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Short-term Outcomes and Long-term Survival in Females after Single, Multiple, and Total Arterial Grafting

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Abstract: Objective: Arterial grafting strategies in coronary artery bypass grafting (CABG) may influence outcomes, particularly in female patients, who remain underrepresented in cardiovascular research. This study aimed to evaluate short-term outcomes and long-term survival in females undergoing single arterial grafting (SAG), multiple arterial grafting (MAG), and total arterial grafting (TAG). Methods: A retrospective cohort of 2,093 female patients undergoing CABG was stratified into SAG (n=1,507), MAG (n=307), and TAG (n=279). Baseline demographics, procedural characteristics, and postoperative outcomes were compared using appropriate statistical tests. Long-term survival was assessed using inverse probability treatment weighted Cox regression, accounting for age, comorbidities, and extent of coronary artery disease. Results: TAG and MAG patients were significantly younger than SAG patients ($p<0.001$). TAG patients had fewer prior myocardial infarctions ($p=0.003$) and lower diabetes prevalence ($p=0.003$). Deep sternal wound infection was more frequent in TAG (7.2%) compared to SAG (2.6%, $p=0.003$). Thirty-day mortality and other short-term complications did not differ significantly across groups. Weighted Cox regression revealed no significant difference in long-term survival between grafting strategies (MAG HR=1.193, $p=0.213$; TAG HR=0.952, $p=0.729$). Age and prior cardiac surgery were independent predictors of mortality. The proportional hazards assumption was met (global test $p=0.378$), and Kaplan-Meier analysis confirmed comparable survival across groups (Wald $\chi^2=0.56$, $p=0.755$). Conclusion: In female patients undergoing CABG, TAG was associated with higher wound infection rates but did not confer a survival advantage over SAG or MAG. These findings support individualized arterial grafting strategies based on patient risk profiles and surgical judgment.

Keywords: Arterial grafting strategy, coronary artery bypass grafting, deep sternal wound infection, female, long-term survival

INTRODUCTION

Coronary artery bypass grafting (CABG) remains a cornerstone of surgical revascularization for patients with multivessel coronary artery disease[1]. Over the past two decades, arterial grafting strategies have gained prominence due to their superior long-term patency compared to venous conduits[2]. While multiple arterial grafting (MAG) and total arterial grafting (TAG) have demonstrated promising outcomes in selected populations, their adoption remains variable, particularly in female patients[3].

Women undergoing CABG represent a distinct clinical subgroup, often presenting with smaller coronary vessels, higher comorbidity burden, and increased perioperative risk[4]. Despite these differences, female patients have historically been underrepresented in cardiovascular surgical trials, limiting the generalizability of existing evidence[5]. Moreover, concerns regarding deep sternal wound infection (DSWI), technical complexity, and perceived lack of survival benefit have contributed to cautious use of extensive arterial grafting in women[4,6].

Recent studies have begun to explore the impact of arterial grafting strategies on outcomes in female cohorts, yet comparative data across single arterial grafting (SAG), MAG, and TAG remain sparse[7]. In particular, the balance between short-term morbidity and long-term survival benefit in women undergoing more extensive arterial revascularization warrants further investigation[8].

This study aims to evaluate short-term outcomes and long-term survival in female patients undergoing SAG, MAG, and TAG. By utilizing a large retrospective cohort and applying inverse probability treatment weighting (IPTW) to adjust for baseline differences, we seek to clarify the prognostic implications of arterial grafting strategy in women and inform individualized surgical decision-making.

METHODS

Data Source

This retrospective study was conducted using prospectively collected data from the institutional cardiac surgery registry (Patient Analysis and Tracking System, Dendrite Clinical Systems, Oxford, UK). The registry captures detailed clinical information across the perioperative continuum, including procedural variables, in-hospital outcomes, and long-term survival. It undergoes regular external validation and contributes annually to the National Adult Cardiac Surgery Audit, coordinated by the National Institute for Cardiovascular Outcomes Research. Mortality data were verified using both internal hospital records and the NHS Spine system. Follow-up completeness was confirmed for all patients, with mean durations of 10.9 ± 7.0 years for SAG, 11.5 ± 7.9 years for MAG, and 13.2 ± 7.4 years for TAG. Institutional approval was granted (QS/SR-FCABG 04/24), and individual consent was waived in accordance with the retrospective nature of the study and the principles of the Declaration of Helsinki.

