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The effect of completeness of revascularization during CABG with single versus multiple arterial grafts

Thomas A. Schwann MD[1,2] | Maroun B. Yammine MD[3] | Abdul-Karim M. El-Hage-Sleiman MD[3] | Milo C. Engoren MD[2,4] | Mark R. Bonnell MD[1] | Robert H. Habib PhD[3,5]

[1] College of Medicine and Life Sciences, University of Toledo, Toledo, Ohio

[2] Mercy Saint Vincent Medical Center, Toledo, Ohio

[3] Department of Internal Medicine, Outcomes Research Unit, Vascular Medicine Program, American University of Beirut, Beirut, Lebanon

[4] Department of Anesthesiology, University of Michigan, Ann Arbor, Michigan

[5] Society of Thoracic Surgery Research Center, Chicago, Illinois

Correspondence
Thomas A. Schwann MD, MBA, University of Toledo College of Medicine and Life Sciences, 3000 Arlington Ave, Toledo, OH 43615.
Email: thomas.schwann@utoledo.edu

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Abstract

Introduction: Incomplete coronary revascularization is associated with suboptimal outcomes. We investigated the long-term effects of Incomplete, Complete, and Supra-complete revascularization and whether these effects differed in the setting of single-arterial and multi-arterial coronary artery bypass graft (CABG).

Methods: We analyzed 15-year mortality in 7157 CABG patients (64.1 ± 10.5 years; 30% women). All patients received a left internal thoracic artery to left anterior descending coronary artery graft with additional venous grafts only (single-arterial) or with at least one additional arterial graft (multi-arterial) and were grouped based on a completeness of revascularization index (CRI = number of grafts minus the number of diseased principal coronary arteries): Incomplete (CRI ≤ −1 [*N* = 320;4.5%]); Complete (CRI = 0 [*N* = 2882;40.3%]; reference group); and two Supra-complete categories (CRI = +1[*N* = 3050; 42.6%]; CRI ≥ + 2 [*N* = 905; 12.6%]). Risk-adjusted mortality hazard ratios (AHR) were calculated using comprehensive propensity score adjustment by Cox regression.

Results: Incomplete revascularization was rare (4.5%) but associated with increased mortality in all patients (AHR [95% confidence interval] = 1.53 [1.29-1.80]), those undergoing single-arterial CABG (AHR = 1.27 [1.04-1.54]) and multi-arterial CABG (AHR = 2.18 [1.60-2.99]), as well as in patients with 3-Vessel (AHR = 1.37 [1.16-1.62]) and, to a lesser degree, with 2-Vessel (AHR = 1.67 [0.53-5.23]) coronary disease. Supra-complete revascularization was generally associated with incrementally decreased mortality in all patients (AHR [CRI = +1] = 0.94 [0.87-1.03]); AHR [CRI ≥ +2] = 0.74 [0.64-0.85]), and was driven by a significantly decreased mortality risk in single-arterial CABG (AHR [CRI = +1] = 0.90 [0.81-0.99]; AHR [CRI ≥ +2] = 0.64 [0.53-0.78]); and 3-Vessel disease patients (AHR [CRI = +1] = 0.94 [0.86-1.04]; and AHR [CRI ≥ +2] = 0.75 [0.63-0.88]) with no impact in multi-arterial CABG (AHR [CRI = +1] = 1.07 [0.91-1.26]; AHR [CRI ≥ +2] = 0.93 [0.73-1.17]).

Conclusions: Incomplete revascularization is associated with decreased late survival, irrespective of grafting strategy. Alternatively, supra-complete revascularization is

associated with improved survival in patients with 3-Vessel CAD, and in single-arterial but not multi-arterial CABG.

KEYWORDS

CABG, completeness of revascularization, multi-arterial grafting, propensity score

1 | INTRODUCTION

Coronary artery bypass grafting (CABG) remains the optimal treatment for multi-vessel coronary artery disease (CAD).[1–3] Certain surgeon decisions may substantially impact late CABG outcomes. Among these are: (i) the extent to which normal myocardial perfusion is restored, or completeness of revascularization[4–12] and (ii) the choice of arterial versus venous conduits as coronary grafts.[13–16]

Incomplete coronary revascularization has been repeatedly associated with worse survival after CABG, leading surgeons to adopt strategies to facilitate complete revascularization.[4–6] One approach to accomplish complete revascularization focuses on the construction of one graft for each major diseased coronary artery system.[7–9] Another approach to complete revascularization entails placement of grafts to all diseased coronary vessels supplying viable myocardium, even within the same coronary system.[10–12] This approach necessarily entails a higher number of grafts, but whether this technique translates to incrementally improved survival has not been systematically assessed.[11]

