

# Rate of Incomplete Revascularization Following Coronary Artery Bypass Grafting at a Single Institution Between 2007 and 2017



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**Incomplete revascularization following coronary artery bypass grafting (CABG) is associated with increased repeat revascularization, myocardial infarction and death. Whether the rate of incomplete revascularization is increasing over time has not been previously described. All patients with multivessel coronary artery disease who underwent isolated and elective CABG at our Institution in 2007 (n = 291) were compared to patients who underwent CABG in 2017 (n = 290). A Revascularization Index Score was created to compare rates of incomplete revascularization between the 2 years based on the coronary anatomy and degree of stenosis. Comparison of the 2 years disclose that the rate of incomplete revascularization increased from 17.9% in 2007 to 28.3% in 2017 (p = 0.003) and was accompanied by a decline in the Revascularization Index Score from 0.73 to 0.67 (p = 0.005). Left ventricular function improved in both groups following CABG. Two-year cardiovascular mortality was significantly higher in the 2017 cohort compared to the 2007 cohort. These differences may be attributable to patient factors including more severe coronary artery disease associated with older age, greater incidence of smoking and previous percutaneous coronary intervention. In conclusion, the rate of incomplete revascularization following CABG significantly increased in 2017 compared to 2007 and was associated with higher cardiovascular mortality. © 2021 Elsevier Inc. All rights reserved. (Am J Cardiol 2021;144:33–36)**

Coronary artery bypass grafting (CABG) may improve survival compared to medical therapy in patients with severe coronary artery disease (CAD) and angina<sup>1</sup> and offers a mortality advantage compared to percutaneous coronary intervention (PCI) in patients with multivessel CAD,<sup>2</sup> particularly in those with diabetes mellitus.<sup>3</sup> This benefit has been attributed in part, to the greater ability of CABG to achieve complete revascularization over PCI.<sup>4</sup> Multiple surgical studies dating back over several decades have observed that the ability to completely revascularize a patient at the time of CABG confers a significant benefit on mortality and the occurrence of major adverse cardiovascular events<sup>1,5–7</sup> especially in sub-groups with left-ventricular (LV) dysfunction,<sup>1,8</sup> advanced age<sup>9</sup> and diabetes.<sup>10</sup> This benefit appears to be increasing perhaps as a result of the growing burden of diabetes and other cardiovascular risk factors.<sup>11</sup> In this report, we performed a retrospective analysis of all patients who underwent elective and isolated CABG for multivessel CAD at our Institution over a 10-year period between 2007 and 2017 using a numerical,

score-based approach to compare the outcomes and rates of complete versus incomplete revascularization.

## Methods

This retrospective cohort study was approved by the Institutional Review Board of Allina Health and Abbott Northwestern Hospital. A review of patients with multi-vessel CAD was performed based on the date of CABG operations at the Minneapolis Heart Institute at Abbott Northwestern Hospital. Two cohorts were analyzed, a historical cohort consisting of all patients who underwent elective and solitary CABG in 2007 (n = 291) and a contemporary cohort consisting of all patients who underwent CABG in 2017 (n = 290).

All operative reports of CABG procedures were reviewed for placement of bypass grafts and whether revascularization was performed “on” or “off” bypass. Preoperative coronary artery diagrams were independently adjudicated in conjunction with coronary angiograms to determine vessel stenosis severity. Rationale for not bypassing vessels, patient demographics (age, sex), risk factors (smoking, diabetes, etc.), and mortality were recorded from the patient’s electronic medical record. Revascularization was considered complete when all major epicardial vessels and their major branch vessels (>2.0 mm) with stenosis greater than 60% were bypassed either directly via a graft or indirectly via antegrade or retrograde perfusion from a neighboring vessel. Baseline left ventricular function was assessed by LV ejection fraction (LVEF) and was measured by echocardiography or SPECT in the month prior to

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bypass surgery when provided. Follow-up LVEF was measured as the first measurement obtained more than 6-months following CABG.