Study Cohort

All female patients undergoing isolated coronary artery bypass grafting with two or more grafts between January 1996 and September 2023 were eligible. A total of 2,093 patients were included and stratified into three groups: SAG (n=1,507), MAG (n=307), and TAG (n=279). Surgical planning was guided by a multidisciplinary team comprising cardiac surgeons, interventional cardiologists, and imaging specialists. Urgency of surgery was managed through a standardized institutional triage protocol.

Operative Strategy

All procedures were performed via median sternotomy. Use of cardiopulmonary bypass was at the discretion of the operating surgeon and recorded for each case. Conduit selection was based on coronary anatomy and surgeon preference. SAG involved a single arterial conduit—typically the left internal mammary artery—supplemented by saphenous vein grafts. MAG included two or more arterial conduits (e.g., left and right internal mammary arteries or radial artery) with additional venous grafts as needed. TAG comprised exclusively arterial conduits, including combinations of internal mammary, radial, and gastroepiploic arteries, without venous grafting.

Postoperative Care

All patients received standardized postoperative management in a dedicated cardiac intensive care unit. Protocols for ventilation, fluid management, and inotropic support were uniformly applied. Antiplatelet therapy, including dual-agent regimens, was individualized based on surgeon discretion and patient-specific factors.

Statistical Analysis

Continuous variables were reported as means ± standard deviations and compared using one-way analysis of variance (ANOVA), followed by Bonferroni-adjusted post hoc testing. Categorical variables were presented as counts and percentages, with comparisons made using the chi-squared test or Kruskal-Wallis test for non-parametric distributions. Pairwise comparisons were conducted using the Dunn test. Survival estimates were generated using Kaplan-Meier analysis, and differences between groups were assessed using the log-rank test. All analyses were performed using STATA version 18.0 (StataCorp LLC, College Station, TX, USA), with statistical significance defined as $p < 0.05$.

Multivariable Mortality Analysis

Cox proportional hazards regression was used to identify independent predictors of long-term mortality. Variables with $p < 0.05$ in univariate analysis were considered for inclusion in the multivariable model, with conduit type (SAG, MAG, TAG) retained as a forced variable. Initial covariates included age, NYHA class, prior myocardial infarctions, previous cardiac surgery, hypertension, diabetes, hypercholesterolemia, congestive heart failure, peripheral vascular disease, renal dysfunction, cerebrovascular disease, pulmonary disease, left main stem involvement, extent of coronary artery disease, left ventricular ejection fraction, preoperative atrial fibrillation, and smoking status. To avoid overfitting, variable inclusion was limited to one per ≥20 events. Stratification was applied for NYHA class and LMS disease due to proportionality violations, and time-dependent covariates were introduced for diabetes and ejection fraction.

Inverse Probability Treatment Weighted Analysis

To address baseline imbalances and reduce confounding, inverse probability treatment weighting (IPTW) was applied using propensity scores derived from logistic regression. Each patient was assigned a weight inversely proportional to the probability of receiving their observed grafting strategy. This generated a pseudo-population with balanced covariates across SAG, MAG, and TAG groups. Covariate balance was confirmed using weighted means. Weighted Cox regression was then performed on the IPTW sample, with additional adjustment for residual confounders and stratification for variables violating proportional hazards assumptions. This doubly robust approach enhances the validity of treatment effect estimates.

RESULTS

Baseline Characteristics

A total of 2,093 female patients undergoing coronary artery bypass grafting were included: 1,507 received single arterial grafting (SAG), 307 received multiple arterial grafting (MAG), and 279 underwent total arterial grafting (TAG). Patients in the MAG and TAG groups were significantly younger than those in the SAG group (MAG vs SAG: mean difference −4.52 years, p<0.001; TAG vs SAG: −3.79 years, p<0.001). TAG patients had fewer prior myocardial infarctions (68.1% with no MI vs 56.1% in SAG, p=0.003) and lower diabetes prevalence (26.2% vs 38.4%, p=0.003). Prior cardiac surgery was more frequent in MAG (2.9%) compared to SAG (0.3%, p=0.003). The extent of coronary artery disease differed significantly across groups, with three-vessel disease most prevalent in MAG (87.9%) and least in TAG (57.0%, p<0.001). Other baseline variables, including NYHA class, hypertension, hypercholesterolemia, and left ventricular ejection fraction, were comparable across groups (Tables 1 and 2). Conduit strategy also varied across surgical eras (Table 3).

