Total Arterial Revascularization is Safe: Multicenter Ten-Year Analysis of 71,470 Coronary Procedures

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Background. **The purpose of this study was to assess the use of arterial revascularization and to compare the in-hospital mortality with other CABG grafting strategies.**

Methods. **A total of 71,470 CABG patients (1992–2001) in 27 centers in the United Kingdom were studied. The proportion of patients with arterial revascularization was compared. In-hospital mortality was compared for various grafting strategies: all-arterial (n = 5,401), all non-all-arterial patients (n = 66,069), one artery any number of veins (n = 49,801). The groups were compared for in-hospital mortality using multivariate logistic regression to assess the independent effect of the grafting strategies on mortality; logistic EuroSCORE-predicted mortality was compared to actual mortality, and all arterial and one artery and veins patients were compared with propensity score analysis.**

Results. **There was a significant increase in the proportion of all-arterial patients over time (3.2% to 11.7%, $p < 0.001$) with evidence of variability across centers. Crude mortality for all-arterial patients was 2% vs 3% for all non-all-arterial patients ($p < 0.001$). In multivariate analysis, all-arterial was associated with a slight but insignificant increase in in-hospital mortality (odds ratio [OR] 1.13; [95% confidence interval {CI} 0.86–1.48], $p = 0.36$). There was a trend toward higher mortality in the all-arterial group when compared with the one artery and veins group (OR 1.19 [95% CI 0.91–1.56], $p = 0.10$). The one artery and veins group was the only group where actual mortality was significantly lower than predicted by EuroSCORE ($p < 0.001$). In propensity analysis the mortality was 1.51% for one artery and veins and 1.74% of all-arterial patients ($p = 0.56$).**

Conclusions. **The use of arterial grafting has increased over time, varies by center, and appears to be safe in terms of in-hospital mortality.**

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The left internal mammary artery (LIMA) has been definitively established as the conduit of choice in coronary artery bypass grafting (CABG) because of superior survival and event-free survival [1]. Naturally, interest has developed in the use of multiple arterial grafts. More recent reports of superior long-term patency and clinical outcomes with the use of multiple arterial grafts have led to growing interest in the use of complete arterial revascularization in CABG [2–5]. There is also some recent evidence that strategies that use only arterial conduits for bypass grafts provide excellent intermediate term clinical results, and appear to have graft patencies that are superior to saphenous vein grafts [6–8]. Several single center reports have demonstrated that complete arterial revascularization can be accomplished with acceptable in-hospital morbidity and mortality in selected patients [9–12].

However, concern has been raised about the immediate safety of total arterial grafting and its widespread applicability [13, 14]. Few studies have compared complete arterial revascularization with conventional LIMA and venous conduits (the standard operation in most centers), and none have been multicentered studies [14, 15]. The results are inconclusive and there is little knowledge about the use and safety of total arterial revascularization in general cardiac surgical practice.

The objectives of this study were to examine the trend in the use of total arterial revascularization over time in a large contemporary CABG database. In addition, the safety (in terms of in-hospital mortality) of this grafting strategy was compared with conventional single artery and venous grafting, as well as other combinations of arterial and venous grafting, in a multicenter database.

Material and Methods

Institutional ethical approval was obtained from Papworth Hospital and The National Adult Cardiac Surgical Database of the Society of Cardiothoracic Surgeons of Great Britain and Ireland (December 2003) for this retrospective database review. Data were obtained on isolated CABG patients from 27 centers in the United Kingdom, 1992–2001 (n = 97,291) from the National Adult Cardiac Surgical Database of the Society of Cardiothoracic Surgeons of Great Britain and Ireland [16]. This is a voluntary registry with centrally submitted and collated data, which is checked for internal consistency of data.