A Revascularization Index Score (RIS) was created to compare differences in incomplete revascularization between the 2 cohorts. Regardless of vessel diameter, the presence of significant stenosis in any major epicardial vessel (left-ante-rior descending artery (LAD), Circumflex artery (CX), and posterior descending artery of dominant right coronary artery (RCA) or CX) was assigned 1 point if it was revascularized and 0 points if it was not revascularized at the time of CABG. Major side branches including the first Diagonal and Ramus Intermedius (>2.0 mm diameter and length >50% of LAD length) were also scored in a similar manner in addition to the Posterior-Lateral Branch and other large obtuse marginal branches (>2.0 mm diameter) if isolated by a significant stenosis. Thus, a completely revascularized patient would receive an RIS of 1.0 while a patient having only 3 of 4 stenoses bypassed received an RIS of 0.75.

Demographics, mortality, and RIS were compared between the 2 cohorts. Continuous study variables are presented as mean  $\pm$  standard deviation or as median (25th, 75th percentiles) when appropriate. Discrete variables are reported as counts and percentages. Continuous variables were assessed using the Student's t-test if normally distributed or the Wilcoxon rank-sum test if skewed. Categorical variables were assessed using the chi-square or Fisher exact test where appropriate. Survival rates are presented with Kaplan-Meier plots, and differences in survival were assessed using the log-rank test. The analysis was performed using Stata version 15.1 (College Station, Texas).

## Results

The historical cohort was composed of 291 consecutive patients who underwent elective and isolated CABG in 2007. The contemporary cohort was composed of 290

consecutive patients who underwent elective and isolated CABG in 2017.

In the historical cohort, 52 (17.9%) operations were classified as incomplete while in the contemporary cohort, 82 (28.3%) operations were classified as incomplete resulting in a significant increase in incomplete revascularization ( $p = 0.003$ ) over the 10-year period (Table 1). The patients in the contemporary cohort were older ( $p = 0.005$ ), consisted of a larger proportion of males ( $p = 0.024$ ) and were more likely to be smokers and have previous myocardial infarction.

Patients with incomplete revascularization were compared between the 2 cohorts (Table 2). Those in the contemporary cohort tended to be older, have greater numbers of PCIs and had higher numbers of myocardial infarctions ( $p < 0.017$ ). The RIS for patients with incomplete revascularization decreased from 0.73 to 0.67 over the 10-year period ( $p = 0.002$ ) (Table 2). Patients in the 2017 cohort experienced a higher percentage of cardiac death and mortality compared to the 2007 cohort over the first 2 years (Figure 1). When comparing the 10-year survival rates of patients in the 2007 cohort, the survival rates declined more rapidly for those with incomplete revascularization than those with complete revascularization but this did not achieve statistical significance (Figure 2). The rates of rehospitalization for MI and heart failure in the year following CABG was 4.2% in the complete revascularization group and 9.7% in the incomplete revascularization group.

## Discussion

We observed that the incidence of incomplete revascularization following CABG significantly increased over a 10-year period (2007 to 2017) from 17% to 28%. This occurred despite a 50% decline in off-pump CABG in the 2017 group which has previously been associated with greater incomplete revascularization in several studies.<sup>6,12</sup> Subjects in the 2007 group were more likely to be smokers and had a greater

Table 1.  
Demographics of patients who underwent elective and isolated CABG operations 2007 versus 2017