Table 1: Baseline demographic and procedural characteristics for study population comparing SAG, MAG, and TAG

Variable	SAG (n = 1507)	MAG (n = 307)	TAG (n = 279)	p value
Age (years)	68.3 +-9.0	63.7 +-9.9	64.5 +-10.5	<0.001[a,b]
NYHA classification				0.325
Class I	321 (21.3%)	66 (21.5%)	74 (26.5%)	
Class II	653 (43.3%)	145 (47.2%)	122 (43.7%)	
Class III	418 (27.7%)	74 (24.1%)	64 (22.9%)	
Class IV	115 (7.6%)	22 (7.2%)	19 (6.8%)	
CHF				0.309
Never	1381 (91.6%)	279 (90.9%)	265 (95.0%)	
Past	65 (4.3%)	16 (5.2%)	6 (2.2%)	
Now	61 (4.0%)	12(3.9%)	8 (2.9%)	
Previous MI				<0.001[b,c]
None	846 (56.1%)	168 (54.7%)	190 (68.1%)	
One MI	589 (39.1%)	123 (40.1%)	81 (29.0%)	
Two MIs	27 (1.8%)	11 (3.6%)	7 (2.5%)	
Three or more MIs	45 (3.0%)	5(1.6%)	1 (0.4%)	
Previous cardiac surgery	5 (0.3%)	9 (2.9%)	3 (1.1%)	<0.001[a]
Diabetes	579 (38.4%)	106 (24.5%)	73 (26.2%)	<0.001[b]
Hypercholesterolemia	1157 (76.8%)	229 (74.6%)	207 (74.2%)	0.517
Hypertension	1013 (67.2%)	196 (63.8%)	184 (65.9%)	0.507
PVD	138 (9.2%)	27 (8.8%)	25 (9.0%)	0.977
Smoking Status				0.220
Never	879 (58.3%)	171 (55.7%)	148 (53.0%)	
Ex-smoker	511 (33.9%)	108 (35.2%)	114 (40.9%)	

Current smoker	117 (7.8%)	28 (9.1%)	17 (6.1%)	
Renal disease	63 (4.2%)	7 (2.3%)	9 (3.2%)	0.246
Respiratory disease	167 (11.1%)	32 (10.4%)	28 (10.0%)	0.847
Cerebrovascular disease	69 (4.6%)	16 (5.2%)	16 (5.7%)	0.670
Preoperative AF	36 (2.4%)	8 (2.6%)	6 (2.2%)	0.937
Extent of CAD				<0.001[a,b,c]
1 vessel	48 (3.2%)	6(2.0%)	21 (7.5%)	
2 vessels	338 (22.4%)	31 (10.1%)	99 (35.5%)	
3 vessels	1121 (74.4%)	270 (87.9%)	159 (57.0%)	
LMS disease	347 (23.0%)	77 (25.1%)	79 (28.3%)	0.148
LVEF				0.138
Good (>50%)	1229 (81.6%)	247(80.5%)	244(87.5%)	
Fair (30-50%)	241 (16.0%)	50 (16.3%)	31 (11.1%)	
Poor (<30%)	37 (2.5%)	10 (3.3%)	4 (1.4%)	
Logistic EuroSCORE	4.2 ± 6.2	4.1 ± 6.0	3.8 +-4.4	0.557

Superscripts indicate pairwise group comparisons with statistical significance (P < 0.05):, a = SAG vs MAG, b = SAG vs TAG, c = MAG vs TAG, AF = atrial fibrillation; CAD = Coronary Artery Disease; LMS = Left Main Stem; LVEF = left ventricular ejection fraction; MAG = multiple arterial grafting; MI = Myocardial infarction; NYHA = New York Heart Association; SAG = single arterial grafting; TAG = total arterial grafting

Table 2: Post hoc Bonferroni comparisons

Variable	Comparison	Mean Difference	Bonferroni Adjusted p value
Age	MAG vs SAG	-4.52	<0.001
	TAG vs SAG	-3.79	<0.001
	MAG vs TAG	0.72	1.000
Previous MIs	MAG vs SAG	—	0.372
	TAG vs SAG	—	0.003
	MAG vs TAG	—	0.021
Previous Cardiac Surgery	MAG vs SAG	—	0.003
	TAG vs SAG	—	0.264
	MAG vs TAG	—	0.339
Diabetes	MAG vs SAG	—	0.600
	TAG vs SAG	—	0.003
	MAG vs TAG	—	0.084
Extent of CAD	MAG vs SAG	—	0.003
	TAG vs SAG	—	0.003
	MAG vs TAG	—	0.003
DSWI	MAG vs SAG	—	0.093
	TAG vs SAG	—	0.003
	MAG vs TAG	—	0.732
Follow-up Years	MAG vs SAG	0.553	0.659
	TAG vs SAG	2.22	<0.001
	MAG vs TAG	1.66	0.016

