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ORIGINAL ARTICLE

Incidence, predictors and outcomes of incomplete revascularization after percutaneous coronary intervention and coronary artery bypass grafting: a subgroup analysis of 3-year SYNTAX data†

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Abstract

OBJECTIVE: To assess whether incomplete revascularization by percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) has an effect on long-term outcomes.

METHODS: During a heart team discussion to evaluate whether patients were eligible for randomization in the SYNTAX trial, both the cardiologist and surgeon agreed on which vessels needed revascularization. This statement was compared with the actual revascularization after treatment. Incomplete revascularization was defined as when a preoperatively identified vessel with a lesion was not revascularized. Outcomes were major adverse cardiac or cerebrovascular events (MACCE), the composite safety endpoint of death/stroke/myocardial infarction (MI), and individual MACCE components death, MI and repeat revascularization at 3 years. Predictors of incomplete revascularization were explored.

RESULTS: Incomplete revascularization was found in 43.3% (388/896) PCI and 36.8% (320/870) CABG patients. Patients with complete revascularization by PCI had lower rates of MACCE (66.5 versus 76.2%, $P < 0.001$), the composite safety endpoint (83.4 versus 87.9%, $P = 0.05$) and repeat revascularization (75.5 versus 83.9%, $P < 0.001$), but not death and MI. In the CABG group, no difference in outcomes was seen between incomplete and complete revascularization groups. Incomplete revascularization was identified as independent predictor of MACCE in PCI (HR = 1.55, 95% CI 1.15–2.08, $P = 0.004$) but not CABG patients. Independent predictors of incomplete revascularization by PCI were hyperlipidaemia (OR = 1.59, 95% CI 1.04–2.42, $P = 0.031$), a total occlusion (OR = 2.46, 95% CI 1.66–3.64, $P < 0.001$) and the number of vessels (OR = 1.58, 95% CI 1.41–1.77, $P < 0.001$). Independent predictors of incomplete revascularization by CABG were unstable angina (OR = 1.42, 95% CI 1.02–1.98, $P = 0.038$), diffuse disease or narrowed (< 2 mm) segment distal to the lesion (OR = 1.87, 95% CI 1.31–2.69, $P = 0.001$) and the number of vessels (OR = 1.70, 95% CI 1.53–1.89, $P < 0.001$).

CONCLUSIONS: Despite the hypothesis-generating nature of this data, this study demonstrates that incomplete revascularization is associated with adverse events during follow-up after PCI but not CABG.

Keywords: Myocardial revascularization • Completeness • Percutaneous coronary intervention • Coronary artery bypass grafting • Outcomes • SYNTAX

BACKGROUND

Percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG) are both options for the treatment of coronary disease. Whether PCI or CABG is preferred for a particular patient often depends on the number of diseased vessels, lesion complexity and co-morbidities. Complete revascularization cannot always be achieved due to procedural difficulties [1, 2].

Previous studies have tried to address whether incomplete revascularization is associated with reduced survival and increased revascularization [3–6]. However, these have been methodologically restricted by a retrospective design and most often relied on post-procedural classification of completeness of revascularization by the treating physician. The Synergy between

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PCI with TAXUS and Cardiac Surgery (SYNTAX) trial [7] had a more accurate method to determine the completeness of revascularization. Preoperatively, both the interventional cardiologist and surgeon had to agree which vessels needed revascularization on a basis of any lesion with more than 50% diameter stenosis in coronary vessels ≥1.5 mm. Patients were categorized as incompletely revascularized when the number of diseased segments that were treated did not match the Heart Team decision. The objective of this study was to assess whether incomplete revascularization according to the SYNTAX definition had an effect on the 3-year outcome of the SYNTAX trial.

METHODS

Study design

The SYNTAX trial design and methods have been described previously [7, 8]. It was a prospective, multicentre randomized trial in which patients with *de novo* left main and/or three-vessel disease were randomly assigned to undergo PCI with the TAXUS drug-eluting stent or CABG. The institutional review board of each of the 85 participating cites approved the protocol. The trial is registered on the National Institute of Health website with identifier NCT00114972.

Definitions

During the Heart Team meeting when patients were assessed for randomization [9], both the interventional cardiologist and surgeon documented which vessels with a ≥1.5 mm diameter and a 50% stenosis needed revascularization. Incomplete revascularization was assessed by correlating this preoperative statement to the actual revascularization.

