Original Article

The impact of incomplete revascularization on survival in minimal invasive off-pump coronary artery surgery: a propensity score analysis of 1,149 cases

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Background: Minimally invasive concepts are increasingly influential in modern cardiac surgery. This study aimed to evaluate the effect of completeness of revascularization on clinical outcomes and overall survival in minimally invasive, thoracoscopic coronary artery bypass grafting (CABG) surgery.

Methods: We retrospectively evaluated a consecutive series of 1,149 patients who underwent minimally invasive off-pump CABG with single, double, or triple-vessel revascularization between 2007 and 2018. Of these patients, 185 (16.1%) had incomplete revascularization (IR) (group I), and 964 (83.9%) had complete revascularization (CR) (group C). We used gradient boosted propensity score estimation to account for possible confounding variables.

Results: Median age was 69 years, interquartile range (IQR) 60–76 years, and median EuroSCORE II was 4, IQR 2–7. Of the 1,149 patients, 495 patients suffered from two vessel disease (VD) and 353 presented with three VD. Long-term median follow-up 5.58 (3.27–8.48) years was available for 1,089 patients (94.8%). The incidence of recurrent or persisting angina, myocardial infarction, redo-bypass surgery, and stroke during follow-up did not differ significantly between groups. During follow-up, there were 47 deaths in group I and 172 deaths in group C. The 1-, 3-, 5-, 8-, and 10-year unadjusted survival rates were 94%, 84%, 75%, 62%, and 51% for group I, and 97%, 94%, 88%, 77%, and 72% for group C, respectively (long-rank test P<0.001), favouring CR. Following risk adjustment the long-rank test P value for survival was 0.23.

Conclusions: In minimally invasive coronary surgery, IR resulted in decreased long-term survival, but did not achieve statistical significance after risk adjustment. However, IR should only be used in carefully selected cases.

Keywords: Coronary artery bypass grafting (CABG); minimally invasive off-pump coronary artery bypass grafting (MICS CABG); minimally invasive direct coronary artery bypass (MIDCAB); coronary artery disease (CAD); complete revascularization (CR)

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Introduction

Patients with severe coronary artery disease (CAD) who undergo coronary artery bypass grafting (CABG) experience long-term benefits. Since its inception, the invasiveness of CABG has remained virtually stable, primarily due to the use of complete median sternotomy and cardiopulmonary bypass (CPB). However, patients are increasingly presenting with more severe CAD, as well as comorbidities and frailty, which has led to a growing need for less invasive surgery and other minimally invasive revascularization methods (1).

Only a small number of pioneering groups have published information on minimally invasive CABG (2-4). Most of these studies focus on the efficacy, safety, and feasibility of incorporating these techniques into the standard toolkit at most CABG centers. However, long-term data on the effects of complete versus incomplete revascularization (IR) in this highly selected population is scarce.

For the majority of patients with CAD, complete revascularization (CR) is the goal. However, there is no class I evidence, societal standards, or expert consensus on how complete coronary artery revascularization should be. Additionally, there is no clear guidance on when CR is best or which patients can benefit from IR (5).

Several definitions of complete and IR have been proposed (5). The two most common definitions are anatomical (revascularization of all coronary segments with stenosis greater than a predefined size) and functional (revascularization of all ischemic and viable territories) (6).

In many clinical situations, CR is not possible due to comorbidities, coronary anatomy, or operator expertise. In these cases, IR occurs, leaving significant untreated CAD (5).

The clinical ramifications of IR in the majority of patients with CAD, particularly those with chronic coronary syndrome, remain controversial to this day (5). The results that have been reported so far are confusing as they are based on a wide range of definitions, measurement methods, study populations, and revascularization methods (5). Nowadays, patients who are referred to surgery tend to be older and have a greater number of co-occurring medical conditions. Additionally, the surgical method has undergone significant development, as evidenced by the increased utilization of arterial grafts, the off-pump CABG, and advances in perioperative management (6).