CAD = coronary artery disease; DSWI = deep sternal wound infection; MAG = multiple arterial grafting; MI = myocardial infarction; SAG = single arterial grafting; TAG = total arterial grafting

Table 3: Distribution of conduit strategies according to surgical era

Surgical era	SAG, n (%)	MAG, n (%)	TAG, n (%)	Total, n
1996–2005	493 (63.0)	149 (19.0)	141 (18.0)	783
2006–2014	578 (81.9)	67 (9.5)	61 (8.6)	706
2015–2023	428 (73.5)	88 (15.1)	66 (11.3)	582

SAG = single arterial grafting; MAG = multiple arterial grafting; TAG = total arterial grafting.

Short-Term Outcomes

Thirty-day mortality did not differ significantly between groups (SAG: 2.8%, MAG: 4.2%, TAG: 2.5%; p=0.352). Rates of reoperation, tracheostomy, cerebrovascular events, and renal replacement therapy were also similar. However, deep sternal wound infection was significantly more frequent in TAG (7.2%) compared to SAG (2.6%, p=0.003). Mean follow-up duration was longest in the TAG group (13.2 ± 7.4 years), followed by MAG (11.5 ± 7.9 years) and SAG (10.9 ± 7.0 years; p<0.001) (Tables 2 and 4).

Table 4: Short-term outcomes

Variable	SAG (n = 1507)	MAG (n = 307)	TAG (n = 279)	p value
Reoperation	51 (3.4%)	14 (4.6%)	6 (2.2%)	0.274
Tracheostomy	21 (1.4%)	6 (2.0%)	3 (1.1%)	0.650
CVA/TIA	29 (1.9%)	7 (2.3%)	7 (2.5%)	0.782
RRT	41 (2.7%)	8 (2.6%)	6 (2.2%)	0.861
DSWI	39 (2.6%)	15 (4.9%)	20 (7.2%)	$<0.001^{b}$
Death at 30 Days	42 (2.8%)	13 (4.2%)	7 (2.5%)	0.352
Mean Follow-up (years)	10.9 ± 7.0	11.5 ± 7.9	13.2 ± 7.4	$<0.001^{b,c}$

Superscripts indicate pairwise group comparisons with statistical significance (p < 0.05): a = SAG vs MAG, b = SAG vs TAG, c = MAG vs TAG, CVA = Cerebrovascular Accident; DSWI = Deep Sternal Wound Infection; MAG = multiple arterial grafting; RRT= Renal Replacement Therapy; SAG = single arterial grafting; TAG = total arterial grafting; TIA = Transient Ischaemic Attack

Unadjusted Survival Analysis

Kaplan-Meier analysis of the unweighted sample revealed no significant difference in long-term survival between grafting strategies (log-rank x^2=1.03, p=0.599). Estimated survival at 10 years was 87.4% for SAG, 86.2% for MAG, and 89.8% for TAG. At 25 years, survival declined to 47.1% for SAG, 58.8% for MAG, and 51.1% for TAG (Table 5, Figure 1).

Table 5: Survival estimates of unweighted sample

Time (years)	SAG	MAG	TAG
5	0.951	0.945	0.976
10	0.874	0.862	0.898
15	0.758	0.736	0.805
20	0.612	0.600	0.632
25	0.471	0.588	0.511

X^2 = 1.03 p = 0.599 - no significant difference in long term survival, MAG = multiple arterial grafting; SAG = single arterial grafting; TAG = total arterial grafting