The composite endpoint of major adverse cardiac or cerebrovascular events (MACCE) included all-cause death, myocardial infarction (MI), cerebrovascular accident (CVA) or repeat revascularization (subsequent PCI or CABG) [10]. Cerebrovascular events, or stroke, were defined as focal neurological deficits of central origin lasting >72 h, resulting in permanent brain damage or body impairment. MI was defined in relation to intervention status as follows: (i) after allocation but before treatment: Q-wave [new pathological Q-waves in ≥2 leads lasting ≥0.04 s with creatine kinase-MB (CK-MB) levels elevated above normal] and non-Q-wave MI [elevation of CK levels >2× the upper limit of normal (ULN) with positive CK-MB or elevation of CK levels to >2× ULN without new Q-waves if no baseline CK-MB was available]; (ii) <7 days after intervention: new Q-waves and either peak CK-MB/total CK >10% or plasma level of CK-MB 5× ULN; and (iii) ≥7 days after intervention: new Q-waves or peak CK-MB/total CK >10% or plasma level of CK-MB 5× ULN or plasma level of CK 5× ULN. The CK/CK-MB enzyme levels were obtained and measured by a core laboratory for all randomized patients. All events were adjudicated by a Clinical Event Committee.

Statistical analysis

Baseline data were presented as proportions or mean ± standard deviation. Continues variables were compared using Student's *t*-tests. Discrete variables were compared with the Chi-square test. Uni- and multivariate logistic regression analyses were performed to identify predictors of incomplete revascularization in PCI and CABG patients. Variables tested in the univariate analysis were: age, gender, any medically treated diabetes, diabetes requiring insulin, triglycerides ≥150 mg/dl (1.7 mmnol/l), fasting glucose ≥110 mg/dl, hyperlipidaemia, current smoker, previous MI, previous stroke, previous TIA, congestive heart failure, peripheral vascular disease, carotid artery disease, renal failure (creatinine >200 micromol/l), unstable angina, low left ventricular ejection fraction (<35%), logistic EuroSCORE, Parsonnet score, SYNTAX score tercile, total occlusion, bifurcation lesion, diffuse disease or narrowed (<2 mm) segment distal to the lesion and the number of lesions. If a variable had a trend towards an association with incomplete revascularization ($P < 0.20$), it was entered in the multivariate forward Wald model. Univariate cox-regression was used to determine the effect of incomplete revascularization on outcomes. Variables with a trend towards an association ($P < 0.20$) were included in a final forward Wald multivariate model.

For all analyses, a *P*-value <0.05 was considered to be statistically significant. Analyses were performed using SPSS version 17.0 statistical software (SPSS Inc., Chicago, IL, USA).

RESULTS

Patient characteristics

In the SYNTAX trial, 1800 patients were randomized to PCI ($n = 903$) or CABG ($n = 897$). Revascularization was not performed or informed consent was withdrawn in 34 patients. A total of 1766 patients were analysed. In the PCI cohort, 43.3% (388/896) had incomplete revascularization, compared with 36.8% (320/870) in the CABG cohort. Table 1 shows the baseline characteristics of complete and incomplete revascularized patients.

Incomplete revascularization was especially present in patients with three-vessel disease (Fig. 1). Within SYNTAX score terciles, an increasing score is associated with an increased rate of incomplete revascularization (Fig. 2).

In the PCI group, patients with incomplete revascularization had a higher prevalence of diabetes and hyperlipidaemia. Patients with complete and incomplete revascularization had a comparable logistic EuroSCORE (3.7 ± 5.0 versus 3.9 ± 3.8, respectively, in the complete and incomplete revascularization groups) and Parsonnet score (8.2 ± 6.8 versus 9.0 ± 7.1, respectively). The coronary disease complexity, however, was significantly worse in patient with incomplete revascularization. The SYNTAX score was 31.4 ± 11.8 compared with 26.2 ± 10.6 in the complete revascularization group. More often, a total occlusion (33.4 versus 16.9%, $P < 0.001$) or bifurcation (67.3 versus 58.9%, $P = 0.010$) lesion was present. Patients with incomplete revascularization had more frequently diffuse disease or narrowed (<2 mm) segments distal to the lesion (26.5 versus 19.1%, $P = 0.008$). A higher mean number of lesions were seen in incompletely revascularized patients (4.6 ± 1.5 versus 3.5 ± 1.6, $P < 0.001$).