This study aimed to assess the impact of completeness of revascularization on clinical outcomes and overall survival in risk-adjusted cohorts of patients undergoing minimally invasive off-pump thoracoscopic CABG surgery. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-387/rc).

Highlight box

Key findings

- Although incomplete revascularization (IR) did not reach statistical significance after risk adjustment, it was associated with a greater major adverse cardiovascular and cerebrovascular events (MACCE) rate and a shorter long-term survival in minimally invasive coronary surgery.

What is known and what is new?

- The long-held belief that complete revascularization (CR) is preferable to IR in terms of long-term survival makes achieving CR a primary objective in coronary artery bypass grafting (CABG) surgery. The limited number of retrospective studies on IR have shown wide variation in its prognostic effect.
- We focused on the prognostic impact of IR on all cause mortality and MACCE in a multivessel coronary artery disease (CAD) population operated on using minimally invasive, off-pump technique and receiving in mostly arterial grafts.

What is the implication, and what should change now?

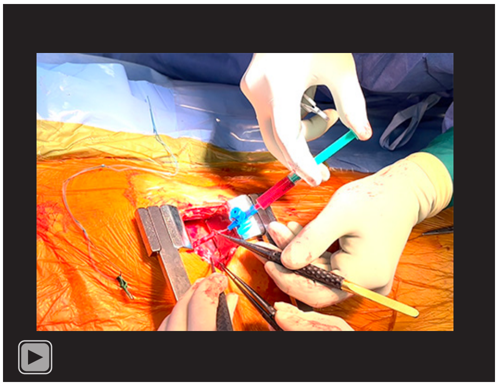
- Complete revascularization had a beneficial effect, although not to the point of statistical significance, on all-cause mortality and MACCE in our CAD study population operated on employing minimally invasive, off-pump CABG approach and receiving in a high majority arterial grafts. Hybrid revascularization strategies allow for IR as long as the percutaneous coronary intervention (PCI) step following surgery is performed. Rarely, following careful assessment in a heart-team setting, IR can be advantageous when the cost of establishing CR greatly surpasses the benefit.

Methods

Study design

From January 2007 to December 2018, a total of 1,149 consecutive patients underwent isolated, minimally invasive, off-pump CABG surgery at Robert Bosch Hospital. Of these patients, 626 underwent minimally invasive direct coronary artery bypass (MIDCAB) surgery and 523 underwent minimally invasive off-pump CABG (MICS CABG) surgery. The study consisted of two groups: patients with IR and patients with CR. CR was defined as treatment of all major coronary artery regions with stenosis greater than 70% or fractional flow reserve less than 0.8.

The aim of this study was to assess the effects of IR on this demographic by determining the incidence of major



Video 1 This video shows our setting for minimally invasive off-pump coronary artery bypass grafting procedures, which includes preparing the skeletonized LITA with a heparine-papaverine solution and sewing of the left internal thoracic artery to LAD artery. LITA, left internal mammary artery; LAD, left anterior descending.

adverse cardiovascular and cerebrovascular events (MACCE) and survival rates during mid-term and long-term follow-up. MACCE was defined as acute myocardial infarction, stroke, repeat revascularization and all-cause mortality.

Demographic and clinical profiles were systematically collected and analyzed, including CAD severity and history, comorbidities, and preoperative risk factors. The majority of follow-up data was collected via mail or telephone interviews with study participants, or through communication with their referring cardiologists or primary care physicians if the participant could not be reached. Indicators of quality of life, such as angina symptoms and subsequent procedures, were also collected. Additionally, information regarding the date and cause of death was collected, where applicable.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study protocol was evaluated and approved by the ethics committee of the Medical University Tübingen (ethics registration number: 777/2021B02 as of December 6, 2021). Prior to their inclusion in the investigation, all study participants provided written informed consent.