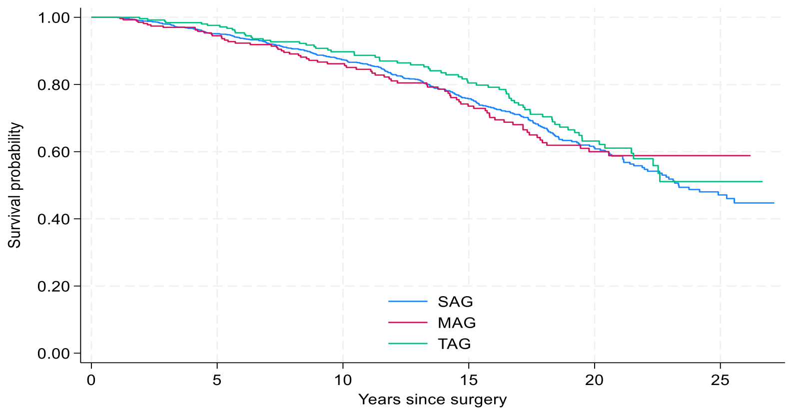

Figure 1: Unadjusted Kaplan-Meier survival curves

IPTW Survival Analysis

Inverse probability treatment weighting was applied to balance baseline covariates across groups; all covariates achieved adequate balance after weighting (Table 6, Figure 2). Weighted Kaplan-Meier curves confirmed comparable survival outcomes (Wald x^2=0.56, p=0.755). Ten-year survival estimates in the IPTW sample were 1,155 for SAG, 1,143 for MAG, and 1,253 for TAG (Table 7, Figure 3).

Table 6: Baseline covariate balance before and after inverse probability treatment weighting

Variable	SMD Before IPTW	SMD After IPTW
PVD	0.013	0.056
Preoperative AF	0.03	0.049
Chronic pulmonary disease	0.034	0.03
Cerebrovascular disease	0.052	0.064
Hypercholesterolemia	0.06	0.032
Hypertension	0.071	0.054
Logistic EuroSCORE	0.078	0.057
Renal dysfunction	0.107	0.014
LMS disease	0.121	0.072
NYHA	0.122	0.054
Smoking	0.144	0.075
CHF	0.163	0.122
LVEF	0.191	0.045
Previous cardiac surgery	0.205	0.047
Year of surgery	0.248	0.05
Diabetes	0.262	0.06
Previous MI	0.275	0.049
Age	0.477	0.098
Extent of CAD	0.693	0.049

AF = atrial fibrillation; CAD = coronary artery disease; CHF = congestive heart failure; IPTW = inverse probability treatment weighting; LMS = left main stem; LVEF = left ventricular ejection fraction; MI = myocardial infarction; NYHA = New York Heart Association; PVD = peripheral vascular disease; SMD = standardized mean difference.

Absolute standardized mean differences are presented across the single, multiple, and total arterial grafting groups. Propensity scores were estimated using multinomial logistic regression, and stabilized inverse probability treatment weights were applied. Covariate balance was considered adequate when absolute standardized mean differences were <0.10.

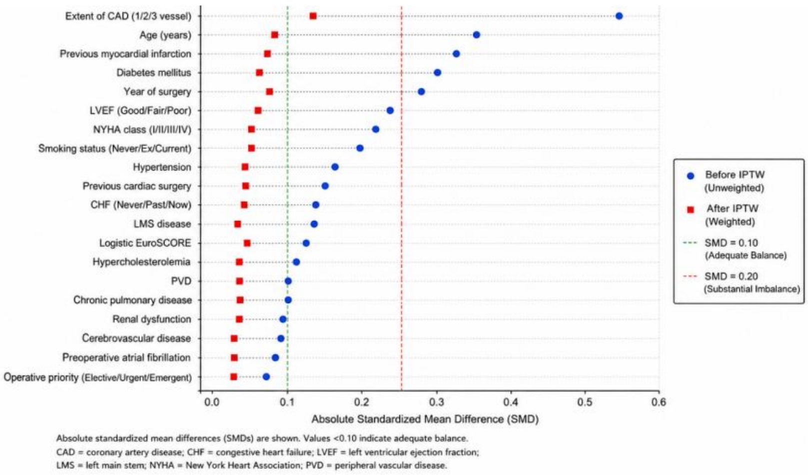

Figure 2: Love plot demonstrating absolute standardized mean differences for baseline covariates before and after inverse probability treatment weighting. Values <0.10 indicate adequate covariate balance.