In the CABG cohort, patients with incomplete revascularization had a higher logistic EuroSCORE (4.3 ± 4.9 compared with 3.6 ± 4.0 in the complete revascularization group, $P = 0.014$) (Table 1). Similar to the PCI cohort, CABG patients with incomplete revascularization had more complex coronary disease according to the SYNTAX score (31.3 ± 11.4 versus 27.9 ± 11.1), and higher incidences of diffuse disease or narrowed vessels

Table 1: Baseline characteristics

Characteristics	PCI (*n* = 896)			CABG (*n* = 870)		
	Complete (*n* = 508, 56.7%)	Incomplete (*n* = 388, 43.3%)	*P*-value	Complete (*n* = 550, 63.2%)	Incomplete (*n* = 320, 36.8%)	*P*-value
Age, years	65.1 ± 9.4	65.6 ± 10.0	0.392	64.7 ± 9.9	65.3 ± 9.8	0.339
Male sex	74.2% (377/508)*	79.6% (309/388)	0.057	79.4% (439/550)*	78.8% (252/320)	0.707
Comorbid risk factors						
Body-mass index (kg/m_2)	28.2 ± 4.9	28.0 ± 4.7	0.408	28.0 ± 4.5	27.8 ± 4.3	0.540
Medically treated diabetes						
Any	22.2% (113/508)	30.2% (117/388)	0.007	22.7% (125/550)	25.3% (81/320)	0.387
Requiring insulin	7.5% (38/508)	13.1% (51/388)	0.005	8.9% (49/550)	12.2% (39/320)	0.122
Triglycerides ≥150 mg/dl (1.7 mmol/l)	32.4% (158/488)*	32.1% (116/361)	0.940	38.5% (191/496)*	39.1% (111/284)	0.874
Blood pressure ≥130/85 mmHg	68.7% (349/508)	69.6% (270/388)	0.776	64.2% (353/550)	63.1% (202/320)	0.754
Fasting glucose ≥110 mg/dl	41.8% (151/361)	49.8% (139/279)**	0.044	39.5% (149/377)	39.3% (95/242)**	0.947
Increased waist circumference	48.6% (221/455)	45.9% (158/344)	0.459	46.7% (221/473)	44.9% (129/287)	0.634
Hyperlipidaemia	75.7% (383/506)	82.2% (315/383)	0.018	77.5% (424/547)	76.8% (242/315)	0.816
Cardiovascular history						
Current smoker	19.1% (97/508)	17.8% (69/388)	0.617	23.8% (130/547)	19.2% (61/318)	0.117
Previous myocardial infarction	32.1% (160/499)	32.0% (124/387)	0.994	31.0% (168/542)	37.1% (118/318)	0.066
Previous stroke	3.9% (20/507)	3.9% (15/385)	0.970	4.9% (27/546)	5.0% (16/319)	0.963
Previous transient ischaemic attack	3.3% (17/508)	5.7% (22/386)	0.088	4.2% (23/544)	6.3% (20/318)	0.180
Previous cardiac surgery	0.2% (1/508)	0% (0/388)	0.382	0.2% (1/550)	0.3% (1/320)	0.698
Congestive heart failure	4.2% (21/505)	3.9% (15/386)	0.838	5.0% (27/539)	5.4% (17/314)	0.797
Peripheral vascular disease	7.9% (40/508)	10.8% (42/388)	0.129	8.7% (48/550)	13.4% (43/320)	0.029
Carotid artery disease	8.3% (42/508)	8.0% (31/388)	0.880	7.5% (41/550)	9.7% (31/320)	0.249
Creatinine >200 micromol/l	1.2% (6/508)	1.0% (4/388)	0.832	1.3% (7/550)	1.9% (6/320)	0.480
Chronic obstructive pulmonary disease	7.5% (38/508)	8.5% (33/388)	0.574	10.0% (55/550)	7.8% (25/320)	0.282
Angina						
Stable	57.9% (294/508)	56.2% (218/388)	0.613	60.7% (334/550)	52.2% (167/320)	0.014
Unstable	27.6% (140/508)	30.4% (118/388)	0.350	26.0% (143/550)	32.5% (104/320)	0.040
Ejection fraction <35%	1.4% (7/508)	1.3% (5/388)	0.908	2.4% (13/550)	2.2% (7/320)	0.867
Logistic EuroSCORE	3.7 ± 5.0	3.9 ± 3.8	0.614	3.6 ± 4.0	4.3 ± 4.9	0.014
Parsonnet score	8.2 ± 6.8	9.0 ± 7.1	0.117	8.1 ± 6.7	8.9 ± 7.2	0.079
Lesion complexity						
SYNTAX score	26.2 ± 10.6*	31.4 ± 11.8	<0.001	27.9 ± 11.1*	31.3 ± 11.4	<0.001
Diffuse disease or small vessels	19.1% (97/508)	26.5% (103/388)	0.008	16.4% (90/550)	29.1% (93/320)	<0.001
Total occlusion	16.9% (85/504)	33.4% (129/386)	<0.001	19.3% (106/548)	27.4% (87/317)	0.006
Bifurcation	58.9% (299/508)	67.3% (261/388)	0.010	62.0% (341/550)	69.3% (221/319)	0.030
Number of lesions	3.5 ± 1.6	4.6 ± 1.5	<0.001	3.5 ± 1.5	4.8 ± 1.6	<0.001
Lesion		**	<0.001		**	<0.001
Left main, any	44.7% (227/508)	32.2% (125/388)		45.1% (248/550)	29.5% (94/319)	
Left main only	7.9% (40/508)	0% (0/320)		8.0% (44/550)	0.9% (3/320)	
Left main + 1 vessel	11.8% (60/508)	1.8% (7/388)		10.9% (60/550)	3.1% (10/320)	
Left main + 2 vessel	13.6% (69/508)	10.8% (42/388)		14.9% (82/550)	7.5% (24/320)	
Left main + 3 vessel	11.4% (58/508)	19.6% (76/388)		11.3% (62/550)	17.8% (578/320)	
Three vessel disease only	52.4% (266/508)	67.3% (261/388)		53.5% (294/550)	67.5% (216/320)	