Surgical technique

A 6- to 7-cm left antero-lateral thoracotomy was performed through the bed of the fifth intercostal space. The left internal thoracic artery (LITA) conduit was mobilised to revascularize the left anterior descending (LAD) artery in all cases. A T-graft construct was created to deliver blood flow to the lateral and/or posterior myocardial walls, with either the radial artery or saphenous vein used as bypass grafts and connected to the LITA. All operations were carried out on a beating heart using the off-pump approach (*Video 1*). The operational specifics have been presented previously (7).

The selection between the saphenous vein and radial artery was determined by patient-specific factors rather than surgical or surgical expertise of the operating surgeon. In the event that the radial artery could not be utilised (due to atherosclerosis, dissection of the artery, Allen Test revealed pathology on both sides, and/or the radial artery was utilised for the coronary angiogram prior to surgery), the saphenous vein was employed.

There were several reasons for IR:

- ❖ In 57 cases, the heart team decided to perform IR (single LITA-LAD bypass) due to the patients' severe infirmity and multiple diseases. The mean age of these patients was 79.7 years, and 29.8% of them experienced an acute myocardial infarction within three weeks prior to surgery. Furthermore, 43.9% presented with chronic kidney disease. The referring interventional cardiologist determined that these patients' significantly calcified coronaries and complicated anatomy made them unsuitable for percutaneous coronary intervention (PCI).
- ❖ In 85 cases, hybrid procedures were scheduled, but the intended PCI procedure was never performed. The reason can be attributed to one of two factors. Firstly, some patients did not experience angina symptoms after surgery, leading to the postponement of the procedure. Secondly, the procedure was conducted not only through a coronary angiogram, but also involved subsequent hemodynamic measurements. As a result, it was determined that the remaining stenosis was not significant and did not require PCI or stent implantation.
- ❖ In 43 cases, the intended surgical operation could not be completed because the operating surgeon assessed that the patients' coronaries were too small and excessively atherosclerotic to be revascularized.

Statistical analysis

The study's numeric variables do not exhibit a normal distribution, thus necessitating the reporting of their median and interquartile range (IQR). Baseline characteristics are represented in the form of numerical values and percentages for patients with categorical variables. Given the nature of this observational study, it was anticipated that there would be variations in several preoperative characteristics between the groups under comparison. These characteristics include sex, age, body mass index (BMI), European System for Cardiac Operative Risk Evaluation II (EuroSCORE II), previous myocardial infarction, diabetes history, stroke history, peripheral vascular disease, atrial fibrillation (AF), chronic obstructive pulmonary disease (COPD), arterial hypertension, renal insufficiency, carotid stenosis, left ventricular ejection fraction (LVEF), surgery type, number of anastomoses, and emergency status.

Every case was given a weight equal to the reciprocal of the estimated chance that it would be found in the treatment group under observation, in order to permit legitimate causal inferences. The probabilities, referred to as propensity scores (PS), were assessed using gradient boosted logistic regression, which accounted for potential interaction and nonlinearity of factors (8). The adequacy of group balancing was assessed by employing a PS-adjusted logistic regression model, with completeness of revascularization serving as the dependent variable for each variable. The standardized effect size of the variable was employed as an indicator of the degree to which this variable exhibits balance.

The impact of therapy, namely the extent of revascularization, on peri- or post-treatment variables was evaluated by the utilization of PS-adjusted simple linear, bi- or multinomial logistic, or Cox survival regression models, depending on the nature of the variable. The survival curves of observations that were subject to right censoring were compared using PS-adjusted log-rank testing. The study used a PS-adjusted interval-censored technique to account for the presence of left and right censored observations in the MACCE-free survival data (9). The return date of the questionnaire was utilized for all survival analyses.

A bootstrap-type method was employed to calculate the PS-adjusted P value in the analysis of MACCE-free survival curves. In this method, the treatment variable was sampled based on the PS of each individual case. The lack of data on survival or MACCE for the sixty cases that were lost to follow-up was treated as absent value. All the other variable sets that were gathered were full except for this information.