Concurrently, compared to the standard-of-care single arterial left internal thoracic artery (LITA) based CABG with only additional saphenous vein grafts (SVG), a number of studies have demonstrated improved late CABG survival with multi-arterial CABG achieved by the additional use of either the right-ITA or radial artery (RA) grafts.[13–16] Whether multi-arterial grafting modifies the effect of the completeness of revascularization on late survival is not well elucidated. One recent study suggested that multi-arterial grafts mitigated the unfavorable long-term effects of incomplete revascularization, but the investigators did not differentiate between varying levels coronary revascularization.[17]

The current study analyzed a large CABG experience in multi-vessel CAD patients to test the hypothesis that compared to complete revascularization, incomplete revascularization is associated with decreased late survival, and that Supra-complete revascularization results in incrementally improved late survival. A secondary aim of this analysis was to examine whether these effects are modified in case of multi-arterial compared to single-arterial CABG.

2 | METHODS

This study is a retrospective analysis of prospectively collected cardiac surgery databases from two Ohio hospitals (Mercy Saint Vincent Medical Center [1994-2007] and University of Toledo Medical Center [2000-2011], Toledo, Ohio). Patient data were collected in accordance with the Society of Thoracic Surgeons (STS) Cardiac Surgery Database and did not involve further patient contact or hospital record reviews. Institutional Review Boards from both medical centers approved this study and waived the need for patients' informed consent.

Patients who underwent primary CABG surgery for multi-vessel CAD and received a LITA to left anterior descending coronary artery (LAD) graft were included in the study. Patients were excluded from analysis in case of emergency-salvage, re-operation, no LITA, preoperative renal failure, or in case of concomitant valvular or aortic surgery. We defined completeness of revascularization index (CRI) as the difference between the number of coronary grafts and the number of diseased coronary systems.[18] Each distal anastomosis was counted as a separate graft. Thus a single sequential conduit counted as more than one graft. Patients were grouped based on their derived CRI: Incomplete (CRI ≤ −1 [N = 320; 4.5%]); Complete (CRI = 0 [N = 2882; 40.3%]); and two levels of Supra-complete (CRI = +1 [N = 3050; 42.6%]; CRI ≥ +2 [N = 905; 12.6%]) revascularization.

2.1 | Surgical technique

The surgical techniques have been described previously.[14,16] The RA was used in 41% of the study population. Bilateral internal thoracic artery (BITA) grafting was used infrequently (2.6%).

2.2 | Follow-up

The primary outcome was long-term all-cause mortality. Long-term mortality data was obtained from recurrent searches of the US Social Security Death Index (SSDI) database (http://ssdi.genealogy.rootsweb.com), last search November 2011, as this was no longer a valid research tool thereafter.[19] The available study follow-up period ranged between 3 and 189 months.

2.3 | Statistical methods

Continuous data were presented as mean ± standard deviation and categorical data as percentages. Univariate comparisons were done with chi-square (X^2) and Student t-test or analysis of variance test as appropriate with applied Bonferroni correction. Patient demographics, risk factors, and operative variables exhibited significant differences across CRI Cohorts (Table 1), for single-arterial versus multi-arterial grafting (Table S-1; online supplement), as well as the 2- and 3-Vessel CAD subgroups (Table S-2; online supplement).

Propensity-score adjustment was used as the main method to account for these imbalances and associated confounding in all analyses. The primary analysis comparing survival outcomes across CRI groups was done on the entire study population. Secondary analyses were also done in four specific patient sub-cohorts—each based on a cohort-specific propensity score model: single-arterial CABG, multi-arterial CABG, 2-Vessel disease, and 3-Vessel disease.

For each analysis, a propensity score predicting the probability of CRI = 0 (reference category) versus all other sub-groups combined was calculated using a non-parsimonious logistic regression model based on 37 demographic, comorbidity, risk factor, surgical priority, and graft type variables (Table 1). Highly collinear variables were avoided. Given the long study period (1994-2011), the year of the surgery was included in the propensity score calculation. The resulting propensity scores for the CRI sub-cohorts were distinctly different in all comparisons. Unadjusted (hazard ratio [HR]) and propensity score ± adjusted hazard ratios (AHR [95% confidence intervals]) were derived by Cox regression analysis assuming proportional hazards. Derived AHRs were confirmed using comprehensive risk adjusted Cox regression including all patient factors in the propensity score models. Predictors of incomplete (CRI ≤ −1) and supra-complete revascularization (CRI = +1 and CRI ≥ + 2) were obtained using binary logistic regression with the complete revacularization (CRI = 0) group used as the reference category (Backward selection). A *P* value less than 0.05 was used to indicate statistical significance. Analysis was done using SPSS version 21 software (IBM, Armonk, NY).