Table 7: Survival estimates of IPTW sample

Time (years)	SAG	MAG	TAG
5	1579	1555	1691
10	1155	1143	1253
15	669	751	935
20	244	364	404
25	81	52	36

Wald X^2 = 0.56 p = 0.755 – no significant difference in long term survival. IPTW = inverse probability treatment weighted; MAG = multiple arterial grafting; SAG = single arterial grafting; TAG = total arterial grafting

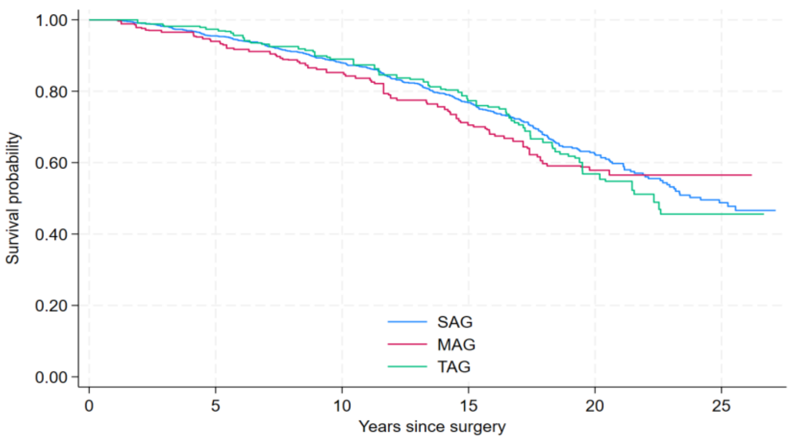

Figure 3: Inverse Probability Treatment Weighted Kaplan-Meier survival curves

Cox Regression Analysis

In the unweighted multivariable Cox model, conduit type was not a significant predictor of mortality (MAG: HR=1.059, p=0.688; TAG: HR=1.010, p=0.941). Independent predictors included age (HR=1.041 per year, p<0.001), previous cardiac surgery (HR=2.391, p=0.003), and reduced ejection fraction (HR=1.238, p=0.023) (Table 8). The proportional hazards assumption was met (global test p=0.323).

Table 8: Unweighted Cox regression

Univariate Cox regression					Multivariate Cox regression			
Variable	**HR**	**95% CI Lower**	**95% CI Upper**	**p value**	**HR**	**95% CI Lower**	**95% CI Upper**	**p value**
SAG (ref)	1							
MAG	0.961	0.736	1.255	0.771	1.059	0.800	1.401	0.688
TAG	0.875	0.680	1.127	0.301	1.010	0.782	1.304	0.941
Age	1.039	1.028	1.050	<0.001	1.041	1.030	1.054	<0.001
NYHA I (ref)	1							
NYHA II	1.021	0.813	1.280	0.860				
NYHA III	1.203	0.934	1.551	0.153				
NYHA IV	01.164	0.791	1.713	0.442				
No previous MIs (ref)	1							
1 previous MI	1.172	0.968	1.420	0.104				
2 previous MIs	2.640	1.660	4.198	<0.001				
3 or more previous MIs	1.192	0.574	2.477	0.638				
Previous cardiac surgery	1.975	1.030	3.789	0.040	2.391	1.349	4.239	0.003
Diabetes	1.306	1.074	1.588	0.007				
Hypercholesterolaemia	1.302	1.048	1.619	0.017				
Hypertension	1.337	1.102	1.622	0.003				
CHF	1.215	1.005	1.470	0.044	1.051	0.856	1.289	0.637
PVD	1.253	0.907	1.730	0.171				
Renal	1.016	0.446	2.313	0.970				
Cerebrovascular disease	1.511	1.009	2.264	0.045	1.281	0.846	1.938	0.242
Never smoker (ref)	1							
Ex-smoker	1.069	0.885	1.291	0.487				
Current smoker	0.707	0.471	1.061	0.094				
Pulmonary disease	0.979	0.714	1.341	0.894				
Preoperative AF	0.764	0.341	1.711	0.513				
LMS disease	0.881	0.699	1.111	0.285				
CAD extent I(ref)	1							
CAD extent II	0.946	0.559	1.601	0.836				
CAD extent III	1.210	0.740	1.980	0.447				
LVEF	1.369	1.147	1.635	0.001	1.238	1.029	1.489	0.023

Stratified by previous MIs, diabetes, renal disease, extent of coronary disease and hypertension, p = 0.323 – proportional hazard model holds, AF = atrial fibrillation; CAD = Coronary Artery Disease; CHF = congestive heart failure; CI = confidence interval; HR = hazard ratio; IPTW = inverse probability treatment weighted; LMS = left main stem; LVEF = left ventricular ejection fraction;

MAG = multiple arterial grafting; MI = myocardial infarction; NYHA = New York Heart Association; PVD = peripheral vascular disease; SAG = single arterial grafting; TAG = total arterial grafting

In the IPTW-adjusted model, conduit type remained non-significant (MAG: HR=1.193, p=0.213; TAG: HR=0.952, p=0.729). Age (HR=1.037 per year, p<0.001), previous cardiac surgery (HR=2.879, p=0.001), and cerebrovascular disease (HR=1.740, p=0.019) were independently associated with increased mortality. The proportional hazards assumption was upheld (global test p=0.378) (Table 9).