A P value below 0.05 was deemed to be statistically significant. The statistical computations were performed using R software, specifically version 4.2 (10). The computation of PS was performed using the R-library twang (8). The majority of survival-related studies were conducted applying the R libraries survival (11) and survey (12). The svyVGAM package (13) was applied to do multinomial regression with weighted observations. The interval library was employed to conduct a comparison of survival curves for interval censored data (9).

Results

Demographics

A total of 964 individuals received CR (group C), while 185 patients had IR (group I). According to *Table 1*, before PS weighting, patients in group I were older [73 (IQR 65–80) *vs.* 68 (IQR 60–75.2) years, P<0.001], had a higher mean EuroSCORE II [5 (IQR 2.68–9) *vs.* 4 (IQR 2–7), P<0.001], and were more likely to have concomitant COPD (11.9% *vs.* 6.3%, P=0.008), AF (25.9% *vs.* 13.2%, P<0.001), peripheral vascular disease (18.4% *vs.* 10.2%, P=0.002), medically treated type II diabetes (28.6% *vs.* 19.9%, P=0.008), impaired renal function defined as glomerular filtration rate (GFR) under 50 mL/min/1.73 m^2) (28.6% *vs.* 13.1%, P<0.001), as well as history of stroke (9.2% *vs.* 5.3%, P=0.04).

All ten redo CABG patients were placed in group C, which also included a considerably greater percentage of patients with normal LVEF (P<0.001), a higher proportion of patients who had been previously treated by PCI (21.6% *vs.* 35.1%, P<0.001), and a higher proportion of patients with 1- and 2-vessel disease (VD) (P<0.001).

After an earlier PCI, only coronary segments with target vessel restenosis or occlusion were considered diseased.

Operative and in-hospital data

Table 2 shows that in group I, 132 (71.3%) patients underwent a MIDCAB procedure and 53 (28.7%) received a MICS CABG. Group C consisted of 494 (51.2%) MIDCAB cases and 470 (48.8%) MICS CABG ones. Both groups had a very high rate of total arterial revascularization and a very low rate of in-hospital complications and adverse outcomes following surgery.

The rate of conversion to either sternotomy or sternotomy with CPB was extremely low. However, all five patients who required conversion belonged to group C.