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Patients with single CABG (n = 4,195) or with inadequate detail of procedural data (n = 21,626) were excluded. An examination of those with and without adequate procedural data found no significant differences in risk factors or mortality. Thus this analysis is of 71,470 isolated CABG cases with two grafts or more. In-hospital mortality was compared for the different grafting strategies: all-arterial (AA, n = 5,401), all non-AA patients (AxV, n = 66,069) and this group was further subdivided based on the number of arterial grafts used (1 artery and veins (A1V), 2 arteries and veins (A2V), 3 arteries and veins (A3V), and veins only (VV). All-arterial use was compared across centers and over time using the χ^2 test. All analyses were performed with S-Plus statistical software (Insightful Corp, Hampshire, UK). Odds ratios (OR) reported are adjusted for all other covariates plus or minus the 95% confidence intervals (95% CI).

To investigate the safety of AA, the data were analyzed in four different ways.

(1) Crude in-hospital mortality was compared among the different grafting strategies.
(2) Logistic regression: 22 preoperative variables were compared among the groups using the χ^2 test (or linear-by-linear association for categoric variables) and *t* tests for continuous variables. Logistic regression analysis [17] was used to assess the independent effect of the different grafting strategies on in-hospital mortality. These are expressed as OR ± 95% CI. In addition, expected mortality was calculated from the logistic regression model for in-hospital mortality and presented as observed to expected mortality ratios.
(3) Actual versus predicted mortality: the crude mortality of each grafting strategy was compared with that predicted by a widely used risk model, the logistic European system for cardiac operative risk evaluation (EuroSCORE) [18].
(4) Propensity score analysis. We then focused the analysis on AA and A1V patients. To compare in-hospital mortality between the AA group and the A1V group (the "gold standard" operation), patients were compared using propensity score analysis [19]. The two groups were combined and AA group assignment was modeled using a nonparsimonious multivariate logistic regression model using 22 preoperative variables (Table 1). Based on the coefficients from this model a propensity score was generated for each of the patients in the two groups. Given the large numbers of patients we felt that in order to maximize the balancing of the propensity score analysis with the largest number of variables, and to avoid the pitfalls of imputing data, only patients with complete data should be considered for the matching process (AA n = 3,442, A1V n = 28,204). The propensity score (or probability of receiving AA) was then used to obtain a one-to-one match of actual AA patients with A1V patients (controls). In-hospital mortality was compared between these matched groups using the method described by Parsons [20].

Results

Trends

A total of 5,401 patients (7.6%) had total arterial grafting (AA). The proportion varied by center from 0.8% to 27.5% ($p < 0.001$). Overall the use of complete arterial grafting increased steadily over the years (Fig 1) from under 4% in 1992 to 12% in 2001 ($p < 0.001$). The remaining 66,069 patients had at least one vein graft (AxV) used. This group was further divided based on the number of arterial and venous conduits used (Table 2).

Crude Mortality

There were 2,095 deaths giving an overall crude mortality for CABG of 2.9%. Unadjusted mortality was 2.0% in the AA group and 3.0% in the AxV group ($p < 0.001$). All of the subgroups of different numbers of arterial and venous grafting had higher crude mortalities than the all-arterial grafting patients (Table 2).

Risk Profile

The lowest risk profile was in patients with more than one arterial graft who were younger, who had fewer comorbidities, and who had fewer urgent and emergency operations. The highest risk profile was in the VV group (Table 1).

Risk-Adjusted Mortality

Logistic EuroSCORE was calculated for the different grafting strategies. The VV group had a significantly worse than predicted mortality (Table 2). Both the AA and the A1V groups had results that were better than predicted by EuroSCORE, although only in the A1V group did this difference reach statistical significance (Table 2).

In our logistic regression analysis the VV group also had a significantly higher mortality than the reference A1V group (Table 3). The AA group had a slight but nonsignificant increased risk of death compared with the A1V group (Tables 2 and 3).