*$P < 0.05$ for comparison PCI complete revascularization versus CABG complete revascularization
**$P < 0.05$ for comparison PCI incomplete revascularization versus CABG incomplete revascularization

(29.1 versus 16.4%, $P < 0.001$), a total occlusion (27.4 versus 19.3%, $P = 0.006$) and a bifurcation (69.3 versus 62.0%, $P = 0.030$). The number of lesions was significantly higher in the incomplete revascularization group (4.8 ± 1.6 versus 3.5 ± 1.5 in the complete revascularization group, $P < 0.001$).

In the PCI cohort, incomplete and complete revascularization groups had similar number of stents implanted (respectively, 4.6 ± 2.0 versus 4.7 ± 2.4, $P = 0.55$) and a comparable total stent length in mm (respectively, 83.6 ± 42.3 versus 88.0 ± 51.7, $P = 0.18$). CABG patients in the incomplete revascularization group had similar procedure time as those with complete revascularization (respectively, 3.4 ± 1.0 versus 3.5 ± 1.5, $P = 0.13$).

Predictors of incomplete revascularization

Predictors of incomplete revascularization are displayed in Table 2. For stent patients, hyperlipidaemia (OR = 1.59, 95% CI 1.04–2.42), a total occlusion (OR = 2.46, 95% CI 1.66–3.64) and the number of lesions (OR = 1.58, 95% CI 1.41–1.77) were independent predictors of incomplete revascularization in the multivariate model (Table 2).

In CABG patients, multivariate analysis identified only unstable angina (OR = 1.42, 95% CI 1.02–1.98), the diffuse disease or small vessels (OR = 1.87, 95% CI 1.31–2.69) and the number of lesions (OR = 1.70, 95% CI 1.53–1.89) as independent predictors.

Outcomes

Incomplete revascularization was associated with a higher MACCE rate at 3 years follow-up in patients who underwent PCI (33.5 versus 23.8% in patients with complete revascularization, $P < 0.001$) (Fig. 3) but not in patients that underwent CABG (21.9 versus 18.9% in patients with complete revascularization, $P = 0.29$).

The composite safety endpoint (16.6 versus 12.1%, $P = 0.05$) was higher with incomplete revascularization in the PCI cohort, but within the CABG cohort there was no difference (12.5 versus 11.4%, respectively, in incomplete and complete revascularization groups, $P = 0.62$).

Mortality was not significantly different between incomplete and complete revascularization groups in patients that underwent PCI (respectively, 10.1 versus 7.4%, $P = 0.13$) or CABG (respectively, 7.1 versus 6.2%, $P = 0.60$). Rates of MI were also not significantly different in PCI (8.2 versus 6.2% in incomplete and complete revascularization, $P = 0.25$) and CABG (respectively, 4.5 versus 2.9%, $P = 0.26$). However, in the incomplete revascularization group, there was a significantly higher rate of repeat revascularization in PCI (24.5 versus 16.1%, $P < 0.001$), but not CABG (13.0 versus 9.4%, $P = 0.11$).