Long-term survival and MACCE

The median follow-up duration was 5.58 (3.27–8.48) years,

Table 1 Baseline patient characteristics

Variable	All (n=1,149)	Group I (n=185)	Group C (n=964)	Std. eff. sz.	Unadj. P	Adj. std. eff. sz.	Adj.P
Age (years)*	69 [60–76]	73 [65–80]	68 [60–75.2]	4.420	<0.001	–0.459	0.64
Male gender*	975 (84.9)	152 (82.2)	823 (85.4)	1.114	0.26	–0.124	0.90
BMI* (kg/m^2)	26.3 [24.2–28.7]	26.5 [24.2–29]	26.3 [24.2–28.7]	–0.646	0.51	–1.01	0.31
EuroSCORE II*	4 [2–7]	5 [2.68–9]	4 [2–7]	–4.04	<0.001	–0.881	0.37
COPD*	83 (7.2)	22 (11.9)	61 (6.3)	–2.632	0.008	–0.202	0.84
Arterial hypertension*	1,142 (99.4)	184 (99.5)	958 (99.4)	–0.131	0.89	–1.074	0.28
Atrial fibrillation*	176 (15.3)	48 (25.9)	128 (13.2)	–3.72	<0.001	–0.681	0.49
Dyslipidaemia	1137 (99)	180 (97.3)	957 (99.3)	2.256	0.02	1.726	0.08
Peripheral vascular disease*	132 (11.5)	34 (18.4)	98 (10.2)	–3.159	0.002	–0.738	0.46
Medically treated type II diabetes*	245 (21.3)	53 (28.6)	192 (19.9)	–2.638	0.008	–0.839	0.40
Creatinine (mg/dL)	1 [0.9–1.1]	1 [0.9–1.3]	1 [0.8–1.1]	–3.050	0.002	–0.73	0.46
Impaired renal function* (GFR <50 mL/min/1.73 m^2)	179 (15.6)	53 (28.6)	126 (13.1)	–5.205	<0.001	–0.660	0.50
Renal replacement therapy	13 (1.1)	6 (3.2)	7 (0.7)	–2.706	0.007	–1.355	0.17
Carotid stenosis*	127 (11.1)	28 (15.1)	99 (10.3)	–1.920	0.055	–0.473	0.63
History of stroke*	68 (5.9)	17 (9.2)	51 (5.3)	–2.031	0.042	–0.730	0.46
History of MI*							
No (BL)	735 (64.0)	112 (60.5)	623 (64.6)	NA	NA	NA	NA
MI <48 h	14 (1.2)	4 (2.2)	10 (1.0)	–1.332	0.18	–0.298	0.76
MI 2 d–21 d	156 (13.6)	32 (17.3)	124 (12.9)	–1.619	0.10	1.132	0.25
MI 21 d–91 d	93 (8.1)	16 (8.6)	77 (8.0)	–0.494	0.62	–0.096	0.92
MI >91 d	151 (13.1)	21 (11.4)	130 (13.5)	0.417	0.67	0.402	0.68
History of PCI	378 (32.9)	40 (21.6)	338 (35.1)	3.516	<0.001	3.514	<0.001
Previous cardiac surgery	13 (1.1)	0 (0)	13 (1.3)	>10	<0.001	>10	<0.001
Previous CABG surgery	10 (0.9)	0 (0)	10 (1.0)	> 10	<0.001	> 10	<0.001
Extent of CAD							
1 VD (BL)	301 (26.2)	1 (0.5)	300 (31.1)	NA	NA	NA	NA
2 VD	495 (43.1)	72 (38.9)	423 (43.9)	–3.902	<0.001	–2.951	0.003
3 VD	353 (30.7)	112 (60.5)	241 (25)	–4.906	<0.001	–4.065	<0.001
LVEF*							
>50%	899 (78.2)	119 (64.3)	780 (80.9)	NA	NA	NA	NA
30–50%	205 (17.8)	53 (28.6)	152 (15.8)	–4.408	<0.001	–0.679	0.49
<30%	45 (3.9)	13 (7)	32 (3.3)	–2.852	0.004	0.118	0.90
Status*: urgent surgery	386 (33.6)	54 (29.2)	332 (34.4)	1.382	0.16	0.039	0.96

Values are presented as number and percentage (%) for categorical variables and as median and interquartile range [Q1 – Q3] for continuous variables. *, variables included in the propensity score (PS)-adjusted logistic regression model. Group I: incomplete revascularization; Group C: complete revascularization. unadj, unadjusted; adj. std. eff. sz., adjusted standardised effect size; adj. P, adjusted P value; BMI, body mass index; EuroSCORE, European System for Cardiac Operative Risk Evaluation; COPD, chronic obstructive pulmonary disease; GFR, glomerular filtration rate; MI, myocardial infarction; BL, base line; NA, not available; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; CAD, coronary artery disease; VD, vessel disease; LVEF, left ventricular ejection fraction.