Arterial Revascularization Versus LIMA and Veins

Comparing AA directly with the "gold standard" operation (A1V), the crude mortality of the AA group (n = 5,401) was lower than the A1V group (n = 49,801); 2.04% vs 2.35% ($p = 0.15$). Bivariate comparison of the two groups demonstrated that the A1V patients as a group were older and had a greater burden of comorbidities (Table 4). In addition there was a slightly greater acuity of presentation and greater use of intravenous nitrates preoperatively in the A1V group. The AA group had significantly better ventricular function and fewer vessels grafted. However, there were significantly more redo procedures, prior cardiologic interventions, and recently failed cardiologic interventions in the AA group (Table 4). Importantly, the majority of AA patients (52.7%) received only two distal grafts; in contrast 81.2% of A1V patients received three or more grafts ($p < 0.001$). In

Table 1. Bivariate Comparisons of Different CABG Conduit Strategies

Variable	VV (%) (n = 9,105)	A1V (%) (n = 49,801)	A2V (%) (n = 6,635)	A3V (%) (n = 528)	AA (%) (n = 5,401)	*p* Value (Bivariate)
Female	29.7	18.3	14.1	10.9	16.7	<0.001
Age (years)	66.5 ± 9.2	62.9 ± 8.6	60.2 ± 9.4	58.3 ± 9.2	59.8 ± 9.5	<0.001
Body mass index	26.8 ± 4.0	27.3 ± 3.8	27.3 ± 3.7	27.6 ± 3.5	27.7 ± 3.8	<0.001
Hypertension	51.6	51.2	51.1	49.8	50.2	0.51
CVD/PVD	22.4	16.7	14.6	11.3	13.8	<0.001
Diabetes	19.2	17.7	14.8	14.3	14.8	<0.001
Renal insufficiency	3.4	1.7	0.8	1.1	1.0	<0.001
Ventilated (preop)	0.9	0.1	0.1	0.2	0.1	<0.001
Recently failed PCI	2.5	0.8	1.7	1.9	1.3	<0.001
Respiratory disease	10.1	7.3	7.0	4.7	6.8	<0.001
IABP	4.1	0.8	0.5	0.2	0.6	<0.001
Inotropes (preop)	1.9	0.3	0.2	0.4	0.2	<0.001
IV nitrates (preop)	8.8	5.9	2.5	3.8	3.8	<0.001
Left main stenosis	16.3	13.7	14.3	13.4	14.4	<0.001
Prior MI	50.5	44.8	33.6	36.6	34.2	<0.001
Redo surgery	7.1	2.7	3.3	1.6	4.2	<0.001
Prior PCI	4.2	3.2	3.7	6.6	6.4	<0.001
Acuity						
Elective	53.3	70.6	71.0	75.4	72.4	<0.001
Urgent	34.8	26.5	27.1	23.3	25.8	
Emergent	12.0	2.9	1.9	1.3	1.8	
EF						
<0.30	14.4	6.7	5.4	3.5	4.2	<0.001
0.30–0.49	31.8	28.3	27.5	28.3	24.4	
>0.49	53.8	65.0	67.0	68.2	71.3	
No. Distal grafts						
2	32.5	18.7	0.0	0.0	52.7	<0.001
3	47.9	48.4	61.1	0.0	38.2	
≥4	19.6	32.8	38.9	100	9.1	
Year of surgery						<0.001
Center						<0.001

A1V = 1 arterial + venous conduits; A2V = 2 arterial + venous conduits; A3V = 3 arterial + venous conduits; AA = all-arterial conduits; CVD/PVD = prior neurologic event; dysfunction or cerebrovascular disease, or peripheral vascular disease; EF = ejection fraction; IABP = intraaortic balloon pump; IV = intravenous; MI = myocardial infarction; No. = number; PCI = percutaneous coronary intervention; VV = all venous conduits.

multivariate analysis the AA patients had a slightly higher but nonsignificant increase in in-hospital mortality compared with the A1V (OR 1.19 [95% CI 0.91–1.56], $p = 0.10$).