3 | RESULTS

The total study population consisted of 7157 (72%) multi-vessel CABG patients drawn from the overall CABG population of 9865 performed between 1994 and 2011. Mean age and female sex decreased with increasing CRI (both $P \le 0.001$), while cardiopulmonary bypass times and multi-arterial grafting increased significantly (both $P \le 0.001$). Ejection fraction, diabetes, and triple vessel disease were also different among CRI groups (all $P \le 0.001$). Generally, incomplete revascularization (CRI ≤ −1) patients had higher prevalence of comorbidities (peripheral vascular disease, cerebrovascular disease, chronic obstructive lung disease; all $P \le 0.001$), but incomplete revascularization was not independently associated with a higher operative mortality risk (Table 1). Despite increased time on cardiopulmonary bypass and a longer aortic cross clamp time, higher levels of CRI did not carry an increased acute operative mortality (CRI ≤ −1: 1.9%, CRI = 0: 1.6%, CRI = +1: 1.4%, CRI ≥ + 2: 0.9%; $P = 0.44$).

Patient and operative factors were also substantially different when compared for the single-arterial ($n = 4015$; 56%) versus multi-arterial ($n = 3142$; 44%) sub-cohorts (Table S-1) and for the 2-Vessel disease ($n = 1564$; 22%) versus 3-Vessel disease ($n = 5593$; 78%) sub-cohorts (Table S-2; online supplement). Multi-arterial CABG patients were younger, more male, with a higher prevalence of 3-Vessel disease and lower prevalence of insulin-dependent diabetes compared to single-arterial counterparts (all $P \le 0.001$). Notably, the distribution of the CRI differed significantly for single-arterial and multi-arterial CABG patients ($P \le 0.001$). The most common level of CRI in single-arterial was CRI = 0 (45.6%) followed by CRI = +1 (40.1%), while this was reversed in multi-arterial CABG patients (CRI = 0 [33.4%], CRI = +1 [45.8%]). CABG corresponding to a CRI ≥ + 2 was performed in 8.2% of single-arterial and 17.8% of multi-arterial CABG patients. Increasing levels of CRI was accomplished by increasing both venous and RA grafts (Table 1): CRI ≤ −1 (SVG-61.6%, RA-25.9%) and CRI ≥ + 2 (SVG-97.8%, RA-57.2%).

Incomplete revascularization (CRI ≤ −1) was relatively rare, found only in 4.5% of all patients, and was more frequent among 3-Vessel disease versus 2-Vessel disease (5.5% vs 1.0%, $P < 0.001$) and single-arterial versus multi-arterial CABG patients (5.6% vs 3.0%, $P < 0.001$). Predictors of incomplete revascularization were: female sex (odds ratio [OR] [95% confidence interval (CI)]: 1.39 [1.06-1.81]), age (1.02 [1.00-1.03] per year), body surface area (1.69 [0.99-2.86] per m^2), peripheral vascular disease (1.66 [1.27-2.17]), and 3-Vessel disease (5.91 [3.50-9.96]). A majority of patients received Supra-complete revascularization (55.2%; CRI = +1 and CRI ≥ +2 groups), and was frequent among multi-arterial versus single-arterial CABG patients (63.6% vs 48.7%; $P < 0.001$), in men (OR [95% CI], 1.66 [1.50-1.85]), in diabetics (any) (1.15 [1.03-1.29]; in insulin-dependent diabetics: 1.31 [1.13-1.53]), and less likely in patients with peripheral vascular disease (0.81 [0.71-0.92]), cerebrovascular disease (0.80 [0.72-0.90]), previous percutaneous intervention (0.82 [0.72-0.92]), and 3-Vessel disease (0.87 [0.78-0.98]).

3.1 | Long-term survival

Unadjusted survival based on CRI category is shown in Figure 1 (Top, middle, bottom) for all patients, single-arterial CABG, and multi-arterial CABG cohorts, respectively. Figure 2 shows the unadjusted Kaplan Meier survival comparison for CRI groups in patients with 2-Vessel and 3-Vessel disease. Generally, Incomplete revascularization (CRI ≤−1) consistently showed worse survival, compared to complete revascularization (CRI = 0), irrespective of arterial grafting strategy or degree of vessel disease. Alternatively, increasing levels of CRI (+1, or ≥ +2) showed incrementally improved survival, compared to complete revascularization (CRI = 0), in case of single-arterial CABG and 3-Vessel disease but not for multi-arterial CABG. The associated unadjusted hazard ratios (±95% CI) are summarized in Table S-3.