Table 2 Operative and in-hospital post-surgery data

Variable	All (n=1,149)	Group I (n=185)	Group C (n=964)	Std. eff. sz.	Unadj. P	Adj. std. eff. sz.	Adj.P
Type of surgery*							
MIDCAB	626 (54.5)	132 (71.3)	494 (51.2)	NA	NA	NA	NA
MICS CABG	523 (45.5)	53 (28.7)	470 (48.8)	4.93	<0.001	1.321	0.18
No. of distal anastomoses*							
1 (BL)	627 (54.6)	132 (71.4)	495 (51.3)	NA	NA	NA	NA
2	453 (39.4)	49 (2.6)	404 (41.0)	0.437	<0.001	0.860	0.39
3	68 (6.0)	4 (2.2)	65 (6.7)	2.795	0.005	1.749	0.08
Type of revascularization according to graft material							
Dominant arterial (BL)	1 (0.1)	0 (0)	1 (0.1)	NA	NA	NA	NA
Dominant venous	4 (0.3)	2 (1.1)	2 (0.2)	<–10	<0.001	<–10	<0.001
Total arterial	1,115 (97.0)	180 (97.3)	935 (97.0)	<–10	<0.001	<–10	<0.001
Equal (no. arterial = no. venous)	29 (2.5)	3 (1.6)	26 (2.7)	<–10	<0.001	<–10	<0.001
Conversion to sternotomy	4 (0.3)	0 (0)	4 (0.4)	>10	<0.001	>10	<0.001
Conversion to sternotomy and CPB	1 (0.1)	0 (0)	1 (0.1)	>10	<0.001	>10	<0.001
Radial artery as bypass graft	395 (34.4)	33 (17.8)	362 (37.6)	5.010	<0.001	1.874	0.06
Saphenous vein as bypass graft	37 (3.2)	5 (2.7)	32 (3.3)	0.434	0.66	0.524	0.60
Length of ICU stay (days)	1 [1–1]	1 [1–1]	1 [1–1]	–0.948	0.34	0.457	0.64
Length of hospital stay (days)	7 [6–9]	7 [6–9]	7 [6–8]	–1.79	0.07	0.468	0.64
Postoperative new onset renal failure requiring dialysis	19 (1.7)	8 (4.3)	11 (1.1)	–2.892	0.004	–1.632	0.10
Postoperative stroke	13 (1.1)	4 (2.2)	9 (0.9)	–1.405	0.16	–0.549	0.58
Postoperative CPR	11 (1.0)	4 (2.2)	7 (0.7)	–1.749	0.08	–0.118	0.90
Postoperative MI	11 (1.0)	2 (1.1)	9 (0.9)	0.188	0.85	1.157	0.24
Reoperation for bleeding	33 (2.9)	3 (1.6)	30 (3.1)	1.091	0.27	1.549	0.12
Reoperation with bypass revision	7 (0.6)	0 (0)	7 (0.7)	>10	<0.001	>10	<0.001
30-d mortality	14 (1.2)	4 (2.2)	10 (1.0)	–1.249	0.21	0.569	0.56

Values are presented as number and percentage (%) for categorical variables and as median and interquartile range [Q1 – Q3] for continuous variables. *, variables included in the propensity score (PS)-adjusted logistic regression model. Group I: incomplete revascularization; Group C: complete revascularization. unadj, unadjusted; adj. std. eff. sz., adjusted standardised effect size; adj. P, adjusted P value; MIDCAB, minimally invasive direct coronary artery bypass; NA, not available; MICS CABG, minimally invasive off-pump coronary artery bypass grafting; BL, base line; CPB, cardiopulmonary bypass; ICU, intensive care unit; CPR, cardiopulmonary resuscitation; MI, myocardial infarction.

Table 3 Follow up outcomes

Variable	All (n=1,089)	Group I (n=185)	Group C (n=964)	Std. eff. sz.	Unadj. P	Adj. std. eff. sz.	Adj.P
Angina pectoris	166 (14.4)	29 (15.6)	137 (14.2)	−0.747	0.45	−1.524	0.12
Myocardial infarction	50 (4.4)	6 (3.2)	44 (4.6)	0.703	0.48	1.073	0.28
Percutaneous coronary intervention	134 (11.7)	22 (11.9)	112 (11.6)	−0.282	0.77	−0.721	0.47
Redo bypass surgery	7 (0.6)	0 (0)	7 (0.7)	>10	<0.001	>10	<0.001
Stroke	49 (4.3)	5 (2.7)	44 (4.5)	1.043	0.29	0.327	0.74
MACCE	387 (33.7)	72 (38.9)	315 (32.6)	−2.081	0.03	−1.112	0.26

Values are presented as number and percentage (%); Group I: incomplete revascularization; Group C: complete revascularization. unadj, unadjusted; adj. std. eff. sz., adjusted standardised effect size; adj. P, adjusted P value; MACCE, major adverse cardiovascular and cerebrovascular event.