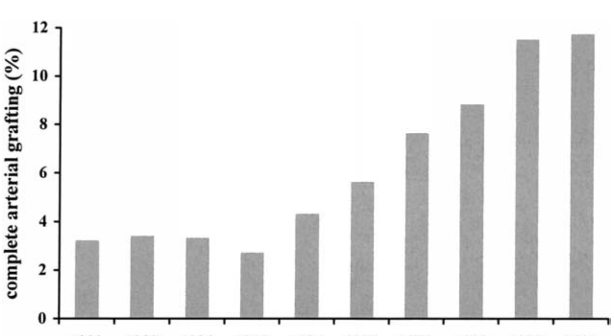

Fig 1. Proportion of patients receiving complete arterial grafting.

In the propensity score analysis we were able to match 2,246 of the AA patients to 2,246 A1V patients. The propensity scores were virtually identical between the groups: A1V mean 0.262 ± STD 0.201, AA 0.262 (± STD 0.201), $p = 0.98$. The groups were very well-matched for all the variables considered, with no statistically of clinically significant differences between the groups (Table 5). There were 34 deaths in the A1V group (1.51%) and 39 deaths in the AA group (1.74%), $p = 0.56$. In order to have 80% power to detect a 0.22% difference in mortality we would require 47,437 patients per group.

Based on our logistic regression model for mortality the predicted mortalities of the propensity-matched groups were 1.38% for the A1V group and 1.48% for the AA group. EuroSCORE also predicted that the AA group would have a slightly higher mortality than the A1V patients (2.47% vs 2.35%).

Table 2. In-Hospital Mortality by CABG Conduit Strategy

Conduit Group	Number	Observed Mortality	Predicted Mortality (EuroSCORE)	Observed/Expected Mortality Ratio[a] [95% CI]	*p* Value
(AA) all-arteries	5,401	2.04%	2.31%	0.88 [0.73–1.06]	0.192
(A3V) 3 arteries + veins	528	2.84%	1.91%	1.48 [0.83–2.45]	0.124
(A2V) 2 arteries + veins	6,635	2.61%	2.28%	1.14 [0.98–1.33]	0.076
(A1V) 1 artery + veins	49,801	2.35%	2.74%	0.86 [0.81–0.91]	<0.001
(VV) veins only	9,105	6.91%	4.87%	1.42 [1.31–1.53]	<0.001
(AxV) all non-AA cases	66,069	3.00%	2.98%	1.01 [0.97–1.06]	0.677
Overall	71,470	2.93%	2.93%	1.00 [0.96–1.05]	0.933

[a] Observed/expected ratio: expected mortality calculated for the group from the logistic regression model for mortality based on this data set.

CABG = coronary artery bypass grafting; CI = confidence interval; EuroSCORE = European system for cardiac operative risk evaluation.

Comment

There has been increasing interest in arterial grafting because of the purported superior longer term results. Long-term graft patency and freedom from reoperation and recurrent angina appear to be better [2–4, 8, 21]. However, very few studies have compared arterial grafting with an appropriate control group and none of the studies has been multicentered. Many surgeons still feel that the effectiveness of arterial grafting, beyond the use of the LIMA-to-left anterior descending coronary artery graft, remains unproven. This is reflected in the poor uptake of arterial grafting in many centers [22].

We have demonstrated in a large contemporary multicenter database that the use of complete arterial revascularization has increased dramatically over time, but appears to vary substantially by center. The crude mortality for patients undergoing complete arterial revascularization was 2.04%, similar to previous single-center series, which range from 0.2% to 3.0% [6, 10–12, 14, 21]. After adjusting for patient profile differences among the various grafting strategies, there was no significant difference in in-hospital. The absolute difference is very small (0.23%) in the propensity analysis, and would require groups of nearly 50,000 propensity-matched patients for this to reach statistical significance.