Variable	Overall (n = 581)	2007 (n = 291)	2017 (n = 290)	p Value
Incomplete Revasc	134 (23%)	52 (17%)	82 (28%)	0.003
Age (years), mean (SD)	66.4 $\pm$ 9.6	65.3 $\pm$ 10.5	67.6 $\pm$ 8.4	0.005
Men	465 (80%)	222 (76%)	243 (84%)	0.024
Diabetes Mellitus	129 (22%)	68 (23%)	61 (21%)	0.499
Smoker	179 (31%)	102 (35%)	77 (27%)	0.027
Hypertension	314 (54%)	176 (60%)	138 (48%)	0.002
Dyslipidemia	327 (56%)	191 (66%)	136 (47%)	0.001
1-year mortality	8 (1%)	0	8 (3%)	0.004
Cardiac Death (1-year),	6 (1%)	0	6 (2%)	0.015
Off pump	103 (18%)	67 (23%)	36 (12%)	0.001
Cardiopulmonary bypass time (minutes), median (IQR)	72 (45, 91)	71 (0, 91)	73 (51, 91)	0.212
Pre-op LVEF %, (SD)		53.3 $\pm$ 10.6	55.3 $\pm$ 10.8	0.020
Previous PCI	100 (17%)	49 (17%)	51 (18%)	0.811
Previous Stroke/TIA	26 (4%)	13 (4%)	13 (4%)	0.993
Previous MI	124 (21%)	46 (16%)	78 (27%)	0.001
PVD	47 (8%)	31 (11%)	16 (6%)	0.023
Left Main $\geq$ 60%	172 (30%)	87 (30%)	85 (29%)	0.877
1-Year MACE	54 (9%)	25 (9%)	29 (10%)	0.559

CVA = cerebral vascular accident; LVEF = left ventricular ejection fraction; MACE = major adverse cardiac events (death, heart failure admissions, myocardial infarction, repeat revascularization); MI = myocardial infarction; PCI = percutaneous coronary intervention; PVD = peripheral vascular disease.

Table 2.  
Demographics of patients with incomplete revascularization 2007 versus 2017

Variable	Overall (n = 134)	2007 (n = 52)	2017 (n = 82)	p value
Age, mean (SD)	66.9 ± 9.1	65.2 ± 10.3	67.9 ± 8.3	0.098
Men	113 (86)	42 (81)	71 (87)	0.681
Diabetes mellitus	37 (28%)	11 (21%)	26 (32%)	0.183
Ever smoker	53 (40%)	18 (35%)	35 (43%)	0.352
Hypertension	93 (69%)	33 (63%)	60 (73%)	0.235
Dyslipidemia	96 (72%)	36 (69%)	60 (73%)	0.622
1-year mortality	3 (2)	0	3 (4%)	0.289
Cardiac Death (1-year)	3 (2)	0	3 (4%)	0.289
Revascularization Index Score, mean (SD)	0.70 ± 0.10	0.73 ± 0.09	0.67 ± 0.11	0.005
Off pump	20 (15%)	10 (20%)	10 (12%)	0.225
Cardiopulmonary Bypass Time (min), mean ± SD		90 ± 32	79 ± 32	0.376
Previous PCI	22 (16%)	5 (10%)	17 (21%)	0.091
LIMA graft utilized		88%	97%	0.03
LVEF (%) – pre-CABG		51.3 ± 13.7	53.0 ± 13.3	0.18
LVEF (%) – 1 year post		54.0 ± 11.8	56.9 ± 10.3	0.01
Previous Stroke/TIA	12 (9%)	4 (8%)	8 (10%)	0.766
Previous MI	36 (27%)	8 (15%)	28 (34%)	0.017
PVD	17 (13%)	8 (15%)	9 (11%)	0.455
Left Main ≥ 60%	41 (31%)	15 (29%)	26 (32%)	0.726
1- Year MACE	20 (15%)	3 (6%)	17 (21%)	0.024

CVA = cerebral vascular accident; LVEF = left ventricular ejection fraction; MACE = major adverse cardiac events (death, heart failure admissions, myocardial infarction, repeat revascularization); MI = myocardial infarction; PCI = percutaneous coronary intervention; PVD = peripheral vascular disease.

incidence of peripheral vascular disease while subjects in the 2017 cohort were older, more likely to be men and had a greater incidence of previous myocardial infarction. Consistent with its greater rate of incomplete revascularization, the 2017 cohort also had a higher 1-year cardiac mortality and MACE rate despite having a slightly higher baseline LVEF (Table 1).

The reasons for the increase in incomplete revascularization over time is likely multifactorial but may be attributable in part to the patient factors we observed that are associated with more severe CAD. This includes older age, diabetes, previous PCIs and myocardial infarctions, all numerically greater in the 2017 cohort that was incompletely revascularized (Table 2). In line with previous studies, we observed that the 10-year mortality in the 2007 cohort favored patients with complete revascularization, although this difference did not reach statistical significance because of the small sample size. (Figure 2).

