be noted that in UK, the training program in cardiothoracic surgery is preceded by a surgical core program that provides basic surgical skills training. In the present analysis, there were only few cases performed by resident without supervision and we cannot draw any final conclusion. In many institutions, trainees are preferentially allocated lower-risk and nonurgent CABG cases, so as not to compromise patient safety.[18] The same trend was found in the present analysis, and the increase in patient risk profile in more recent years translate into a lower relative volume of resident cases. However, subgroup analysis based on Euroscore risk classes confirmed that resident and attending surgeons were comparable in performing MAG regardless patient risk profile. Interestingly, using a mixed model, we found a significant effect of individual attending surgeon on late mortality regardless the procedure was performed by resident or not. These findings support the hypothesis that other factors may contribute to the safety and efficacy demonstrated by residents such as quality of attending surgeon supervision.[19] Indeed, in their analysis of >4000 CABG procedures, Elbardissi et al[20] found that the cumulative experience of a consultant-trainee pairing and their familiarity with one another was more significant predictor of operative outcomes than was individual surgeon experience. Similarly, our findings support the hypothesis that trainees can safely perform CABG with MAG in the context of a well-structured training program and appropriate supervision.

The present analysis has several limitations. First, it is a retrospective, observational report. Propensity technique can adjust only for measurable and included variables, and we cannot exclude a selection bias based on nonmeasurable "eye-ball" in favor of cases performed by residents. Patients operated on by the resident were selected by assessing their suitability for training taking into account not only the urgency of the operation and their comorbidities but also the quality of the coronary arteries. This information was not available for the present analysis. Furthermore, the training usually progresses to gradually increasing levels of complexity and responsibility according to the surgical abilities of the resident. The present analysis could not address whether or not the residents are truly trained on the procedures. Information regarding resident identity was largely missing and we could not analyze its random effect. We stratified our analysis according to stage of training but variation of ability and experience can occur within the same stage. Moreover, cases that were initially assigned to trainees may have required part of the procedure to be performed by the attending surgeon in the event of unexpected intraoperative complications or difficulties. Although this confounding could theoretically have biased our analysis toward a null value, it provides a more real-world clinical assessment of a surgical training program. To support our conclusions, we repeated the analysis in the cohort of non-MAG patients. By comparing 3556 matched pairs, we found that resident non-MAG cases were associated with comparable short-term outcomes (Supplementary Table S4) and survival when compared with non-MAG attending surgeon cases (HR = 0.85; 95% CI: 0.71-1.13; Supplementary Figure S4).

In conclusion, the present analysis confirms that MAG exposure during residency is safe without compromising outcomes when adequately supervised by experienced attending surgeons. Hands-on experience in the operative setting is essential for trainees to develop both the technical skills and clinical judgment required to independently use multiple arterial conduits. Given the perceived conflict between trainees' education and patient safety, it is imperative for surgical training policies to be guided by robust clinical data and high-level evidence.

SUPPLEMENTARY MATERIAL

Supplementary materials associated with this article can be found in the online version at http://dx.doi.org/10.1053/j.semtcvs.2017.01.002.

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