There are theoretical reasons for a possible increased mortality with arterial grafts. All-arterial grafting is technically more demanding and there is undoubtedly a learning curve for the procedure [13, 14, 23]. Patients with critical proximal lesions may be at some early risk if the

Table 3. Multivariate Comparison of In-Hospital Mortality by CABG Conduit Strategy [Adjusted Odds Ratios]

Conduit Group	Odds Ratio	95% CI
(AA) all-arterial conduits	1.19	[0.91–1.56]
(A3V) 3 arterial + venous conduits	1.33	[0.64–2.75]
(A2V) 2 arterial + venous conduits	1.03	[0.81–1.31]
(VV) all venous conduits	1.30	[1.09–1.56]
(A1V) 1 arterial + venous conduits	1	Reference

CABG = coronary artery bypass grafting; CI = confidence interval.

Table 4. Bivariate Comparisons of CABG Conduit Strategy Using 1 Artery and Veins With All-Arterial Grafting

Variable	A1V (%) (n = 49,801)	AA (%) (n = 5,401)	*p* Value (Bivariate)
Female	18.3	16.7	0.005
Age (years)	62.9 ± 8.6	59.8 ± 9.5	<0.001
Body mass index	27.3 ± 3.8	27.7 ± 3.8	<0.001
Hypertension	51.2	50.2	0.161
CVD/PVD	16.7	13.8	<0.001
Diabetes	17.7	14.8	<0.001
Renal insufficiency	1.7	1.0	<0.001
Ventilated (preop)	0.1	0.1	0.611
Recently failed PCI	0.8	1.3	<0.001
Respiratory disease	7.3	6.8	0.175
IABP	0.8	0.6	0.087
Inotropes (preop)	0.3	0.2	0.147
IV nitrates (preop)	5.9	3.8	<0.001
Left main stenosis	13.7	14.4	0.173
Prior MI	44.8	34.2	<0.001
Redo surgery	2.7	4.2	<0.001
Prior PCI	3.2	6.4	<0.001
Acuity			
Elective	70.6	72.4	<0.001
Urgent	26.5	25.8	
Emergent	2.9	1.8	
EF			
<0.30	6.7	4.2	<0.001
0.30–0.49	28.3	24.4	
>0.49	65.0	71.3	
Number distal grafts			
2	18.7	52.7	<0.001
3	48.4	38.2	
≥4	32.8	9.1	
Year of surgery			<0.001
Center			<0.001

AA = all-arterial conduits; A1V = 1 arterial and venous conduits; CVD/PVD = prior neurologic event; dysfunction or cerebrovascular disease, or peripheral vascular disease; EF = ejection fraction; IABP = intraaortic balloon pump; IV = intravenous; MI = myocardial infarction; PCI = percutaneous coronary intervention.

Table 5. Bivariate Comparisons of Propensity-Matched Patients for Two CABG Conduit Strategies

Variable	A1V (%) (n = 2,246)	AA (%) (n = 2,246)	*p* Value (bivariate)
Female	18.7	17.4	0.24
Age (years)	60.67 ± 9.30	60.39 ± 9.40	0.21
Body mass index	27.61 ± 3.94	27.82 ± 3.72	0.07
Hypertension	52.0	52.8	0.63
CVD/PVD	13.8	13.9	0.93
Diabetes	16.3	14.8	0.17
Renal insufficiency	1.3	1.4	0.70
Ventilated (preop)	0.2	0.1	>0.99
Recently failed PCI	1.2	1.0	0.57
Respiratory disease	8.3	7.6	0.38
IABP	0.7	0.9	0.40
Inotropes (preop)	0.1	0.2	0.69
IV nitrates (preop)	5.7	4.6	0.11
Left main stenosis	15.6	15.3	0.77
Prior MI	39.4	38.9	0.69
Redo surgery	3.7	4.1	0.49
Prior PCI	7.2	7.6	0.65
Acuity			
Elective	73.2	74.0	0.80
Urgent	24.5	23.9	
Emergent	2.3	2.1	
EF			
< 0.30	3.5	3.7	0.65
0.30–0.49	21.7	22.7	
> 0.49	74.8	73.6	
Number of distal grafts			
2	45.0	44.3	0.88
3	43.7	44.1	
≥ 4	11.3	11.6	
Year of surgery			0.77
Center			0.99

AA = all-arterial conduits; A1V = 1 arterial and venous conduits; CVD/PVD = prior neurologic event; dysfunction or cerebrovascular disease, or peripheral vascular disease; EF = ejection fraction; IABP = intraaortic balloon pump; IV = intravenous; MI = myocardial infarction; PCI = percutaneous coronary intervention.

arterial conduits used do not "deliver" immediately due to small size or liability to vasospasm. In addition, selection of patients for this grafting strategy and differences in perioperative management are yet to be completely elucidated [3, 14, 23].