Figure 3 summarizes the adjusted hazard ratios across the various revascularization categories for all patients, as well as for arterial grafting strategy (Figure 3 [Left]) and Vessel disease (Figure 3 [Right]) subcohorts. These risk-adjusted analyses confirmed the significantly worse survival with incomplete revascularization in essentially all cases: All-patients ([HR [95% CI]: 1.53 [1.29-1.80]), single-arterial CABG (1.27 [1.04-1.54]), multi-arterial CABG (2.08 [1.52-2.84]), 3-Vessel disease (1.37[1.16-1.62]). The 2-Vessel disease cohort was small ($n = 15$) and the trend toward worse survival did not reach

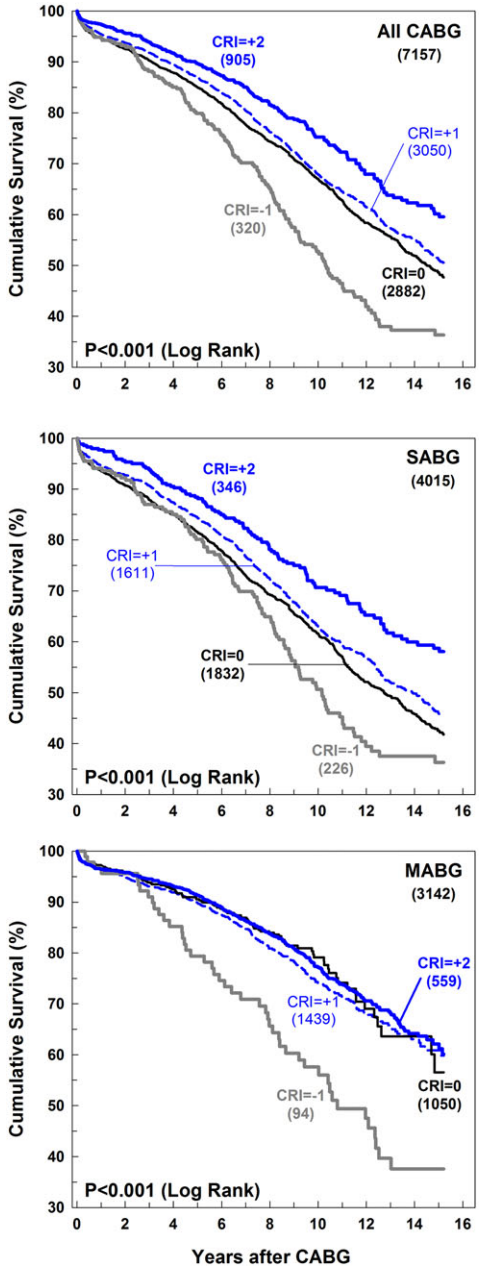
TABLE 1 Selected patient demographic, comorbidity, and operative data compared across completeness of revascularization (CRI) subcohorts

	Completeness of revascularization index				
Variable	**CRI ≤ −1 (*N* = 320)**	**CRI=0 (*N* = 2882)**	**CRI = +1 (*N* = 3050)**	**CRI ≥ +2 (*N* = 905)**	***P*-value[a,b]**
Categorical variables	%	%	%	%	
Female	34.7	36.2	28.2	17.2	≤0.001
BMI (Kg/m^2)					0.274
<25	16.3	17.8	16.4	13.5	
25-29.9	36.6	38.4	39.1	38.8	
30-34.9	29.4	27.2	27.8	28.2	
35-39.9	10.9	10.7	11.0	13.4	
>40	6.9	5.9	5.7	6.2	
Smoking	57.5	62.4	61.3	61.2	0.374
Family History of CAD	66.6	65.5	64.5	62.2	0.278
Diabetes	36.6	34.5	35.8	40.0	0.029
Insulin dependent	15.9	10.9	12.3	11.5	0.043
Hypercholesterolemia	69.1	71.9	70.2	71.3	0.415
Hypertension	85.0	81.0	80.3	78.7	0.086
Peripheral vascular disease	24.7	17.5	14.8	13.7	≤0.001
Cerebrovascular disease	30.3	25.2	21.4	17.8	≤0.001
Stroke	10.9	8.3	7.4	6.0	0.17
COPD	25.0	20.5	20.0	15.7	≤0.001
Myocardial infarction	58.1	52.7	55.4	53.8	0.089
Congestive heart failure	12.2	11.5	10.9	9.8	0.466
Previous PCI	20.6	19.7	17.5	16.9	0.056
Three-Vessel disease	95.3	77.2	78.6	73.5	≤0.001
Left main disease	19.4	23.8	22.6	21.7	0.218
Operative variables					
Emergency	5.3	5.1	5.6	5.9	0.754
On-pump surgery	96.6	97.4	97.9	96.1	≤0.001
Non isolated CABG	10.3	9.1	8.8	10.8	0.508
Radial artery graft use	25.9	33.6	44.5	57.2	≤0.001
Saphenous vein graft use	61.6	87.5	96.8	97.8	≤0.001
Bilateral internal mammary artery	3.4	2.6	2.1	3.9	0.026
Periop mortality	1.9	1.6	1.4	0.9	0.440
Continuous variables	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	***P*-value[a,b]**
Age (years)	66.0 ± 10.7	64.6 ± 10.9	63.9 ± 10.4	62.6 ± 10.0	≤0.001
Body surface area (BSA, m^2)	2.03 ± 0.25	2.01 ± 0.25	2.04 ± 0.25	2.09 ± 0.24	≤0.001
Ejection fraction (%)	48 ± 11	50 ± 11	49 ± 11	48 ± 11	≤0.001
Cardio-pulmonary bypass (min)	49 ± 38	68 ± 30	90 ± 31	112 ± 33	≤0.001
Cross-clamp (min)	29 ± 22	41 ± 20	57 ± 22	76 ± 25	≤0.001
No. of grafts	1.91 ± 0.29	2.77 ± 0.42	3.79 ± 0.41	4.87 ± 0.58	≤0.001
Venous	0.62 ± 0.49	1.36 ± 0.69	2.21 ± 0.78	2.88 ± 1.03	≤0.001
Arterial	1.29 ± 0.46	1.41 ± 0.58	1.58 ± 0.70	2.00 ± 0.98	≤0.001
Internal thoracic artery	1.03 ± 0.19	1.03 ± 0.19	1.04 ± 0.22	1.06 ± 0.27	0.001
Radial artery	0.26 ± 0.44	0.38 ± 0.56	0.54 ± 0.68	0.93 ± 0.98	≤0.001