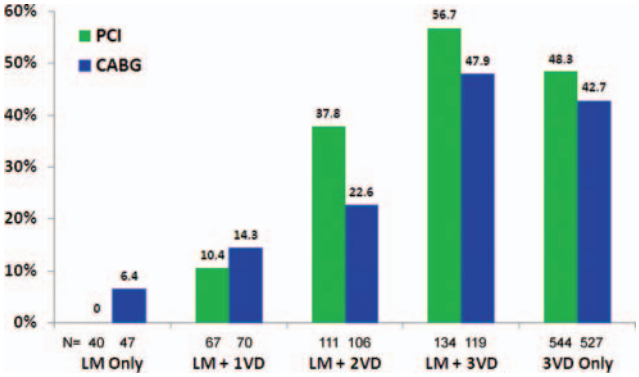

Figure 1: Rates of incomplete revascularization within patient lesion subsets. LM, left main; VD, vessel disease.

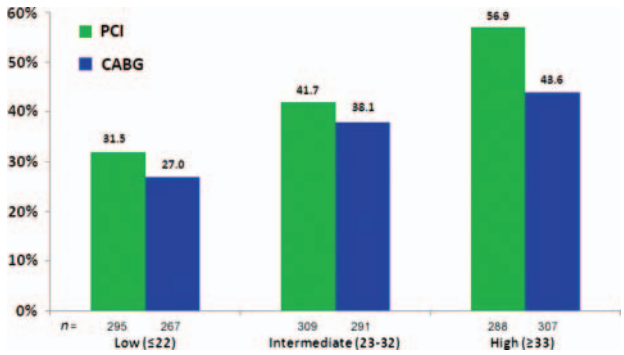

Figure 2: Rates of incomplete revascularization within SYNTAX score terciles.

Predictors of MACCE

Univariate Cox regression analysis identified incomplete revascularization as one of the predictors of MACCE, among others (Table 3). In the PCI arm, significant multivariate predictors for increased MACCE at 3 years were incomplete revascularization (HR = 1.55, 95% CI 1.15–2.08, $P = 0.004$), insulin requiring diabetes (HR = 1.94, 95% CI 1.33–2.84, $P = 0.001$), previous MI (HR = 1.42, 95% CI 1.04–1.92, $P = 0.026$) and carotid artery disease (HR = 1.96, 95% CI 1.24–3.11, $P = 0.004$). In the CABG cohort, only PVD (HR = 1.82, 95% CI 1.21–2.74, $P = 0.004$) and the Parsonnet score (HR = 1.03, 95% CI 1.01–1.05, $P = 0.006$) remained associated with MACCE in the multivariate model.

DISCUSSION

This study shows that in the SYNTAX population of patients with left main and/or multi-vessel coronary disease, PCI with

Table 2: Univariate and multivariate predictors of incomplete revascularization within PCI and CABG cohorts

	Univariate OR (95% CI)	*P*-value	Multivariate OR (95% CI)	*P*-value
PCI				
Any medically treated diabetes	1.51 (1.12–2.04)	0.007		
Insulin requiring diabetes	1.87 (1.20–2.91)	0.006		
Fasting glucose ≥110 mg/dl	1.38 (1.01–1.89)	0.044		
Hyperlipidaemia	1.49 (1.07–2.07)	0.019	1.59 (1.04–2.42)	0.031
SYNTAX score tercile	1.70 (1.43–2.01)	<0.001		
Diffuse disease or small vessels	1.53 (1.12–2.10)	0.008		
Total occlusion	2.45 (1.81–3.39)	<0.001	2.46 (1.66–3.64)	<0.001
Bifurcation	1.44 (1.09–1.89)	0.010		
Number of lesions	1.60 (1.46–1.77)	<0.001	1.58 (1.41–1.77)	<0.001
CABG				
Peripheral vascular disease	1.62 (1.05–2.51)	0.030		
Unstable angina	1.37 (1.01–1.85)	0.041	1.42 (1.02–1.98)	0.038
Logistic EuroSCORE	1.04 (1.01–1.07)	0.017		
SYNTAX score tercile	1.44 (1.21–1.71)	<0.001		
Diffuse disease or small vessels	2.10 (1.51–2.93)	<0.001	1.87 (1.31–2.69)	0.001
Total occlusion	1.58 (1.14–2.18)	0.006		
Bifurcation	1.38 (1.03–1.85)	0.031		
Number of lesions	1.71 (1.55–1.90)	<0.001	1.70 (1.53–1.89)	<0.001