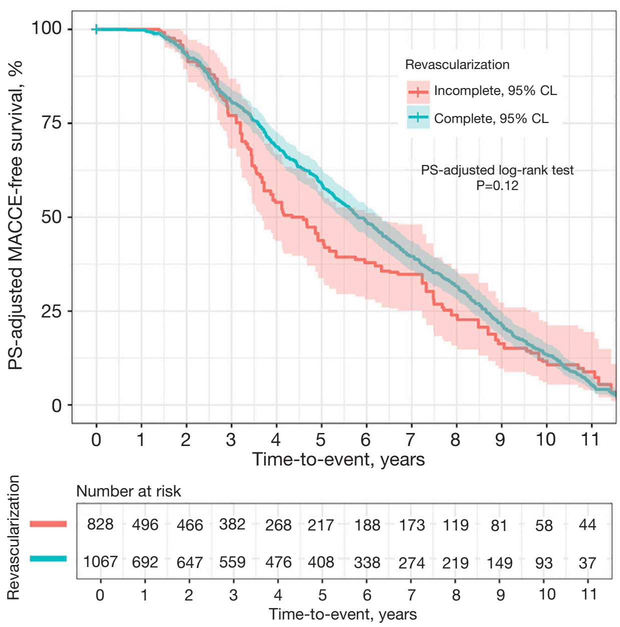


Figure 1 The Kaplan Meier MACCE curves for the two adjusted study populations. CL, confidence limits; MACCE, major adverse cardiovascular and cerebrovascular event; PS, propensity score.

and 1,089 patients were followed up on, for a follow-up rate of 94.8%. *Table 3* presents the number of events for each cohort during follow-up. Fifty patients had a myocardial infarction, accounting for 4.4%, whereas 134 patients, or 11.7%, required a PCI procedure. It is worth noting that none of the seven patients who underwent redo bypass surgery were designated from group I.

No significant differences between the two weighted groups were found with regard to recurrence of angina symptomatic [P=0.12, logOR (odds ratio): −0.387, 95% confidence limit (CL): −0.886 to 0.111], acute myocardial infarction rate (P=0.28, log OR: 0.524, 95% CL: −0.434 to 1.483), stroke rate (P=0.74, logOR: 0.174, 95% CL: −0.874 to 1.224) or repeat revascularization by means of PCI (P=0.47, logOR: −0.198, 95% CL: −0.740 to 0.342). Seven patients, all of whom were in group C, required redo bypass surgery.

In addition, the cumulative MACCE rate was comparable between the two groups [(P=0.26, logOR: −0.217, 95% CL: −0.599 to 0.165), log-rank test P=0.12]. *Figure 1* depicts the Kaplan Meier MACCE-free survival curves for the two adjusted study populations.

On the basis of Kaplan Meier estimates, the 1-, 3-, 5-, 8-, and 10-year unadjusted survival rates were 94%, 84%, 75%, 62%, and 51% for group I, and 97%, 94%, 88%, 77%, and 72% for group C, with a significant advantage for CR, P<0.001 [hazard ratio (HR): 0.510, 95% CL: 0.368–0.705, log-rank test P=0.00003] (*Figure 2*).

The 1-, 3-, 5-, 8-, and 10-year adjusted survival rates were 96%, 90%, 83%, 71%, and 59% for group I, and 97%, 93%, 87%, 76%, and 71% for group C, P=0.19 (HR: 0.777, 95% CL: 0.531–1.137, log-rank test P=0.23).