The clinical benefit of complete revascularization following CABG has been well established and is consistent across multiple subgroups including patients with LV dysfunction,<sup>8</sup> octogenarians<sup>9</sup> and those with diabetes.<sup>10</sup> Multiple meta-analyses<sup>4,5</sup> and many single- and multi-center trials have confirmed the benefit of complete revascularization following CABG.

To our knowledge, this is the first report to describe the temporal changes in complete revascularization following CABG. We hypothesized that the rate of incomplete revascularization would increase over the 10-year period due to the significant increase in diabetes and other cardiovascular risk factors<sup>11</sup> along with a greater use of PCI for straight-forward multivessel CAD. This would result in more patients with diffuse, small vessel disease and chronic total occlusions being referred for CABG where complete revascularization may be more difficult.

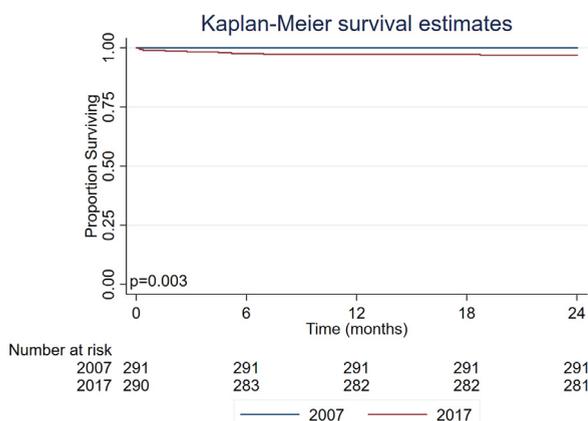


Figure 1. Twenty-four-month survival rates of the historical cohort versus the contemporary cohort in a Kaplan-Meier plot.



Figure 2. Ten-year survival rates of patients in the historical cohort with complete versus incomplete revascularization in a Kaplan-Meier plot.

To assess the degree of incomplete revascularization in our study, we developed a RIS. This anatomically-based approach is more comprehensive than many previous studies that assess only the 3 main epicardial vessels. Our RIS approach also incorporated large branches of these vessels such as the first diagonal or ramus intermedius branch that may supply significant myocardium. Other schemes to assess complete revascularization that have been developed include using functional data such as nuclear scintigraphy<sup>13</sup> or a physiologically-based approach using fractional flow reserve.

An additional novel finding in our study was the observation that the numerical degree of incomplete revascularization increased over the 10-year period as manifested by a significant decline in the RIS measurement (Table 2). We observed that the most common vessel not bypassed was the obtuse marginal branches of the circumflex artery followed by the posterior descending artery of the RCA and then the first diagonal branch which is consistent with previous observations.<sup>7</sup> Operative reports most commonly reported that arteries not bypassed were too small or had diffuse disease throughout their length.

In summary, over a 10-year period we observed that the rate and degree of incomplete revascularization significantly increased in patients undergoing elective and isolated CABG at our Institution and was associated with an increased 1-year cardiovascular mortality. These findings suggest that patients with incomplete revascularization constitute a cohort of subjects with increased cardiovascular risk. The development of novel therapies to improve coronary blood flow to un-revascularized territories is warranted. An approach previously used in patients with refractory angina involving the use of stem cell therapy<sup>14</sup> may be of benefit in addition to therapies that could be delivered at the time of CABG such as gene therapy (NCT04125732) or biomaterials such as extracellular matrices<sup>15</sup> that have or will be tested in upcoming clinical trials.

### Authors' Contributions

Chase Soukup – data curation, investigation, writing-original draft. Christian Schmidt – formal analysis. Carmen Chan-Tram – investigation, data curation. Ross Garberich – formal analysis, methodology. Benjamin Sun – conceptualization, investigation. Jay Traverse – conceptualization, data curation, investigation, methodology, supervision, writing original draft.

### Disclosures

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