BMI, body mass index; BSA, body surface area; CABG, coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; PCI, percutaneous intervention; SD, standard deviation.

[a]Analysis of variance across four treatment groups (overall).

[b]chi square across four treatment groups (overall).



All cases (N=7157)

Group	Events		Patients At Risk (n)						
	n	%	2-yrs	4-yrs	6-yrs	8-yrs	10-yrs	12-yrs	14-yrs
CRI= -1	160	56.7%	279	247	211	165	113	66	47
CRI= 0	1095	38.0%	2610	2427	2131	1684	1263	846	485
CRI= +1	989	32.4%	2791	2610	2242	1656	1042	679	424
CRI= +2	214	23.6%	828	774	680	482	265	160	117

SABG (N=4015)

Group	Events		Patients At Risk (n)						
	n	%	2-yrs	4-yrs	6-yrs	8-yrs	10-yrs	12-yrs	14-yrs
CRI= -1	114	50.4%	195	174	149	115	76	41	34
CRI= 0	837	45.7%	1653	1520	1335	1042	793	532	352
CRI= +1	657	40.8%	1483	1371	1188	916	632	450	327
CRI= +2	110	31.8%	322	299	263	214	149	113	99

MABG (N=3142)

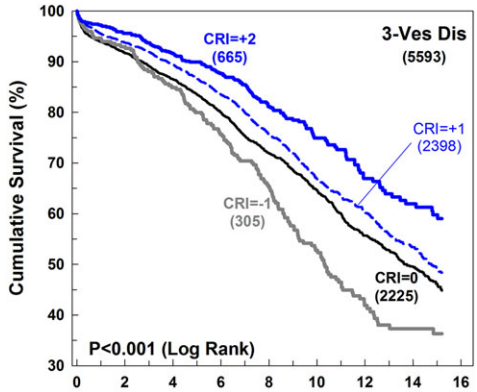
Group	Events		Patients At Risk (n)						
	n	%	2-yrs	4-yrs	6-yrs	8-yrs	10-yrs	12-yrs	14-yrs
CRI= -1	46	48.9%	84	73	62	50	37	25	13
CRI= 0	258	24.6%	957	907	796	642	470	314	133
CRI= +1	332	23.1%	1308	1239	1054	740	410	229	97
CRI= +2	104	18.6%	506	475	417	268	116	47	18

FIGURE 1 Comparison of unadjusted 15-year survival for the four completeness of revascularization (CRI subgroups) shown for the overall cohort (top: All CABG) and separately for the single arterial (middle: single-arterial CABG) and multi-arterial (bottom: multi-arterial CABG) subcohorts. *P* value reflects the long rank test across all four groups (overall). CABG, coronary artery bypass graft; CRI, completeness of revascularization index; MABG, multi-arterial coronary artery bypass; SABG, single arterial coronary artery bypass graft

statistical significance (1.67 [0.53-5.23]). Notably, despite the small number of patients ($n = 94$), the deleterious effects of incomplete revascularization were more pronounced in cases of multi-arterial CABG compared to single-arterial. Increasing CRI (CRI = 0, +1, or ≥ +2) showed incrementally decreased mortality in the overall study cohort. This effect was more substantial and significant in cases of single-arterial CABG (CRI = +1: 0.90 [0.81-0.99], CRI = ≥ +2: 0.64 [0.53-0.78]) but not multi-arterial CABG (CRI = +1: 1.07 [0.91-1.26], CRI = ≥ +2: 0.93 [0.73-1.17]). Lastly, increasing levels of CRI were particularly beneficial in patients with 3-Vessel CAD and less so in patients with 2-Vessel CAD (Figure 3).