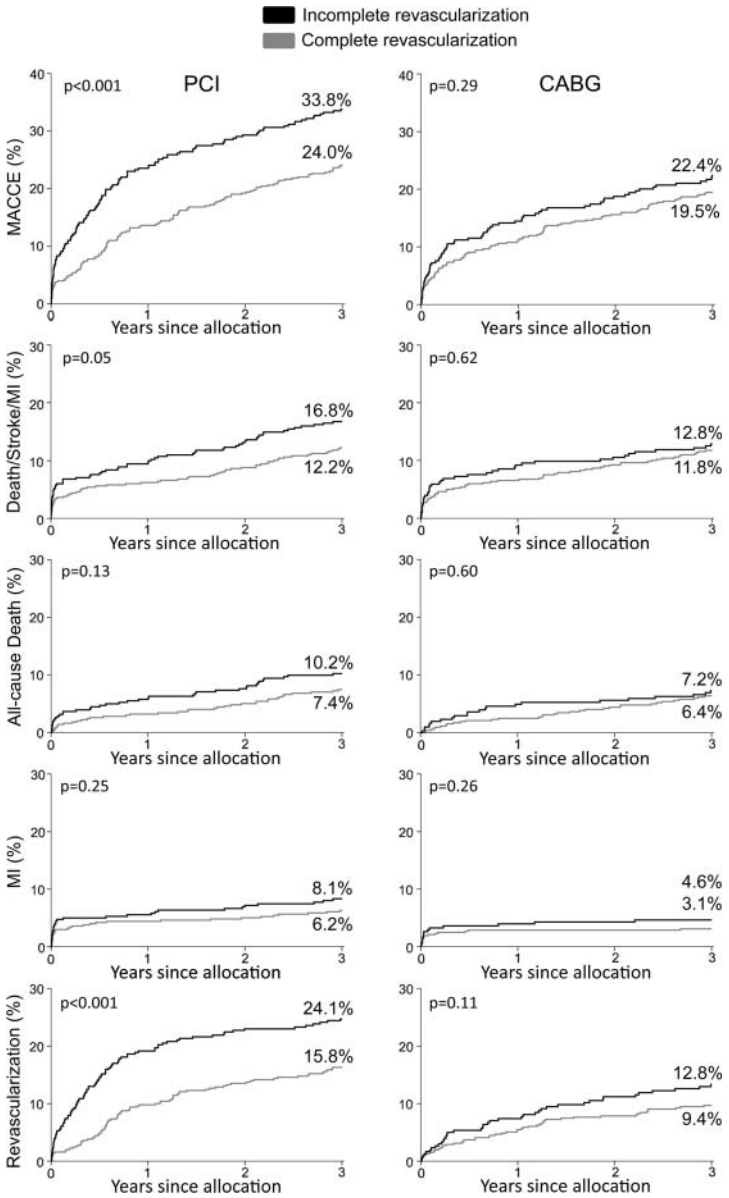

Figure 3: Three-year outcomes of incomplete revascularization versus complete revascularization. Kaplan–Meier estimates of (**A**) total MACCE; (**B**) the composite end-point of death/stroke/MI; (**C**) All-cause mortality; (**D**) MI; and (**E**) repeat revascularization in PCI (left) and CABG (right) cohorts

complete revascularization is associated with improved outcome compared with incomplete revascularization. In CABG patients, there was no additional risk of adverse events with incomplete revascularization.

The increased rate of MACCE in incomplete revascularized PCI patients is mainly attributed to a higher rate of repeat revascularization. The composite endpoint of death, MI and stroke was also higher with incomplete PCI, but for the individual components of MACCE no significant difference between complete and incomplete revascularization could be demonstrated.

The impact of incomplete revascularization on adverse events after CABG has been studied extensively since the early 1980s [11–13]. These studies uniformly concluded that survival and symptom relief after complete revascularization is favourable compared with incomplete revascularization. After the introduction of stents, many studies have also focused on the impact of completeness of revascularization in PCI patients. Several studies found that incomplete revascularization was associated with higher risk of long-term mortality or repeat revascularization [14]. There are, however, only a handful of studies that compared the influence of complete revascularization on MACCE in CABG and PCI patients simultaneously and there is only one report from a randomized study [6, 15, 16]. The evaluation of incomplete revascularization in non-randomized CABG and PCI cohorts is therefore limited because of differences in patient characteristics. Studies can also not be compared due to differences in definitions of complete revascularization.