Table 9: IPTW Cox regression

Univariate Cox regression					Multivariate Cox regression			
Variable	**HR**	**95% CI Lower**	**95% CI Upper**	**p value**	**HR**	**95% CI Lower**	**95% CI Upper**	**p value**
SAG (ref)	1							
MAG	1.114	0.814	1.524	0.502	1.193	0.904	1.576	0.213
TAG	1.061	0.813	1.386	0.662	0.952	0.723	1.255	0.729
Age	1.039	1.024	1.055	<0.001	1.037	1.021	1.053	<0.001
NYHA I (ref)	1							
NYHA II	1.059	0.753	1.488	0.742				
NYHA III	1.191	0.802	1.769	0.385				
NYHA IV	0.976	0.551	1.729	0.935				
No previous Mis (ref)	1							
1 previous MI	1.179	0.878	1.582	0.273				
2 previous Mis	2.244	1.230	4.091	0.008				
3 or more previous MIs	0.914	0.351	2.382	0.855				
Previous cardiac surgery	2.248	1.319	3.830	0.003	2.879	1.569	5.285	0.001
Diabetes	1.254	0.917	1.715	0.156				
Hypercholesterolaemia	1.389	0.974	1.983	0.070				
Hypertension	1.198	0.896	1.602	0.223				
CHF	1.287	0.964	1.719	0.087	1.091	0.816	1.458	0.558
PVD	1.462	0.885	2.415	0.138				
Renal	0.836	0.239	2.924	0.779				
Cerebrovascular disease	1.907	1.207	3.015	0.006	1.740	1.094	2.767	0.019
Never smoker (ref)	1							
Ex-smoker	1.048	0.786	1.397	0.750				
Current smoker	1.133	0.614	2.093	0.689				
Pulmonary disease	1.165	0.701	1.937	0.556				
Preoperative AF	0.624	0.223	1.746	0.369				
LMS disease	0.992	0.695	1.415	0.963				
CAD extent I(ref)	1							
CAD extent II	1.435	0.478	4.315	0.520				
CAD extent III	1.536	0.531	4.441	0.428				
LVEF	1.403	1.073	1.836	0.013	1.296	0.999	1.682	0.051

Stratified by previous MIs, diabetes, renal disease, and extent of coronary disease, Global test p = 0.378 – proportional hazards model holds, AF = atrial fibrillation; CAD = Coronary Artery Disease;

CHF = congestive heart failure; CI = confidence interval; HR = hazard ratio; IPTW = inverse probability treatment weighted; LMS = left main stem; LVEF = left ventricular ejection fraction; MAG = multiple arterial grafting; MI = myocardial infarction; NYHA = New York Heart Association; PVD = peripheral vascular disease; SAG = single arterial grafting; TAG = total arterial grafting

DISCUSSION

In this retrospective cohort of 2,093 female patients undergoing CABG, we found no significant difference in long-term survival between SAG, MAG, and TAG. Despite younger age and fewer comorbidities in the MAG and TAG groups, survival outcomes remained statistically comparable across conduit strategies. TAG was associated with a significantly higher incidence of DSWI, while thirty-day mortality and other short-term complications did not differ significantly. Independent predictors of mortality included age, prior cardiac surgery, and reduced left ventricular ejection fraction.

These findings contrast with several large observational studies that have suggested a survival benefit of MAG over SAG in female patients. Rubens et al., using the Ontario ICES registry, reported improved medium-term survival, reduced myocardial infarction, and lower rates of heart failure hospitalization in women receiving double arterial grafts[9]. Tam et al. similarly found that MAG was associated with longer 10-year survival and greater freedom from major adverse cardiac and cerebrovascular events (MACCE), although early complications were comparable[7]. Ren et al., analyzing data from the ANZSCTS registry, demonstrated significantly lower late mortality in women undergoing MAG[10]. Aboul-Hassan et al. identified subgroups of female patients—those under 70 years, with diabetes, or preserved ventricular function—who derived survival benefit from MAG[11]. These studies collectively support the selective use of MAG in women, particularly in younger and lower-risk cohorts.