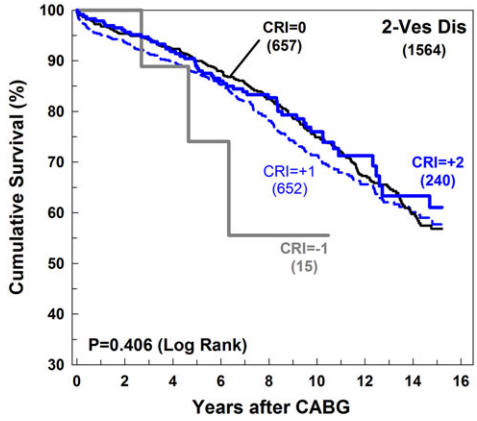
4 | DISCUSSION

In this large CABG experience with substantial use of multiple arterial conduits, our findings confirm that although incomplete revascularization (CRI ≤ −1) does not increase perioperative mortality, it is associated with a significantly increased 15-year mortality. Furthermore, increasing the number of coronary grafts to achieve Supra-complete revascularization (CRI = +1 and CRI ≥ + 2), as opposed to complete revascularization (CRI = 0), results in an incremental systematic decrease in late mortality without any appreciable increase in perioperative risk inherent to increased operative times required to



3-Ves Dis (N=5593)

Group	Events		Patients At Risk (n)						
	n	%	2-yrs	4-yrs	6-yrs	8-yrs	10-yrs	12-yrs	14-yrs
CRI= -1	157	51.5%	269	240	206	163	112	66	47
CRI= 0	892	40.1%	2000	1850	1608	1242	921	599	341
CRI= +1	793	33.1%	2196	2054	1754	1274	771	500	313
CRI= +2	160	24.1%	618	581	511	350	189	121	88



2-Ves Dis (N=1564)

Group	Events		Patients At Risk (n)						
	n	%	2-yrs	4-yrs	6-yrs	8-yrs	10-yrs	12-yrs	14-yrs
CRI= -1	3	20.0%	10	7	5	2	1	0	0
CRI= 0	203	30.9%	610	577	523	442	342	247	144
CRI= +1	196	30.1%	595	556	488	382	271	179	111
CRI= +2	54	22.5%	210	193	169	132	76	39	29

FIGURE 2 Comparison of unadjusted 15-year survival for the four completeness of revascularization (CRI subgroups) shown for the 2-Vessel disease (top) and 3-Vessel disease (bottom) patient sub- cohorts. *P* value reflects the long rank test across all four groups (overall). CABG, coronary artery bypass graft; CRI, completeness of revascularization index

achieve this grafting strategy. This survival benefit of a supra-complete revascularization is particularly evident in case of single-arterial as opposed to multi-arterial CABG, and in patients with 3-Vessel disease as opposed to 2-Vessel disease.

A uniformly accepted definition of incomplete coronary revascularization is lacking and hence its impact on late survival is not well defined. Traditionally, incomplete revascularization has been defined by the lack of a graft placed to one or more of the three principal epicardial coronary systems[20] containing a hemodynamically significant lesion. The lack of a graft to any coronary target with ≥50% stenosis, even within the same coronary artery system (LAD, circumflex, or the right coronary artery) has also been considered as an alternative definition of an incomplete revascularization.[18] Others, using more sophisticated and also more complex criteria, have defined incomplete revascularization based on the residual postprocedural myocardial jeopardy index,[21] a decremental deviation from an "ab initio" grafting strategy as formulated in the Syntax Trial[22] or a residual Syntax score greater than zero.[23] These varied definitions probably contribute to the wide discrepancies in the reported rates of incomplete revascularization from 5%[24] to 36.8%[22] to as high as 69%.[21] We report a relatively low overall incomplete revascularization rate of 4.5%.