Rates of complete revascularization vary significantly between studies. The ARTS trial showed an 82.1 and 70.5% rate of complete revascularization after CABG and PCI for multivessel disease [17]. These rates are much higher compared to this study, which rates were 63.2 and 56.7%, respectively. The rate of revascularization in the ARTS trial was probably higher due to less complex coronary lesions, but also due to the fact that the significant

Table 3: Univariate and multivariate predictors of adverse outcomes in incomplete and complete revascularization groups

	Univariate HR (95% CI)	*P*-value	Multivariate HR (95% CI)	*P*-value
PCI				
Incomplete revascularization	1.54 (1.20–1.97)	0.001	1.55 (1.15–2.08)	0.004
Age	1.02 (1.01–1.03)	0.008		
Any medically treated diabetes	1.62 (1.25–2.11)	<0.001		
Insulin requiring diabetes	1.94 (1.38–2.74)	<0.001	1.94 (1.33–2.84)	0.001
Previous myocardial infarction	1.33 (1.03–1.72)	0.030	1.42 (1.04–1.92)	0.026
Peripheral vascular disease	1.68 (1.16–2.42)	0.006		
Carotid artery disease	1.58 (1.06–2.36)	0.024	1.96 (1.24–3.11)	0.004
Unstable angina	1.39 (1.07–1.81)	0.013		
Logistic EuroSCORE	1.02 (1.01–1.04)	0.002		
Parsonnet score	1.02 (1.00–1.04)	0.029		
Number of lesions	1.09 (1.01–1.17)	0.024		
SXS terciles	1.29 (1.11–1.51)	0.001		
CABG				
Age	1.02 (1.01–1.04)	0.010		
Congestive heart failure	1.85 (1.07–3.19)	0.028		
Peripheral vascular disease	2.02 (1.36–2.99)	<0.001	1.82 (1.21–2.74)	0.004
Low ejection fraction (<35%)	2.19 (1.03–4.67)	0.042		
Logistic EuroSCORE	1.05 (1.03–1.08)	<0.001		
Parsonnet score	1.04 (1.02–1.06)	<0.001	1.03 (1.01–1.05)	0.006

coronary lesions that needed treatment were not defined by the heart team prior to randomization. The surgical procedure was scored as complete revascularization if the diseased segments had been treated according to the surgical report. The ARTS trial showed a significant higher MACCE rate after PCI in the incomplete revascularization group compared with complete revascularized patients (30.6 versus 23.4% respectively, $P < 0.05$), which was driven by a higher rate of repeat CABG (10.0 versus 2.0%, $P < 0.05$) [6]. Similar as in ARTS (12.2 versus 10.1%), however, we found no differences between incomplete and complete revascularization groups within CABG patients [6, 16].

The 43% incompletely revascularized rate with PCI in SYNTAX is lower than 69% that was reported from 39 centres in a study with 11 294 PCI patients [18]. ARTS-II performed PCI with a drug-eluting stent and had a 49% incomplete revascularization rate, quite similar to other studies that reported rates above 50% [15, 16].

In other studies, the rate of incomplete revascularization in CABG patients is ~10–19%, which is much lower than in the SYNTAX trial [5, 6, 19, 20], although Kim *et al*. [15], who also used the SYNTAX score to classify lesions, found a rate of 33% which is close to the 37% in SYNTAX. The reason for such a high incomplete revascularization rate in the SYNTAX CABG cohort is due to the used definition. Previous studies have often based incomplete revascularization on the surgeons report without a pre-operative statement which vessels contained a significant lesion that needed treatment. In the SYNTAX trial, the heart team was obliged to state before the randomization process took place which vessels needed revascularization. Linking this statement to the actual revascularization concludes whether revascularization was complete.

The number of lesions and total occlusion were predictive of incomplete revascularization in the multivariate model, while the SYNTAX score terciles were significant in the univariate analysis. Therefore, incomplete revascularization with PCI is more likely in patients with extensive coronary disease and technically more challenging lesions. In CABG patients, incomplete revascularization was higher in patients with diffusely diseased or narrowed (<2 mm) segments distal to the lesion.

Study limitations

We are aware that this subgroup analysis has limited power due to the methodological limitations of such analyses. The complete and incomplete revascularization subgroups were not predefined in the study protocol. We have performed and reported 10 subgroup analyses and this will produce one significant result by chance only. These results should be interpreted with caution and be considered hypothesis generating.