However, other analyses have reported more equivocal results. Gaudino et al., using New York State registry data, found no significant differences in 1- and 7-year outcomes between MAG and SAG in women, though secondary analyses suggested benefit in low-risk patients[12]. A meta-analysis by Robinson et al. confirmed reduced long-term mortality and myocardial infarction with MAG in women, but sensitivity analyses limited to larger studies showed no significant survival difference[13]. These discrepancies may reflect differences in study design, patient selection, conduit configuration, and follow-up duration.

Our study adds to this body of evidence by focusing exclusively on female patients and applying rigorous statistical adjustment using IPTW. Unlike prior studies, we included a distinct TAG group and examined outcomes across three conduit strategies. Despite favorable baseline characteristics in the MAG and TAG groups, we found no survival advantage over SAG, even after adjustment. This suggests that the benefits of MAG and TAG may be attenuated in female patients, potentially due to anatomical constraints, comorbidity burden, or competing mortality risks.

Mechanistically, the absence of a survival benefit with MAG or TAG in our cohort may reflect a complex interplay of factors. Women often present with smaller-caliber coronary arteries, more diffuse disease, and higher rates of diabetes and obesity, which may limit the feasibility and durability of multiple arterial conduits[14]. The increased DSWI rate observed in TAG patients likely reflects the use of bilateral internal mammary arteries, which has been associated with sternal complications, particularly in high-risk patients[15].

Changal et al. reported a significantly higher incidence of sternal wound complications in MAG patients, especially those receiving right internal thoracic artery grafts[16]. Tam et al. similarly found increased DSWI rates in women undergoing MAG[7]. Rubens et al. noted increased 30-day mortality and MACCE with double arterial grafting in female patients, underscoring the need for cautious application of MAG in this population[9].

Our study has several strengths. It represents one of the largest single-center analyses focused exclusively on women undergoing CABG, with complete long-term follow-up and robust statistical methodology. The inclusion of a TAG group and stratified Cox modeling enhances the granularity and interpretability of our findings. However, limitations must be acknowledged. The retrospective design introduces potential for selection bias, as conduit strategy was not randomized and may reflect surgeon preference or intraoperative findings. Although IPTW adjustment mitigates confounding, unmeasured variables such as conduit configuration, target vessel quality, and intraoperative flow dynamics were not captured. Additionally, our study was conducted at a single high-volume center, which may limit generalizability.

These findings have important implications for clinical practice and policy. They support a personalized approach to conduit selection in female patients, emphasizing surgical judgment and patient-specific risk profiles over routine pursuit of anatomical completeness. While MAG and TAG may offer theoretical advantages, their application in women should be carefully weighed against the risk of sternal complications and the absence of demonstrated survival benefit in this population. These results also highlight the need for greater inclusion of women in prospective trials and for the development of sex-specific guidelines in surgical revascularization.

To address this gap, the ROMA: Women trial—a large, multi-center, international randomized controlled trial led by Gaudino et al.—is underway[3]. This study will randomize female patients undergoing isolated, primary CABG to receive either SAG or MAG, with standardized conduit configurations. The trial aims to clarify the impact of MAG on early and late outcomes in women and inform sex-specific guidelines for coronary revascularization. Its results are anticipated to provide critical insights into optimizing grafting strategies and addressing persistent disparities in CABG outcomes.

Unanswered questions remain regarding the optimal conduit strategy for women, particularly in relation to graft patency, quality-of-life outcomes, and the role of off-pump techniques. Future research should prioritize prospective, sex-stratified studies with detailed anatomical and functional assessments. Additionally, mechanistic studies exploring the impact of hormonal status, microvascular dysfunction, and inflammatory profiles on graft performance in women may yield further insights.

In conclusion, among female patients undergoing CABG, TAG was associated with higher rates of deep sternal wound infection but did not confer a survival advantage over single or multiple arterial grafting. Long-term outcomes were primarily influenced by age, prior cardiac surgery, and ventricular function. While observational studies suggest potential benefits of MAG in selected female subgroups, definitive evidence from randomized trials is needed. Until then, conduit selection should remain individualized, balancing anatomical feasibility, patient risk, and surgical expertise.

Credit Authorship Contribution Statement

Tharun Rajasekar: Writing – review & editing, Software, Formal analysis, Data curation. **Nandor Marczin:** Writing – review & editing, Supervision. **Sunil Kishore Bhudia:** Writing – review & editing, Validation. **Shahzad Gull Raja:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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