Looking at the various grafting strategies, the patients grafted with only venous conduits had a significantly higher observed and predicted mortality than all the other groups. This may be related more to risk profile than the choice of conduit, as this group often contains salvage procedures and multiple comorbidities, which may either prohibit or be perceived to prohibit the harvest of arterial conduits. The all-arterial and the single artery and vein graft patients had lower than predicted mortalities, but only the A1V group did significantly better than EuroSCORE, emphasizing the remarkable safety record of the "standard" operation. Patients who received a mix of two or three arterial grafts and veins were quite similar to the all-arterial graft patients, yet had higher than predicted mortality. Some of these patients may have had attempted complete arterial grafting and subsequently required adjuvant vein grafts due to perioperative complications, or arteries were used due to lack of adequate venous conduit.

There is relatively scant previous work comparing all-arterial grafting with conventional single artery and venous grafts. In a small single-center series Legare and colleagues [14] found increased morbidity but not mortality with complete arterial grafting. Three small single-center randomized trials (from the same center) have recently compared complete arterial grafting with single artery and venous grafting. All three studies demonstrated no difference in in-hospital mortality but significantly better freedom from angina and the need for PCI at 12 months in the all-arterial group [15, 24]. Despite this, total arterial grafting has not become the universal standard. This is perhaps because of the relatively small body of evidence supporting its long-term superiority, together with recent work suggesting that the intermediate outcome with vein grafts may in fact be much better in the current era [25]. In addition the procedure is more complex and takes longer to perform. In fact, previous studies have noted a poor uptake of arterial grafting which is likely due to a perceived higher morbidity and mortality as well as a lack of definitive evidence of benefit [22].

Limitations

There are a number of important weaknesses in this study. The database is voluntary and there is no formal validation process, although a recent study using the STS registry found that unaudited databases can be highly accurate [26]. We were only able to look at in-hospital mortality and not morbidity, which may be significantly higher in the all-arterial patients [14]. The use of complete arterial revascularization is correlated with center and a year, and not all centers contributed consistently for all the years of the study. In addition, surgeon specific detail was not available; clearly some centers (and surgeons) are much more committed to arterial grafting than others. Furthermore this is a fairly low-risk group of patients. Therefore we cannot comment on the outcomes in higher risk patients. This low-risk group of all-arterial patients may in fact reflect good judgment by the surgeons as they attempt to master a new technique.

In addition, the AA patients and the conventional A1V patients were quite different in terms of number of distal grafts and the proportion of cases that were redo cases (Table 4). This may indicate that some AA patients had complete arterial revascularization because of venous conduit unavailability rather than a desire on the part of the surgeon to undertake such a strategy for its supposed benefits. Using propensity analysis, we were able to adjust for the differences in center, year, proportion of redo cases, and number of distal grafts, and the results were consistent with the other analyses. Unfortunately we did not have the level of procedural detail to identify which grafts were placed to which vessels and about the extent of coronary disease, although the number of distal anastomoses performed is probably a reasonable surrogate for extent of disease.

In summary, the present study demonstrates an apparent increasing interest in the use of complete arterial grafting in CABG surgery in the United Kingdom. However, there is great variation across centers and likely between individual surgeons. Despite the purported benefits of complete arterial revascularization, its overall use by surgeons in the United Kingdom remains very low. This method of revascularization is safe in terms of in-hospital mortality in low-risk patients. Further study is needed to examine differences in in-hospital morbidity and long-term results in comparison with the more prevalent standard grafting strategy of single artery and veins.

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