Surgeons are generally committed to a complete coronary revascularization aimed at fully restoring myocardial perfusion in all coronary vessels supplying viable myocardial territories. Unforeseen intraoperative factors (diminutive coronary targets, diffuse atherosclerosis, lack of conduits, a porcelain aorta, or accepting incomplete revascularization to minimize operative time) may lead to modification of such a preoperative plan resulting in incomplete revascularization. The literature on the clinical impact of incomplete revascularization is split, with some reports indicating significant adverse clinical outcomes[5,9,21,24,25] while others suggest a trivial or no impact on clinical end-points.[4,17,18,26] This is crystallized by the results of two separate analyses of the SYNTAX trial data with one study concluding that incomplete revascularization did not impact outcomes,[22] while a follow-up study found incomplete revascularization was associated with adverse outcomes.[23] Our data demonstrate that incomplete revascularization is associated with increased late mortality in the overall CABG population as well as inpatient sub-cohorts undergoing single-arterial CABG, multi-arterial CABG, and in patients with 3-Vessel disease. This trend did not reach statistical significance in 2-Vessel disease patients, although given the small number of patients in this group (n = 15 cases only), these results must be interpreted with caution and require confirmation from larger analyses. This negative effect of incomplete revascularization was particularly prominent in multi-arterial CABG. Our finding in this analysis differs from other studies. Kieser et al reported no adverse long-term outcomes associated with incomplete revascularization in patients younger

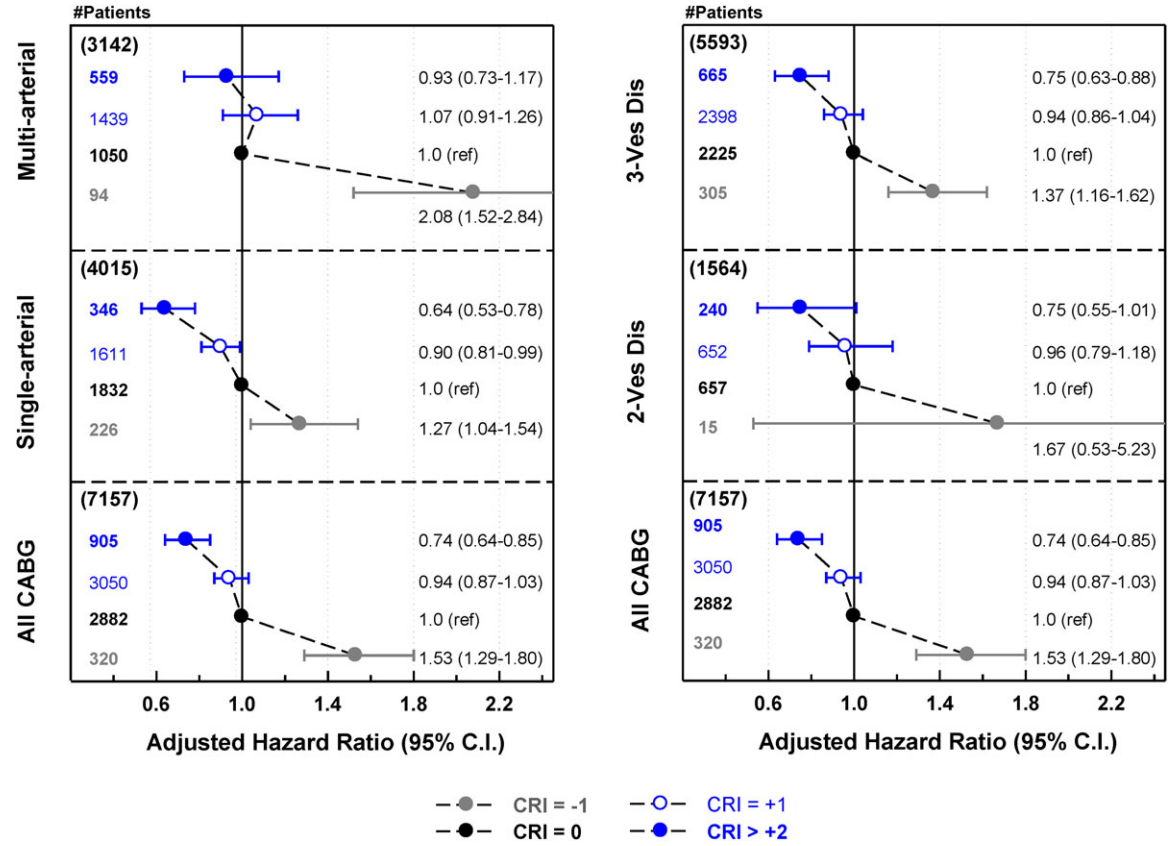


FIGURE 3 Propensity score adjusted hazard ratios for 15-year mortality following CABG surgery shown for different completeness of revascularization levels (CRI = 0 as reference): (Left) overall cohort (All CABG) and separately for the single arterial (single-arterial CABG) and multi-arterial (multi-arterial CABG) sub-cohorts; (Right) overall cohort (All CABG) and separately for the 2- and 3-Vessel disease sub-cohorts. CABG, coronary artery bypass graft; CI, confidence interval; CRI, completeness of revascularization index