CONCLUSION

At 3 years, incomplete versus complete revascularization with PCI is associated with increased rates of MACCE and repeat revascularization. In patients treated with CABG, adverse events are similar in incomplete and complete revascularization groups.

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APPENDIX. CONFERENCE DISCUSSION

Dr M. Mack *(Dallas, TX, USA)*: My discussion is going to be limited to three questions about this study.

First of all, we were surprised at such a high rate of incomplete revascularization, at least in the CABG arm of this study. I remember sitting there with the heart team and deciding what we were intending to revascularize ahead of time. And surely this incomplete revascularisation rate is much higher than any of us thought, or that we've ever seen in the literature before. Is it because the intent for revascularization was decided ahead of time, rather than post hoc, that you think it was so high in CABG?

Dr Head: I think you were spot-on there at the end, that previous studies actually had the definition of incomplete revascularization defined postoperatively, so whenever the surgeons left the OR, they would say, "well, I revascularized everything that I had to revascularize".

But in SYNTAX, they had to define that preoperatively. And if, during the OR, they could not revascularize the vessel because it was, for instance, too small distally, which has also been a predictor of incomplete vascularization, they had an incomplete revascularization. So instead of doing whatever they could have done, they already missed a few vessels, so that's why the percentage is probably higher than in other studies.

Dr Mack: The second question is that every study of both CABG and PCI has shown that the less complete the revascularization, the less good the results. But it only mattered for PCI here rather than CABG. Why do you think that is? Do you think that, for instance, incomplete revascularization with PCI was inability to open a chronic total occlusion, and in CABG it was not bypassing a small diagonal that had diffuse disease? Are there different types of incomplete revascularization that may have led to those outcomes?

Dr. Head: Yes, I think so. And especially the small vessels at the end with the lesions, if they could not be revascularized, it has been said it would impact more on angina instead of survival or adverse events.

And with PCI, exactly as you say, chronic total occlusions are associated with adverse events and that's the difference, I guess, between PCI and CABG.

Dr Mack: The third question is that now with the results of the FAME trial, of looking at functional flow reserve, the concept of functionally complete revascularization rather than anatomically complete revascularization is an area of interest right now, and, at least from an interventional PCI standpoint, I think they have gone back and said that there would probably be 35 percent fewer stents placed in the PCI arm of this. What are your thoughts about this in the CABG arm? Do you think it would influence the number of grafts we place? Would the number of grafts that we end up placing be less in the future if we use FFR, and would that, perhaps, lead to less graft occlusion because of competitive flow? Any thoughts on that?

Dr. Head: Well, what I understand currently is that when the trial was designed, the 50% stenosis of FFR was 0.8, which was defined as haemodynamically significant for stenosis. And I guess in the CABG, the percentage would be lower if you set the threshold maybe higher, the percentage of incomplete revascularization, but I don't think that it would eventually have an impact on the outcomes because, as you already see now, there is no difference between incomplete and complete revascularization.

Dr D. Pagano *(Birmingham, UK)*: Just a thought on the second question that Dr. Mack asked you. The literature of incomplete revascularization in coronary artery bypass grafting is actually quite strong and it does show that incomplete revascularization is associated with worse outcomes. This is just a thought and I'm curious to have your counter thoughts and possibly Dr. Mack's. It is entirely possible that the effects of incomplete revascularization by PCI are manifest earlier in the longitudinal follow-up than for coronary artery bypass grafting and you may see a difference a bit later on with the coronary artery bypass grafting, too. What do you think?

Dr Head: Well, I mean, that's what you normally see, of course, with PCI and CABG, that PCI needs revascularization earlier than CABG. And I guess the follow-up with CABG tends to be with fewer events than PCI, especially in this trial, so we think that you are right, yes.

Dr D.P. Taggart *(Oxford, UK)*: I think what you've illustrated very clearly is that when you look through the literature in cardiac surgery about incomplete revascularization, you find very conflicting answers as to what it actually is. You get papers that say it makes no difference to outcome. You get other papers that say it has a profound influence on outcome. And I think what it does illustrate is that there are two types of incomplete revascularization: there is inappropriate incomplete revascularization and there is appropriate incomplete revascularization.

So, for example, putting a fourth graft to a second small obtuse marginal will have absolutely no adverse impact on outcome, although technically it may lead to temporarily inferior results. Whereas if you leave a big vessel, which may be occluded or whatever, and you don't graft it, that will adversely affect outcome. So I think we should try and be more accurate and define these as appropriate and inappropriate incomplete revascularization.