than 80 who underwent predominantly multi-arterial CABG (98%).[17] In contradistinction to our findings, the authors concluded that multi-arterial grafting mitigates the negative impact of incomplete revascularization. In patients older than 80, however, incomplete revascularization carried an increased risk of mortality but no explanation behind these findings was provided.[17] We did not study the impact of age on the effects of incomplete revascularization. Rastan et al, in a large CABG series with a 21% rate of all arterial grafting, found no difference in survival up to 5 years postoperatively between patients with a complete versus an incomplete revascularization, although the results were not risk adjusted.[27] Potential explanations for the different findings in our analysis compared to these other studies include: the rate of incomplete revascularization in our multi-arterial CABG cohort was quite small ($n = 94$), our 16-year follow-up was substantially longer, and both the Kieser and Rastan groups had a much higher rate of BITA use and a much lower RA use compared to our multi-arterial cohort. Thus, conceivably incomplete revascularization in BITA-based multi-arterial CABG may have distinctly different prognosis than in LITA/RA-based multi-arterial CABG.

A number of preoperative factors were found to be associated with incomplete revascularization including female sex, increasing age, increasing body surface area, peripheral vascular disease, and 3-Vessel disease. Others have also identified older age, diabetes, and peripheral vascular disease as predictors.[23] Conversely, we identified that male sex (OR [95% CI]: 1.66 [1.50-1.85]) and diabetes (OR = 1.15 [1.03-1.29]) are associated with a greater frequency of supra-complete revascularization (CRI = +1 and CRI ≥ + 2). Possibly the larger size of coronary targets in males lend themselves to a higher number of grafts, while the more diffuse and aggressive diabetic coronary angiopathy may necessitate more grafts to secure an adequate revascularization.

Our data support a supra-complete revascularization particularly in cases of single-arterial CABG and in patients with 3-Vessel disease. Chu et al[28] compared risk adjusted 10-year outcomes in Veterans Administration CABG patients receiving one conduit per diseased coronary system to those receiving multiple grafts per diseased coronary system and found no difference in survival with either grafting strategy. The fact that 99% of this cohort was male, with a relatively low incidence of triple vessel disease (53% vs 78% in the current study) and the exclusive use of the LITA as the only arterial graft, may account for the differences in the results. Our finding that a supra-complete revascularization strategy is not associated with an incremental survival benefit compared to complete revascularization in patients undergoing multi-arterial CABG may be due to the survival benefit associated with the increased durability of arterial grafts compared to venous grafts and thus a smaller number of arterial grafts may have a similar impact on survival as a larger number of venous

grafts. Furthermore, slower progression of atherosclerotic burden downstream from arterial grafts compared to venous grafts may also play a role in our findings,[29] suggesting that it is the quality of the grafts rather than quantity of grafts among multi-arterial CABG patients that is important.

The limitations of our study include its retrospective, single practice two institutional nature. Our assessment of coronary disease, consistent with the STS database criteria, is rather rudimentary based on the number of diseased major coronary artery systems without consideration of the specific number of vessels diseased within each system. In addition, our CRI calculation includes the number of completed coronary grafts without consideration of the specific coronary targets. In certain cases, due to our reliance on the derived CRI metrics, a CRI = 0 designation may, in fact, represent an incomplete revascularization, if the grafts were placed to the same coronary artery system leaving diseased vessel in other coronary artery systems unreconstructed. The limited granularity of our dataset does not permit this level of detailed analysis. Furthermore, our data did not include information on the complexity of the atherosclerotic burden, the quality of the target vessels, or their size. Also, we are unable to categorize the coronary artery lesions as proximal or distal and how much myocardium remains at risk by not bypassing them. In addition, our database does not contain the reasons why a patient left the operating room with an incomplete revascularization, the details of the physiologic significance of the coronary lesions as the severity of each stenosis was exclusively based on angiographic assessment rather than their impact on physiologic myocardial perfusion or whether a diseased vessel supplied viable or non-viable myocardium. We also do not have an assessment of the collateral flow in patients with an incomplete revascularization. Lastly, the specific cause of death was unavailable to us to specifically assess the cardiovascular consequences of the achieved revascularization.

In conclusion, our data strongly support the perspective that incomplete revascularization is associated with increased long-term mortality regardless of whether a patient undergoes single-arterial CABG or multi-arterial CABG. Furthermore, supra-complete revascularization (CRI = +1 and CRI ≥ +2), compared to complete revascularization (CRI = 0), is associated with improved long-term survival especially in patients undergoing single-arterial CABG and in those with 3-Vessel disease. In multi-arterial CABG, the incremental benefit of additional grafts beyond those required for a complete revascularization is likely of smaller magnitude. Given the small numbers of patients within our study subcohorts, our findings should be considered hypothesis generating and additional, more granular, confirmatory studies are warranted to inform shared decision making by the Heart Team and the patient.

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CONFLICTS OF INTEREST

All authors have no conflict of interest to disclose.

ORCID

Thomas A. Schwann http://orcid.org/0000-0003-4272-1140

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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