The Kaplan Meier survival curves for the two adjusted study populations are presented in *Figure 3*.

Discussion

The primary findings of this study, which included 1,149 PS-adjusted MIDCAB and MICS CABG patients, were improved mid- and long-term survival and reduced severe adverse events for patients who underwent CR.

One of the study's significant findings is that more than half of the patients in our IR study cohort were initially

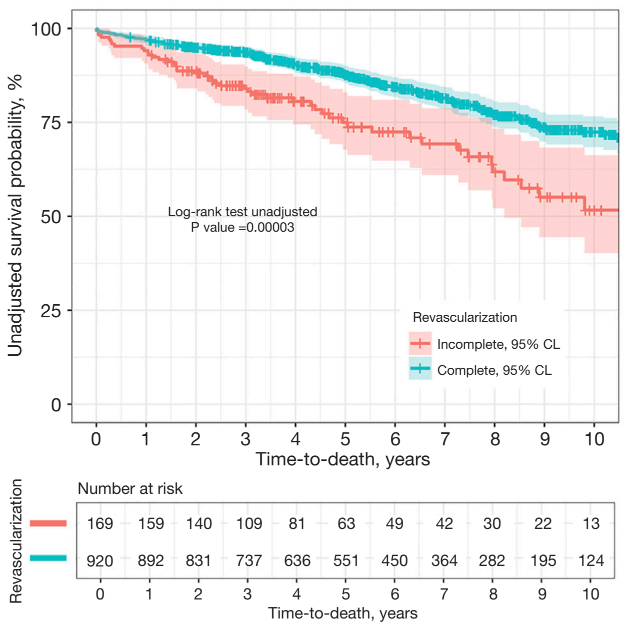


Figure 2 The Kaplan Meier survival curves for the two unadjusted study populations. CL, confidence limits.

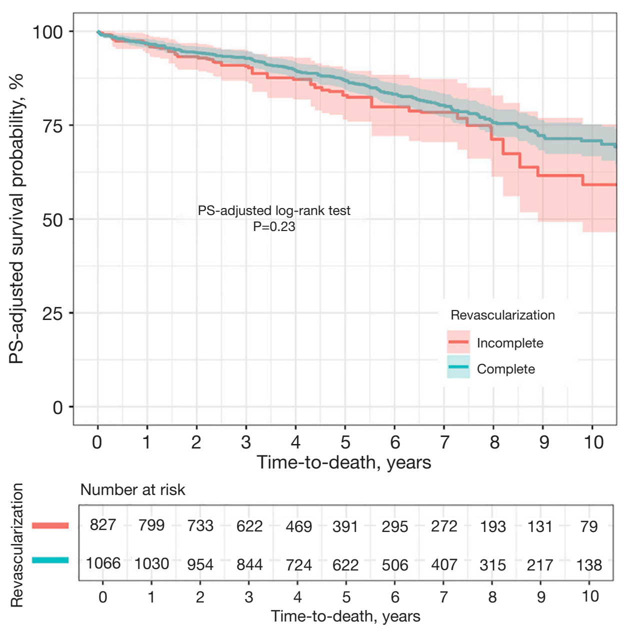


Figure 3 The Kaplan Meier survival curves for two adjusted study populations. PS, propensity score.

scheduled for a hybrid treatment, but the planned PCI procedure did not occur. This could explain why the IR group had a lower survival rate. The organization of the PCI step following heart surgery must be prioritized in the future.

The long-held belief that CR is preferable to IR in terms of long-term survival makes achieving CR a primary objective in CABG (5). However, between 9% and 39% of patients in clinical practice have IR (14-23).

The limited number of retrospective studies on IR have shown wide variation in its prognostic effect. This is likely due to the use of different definitions of IR, surgical approaches, patient groups, CAD patterns, and follow-up times (14-21).

In stable patients with multivessel (MV) disease, early trials from the 1980s showed a survival benefit of CR versus IR in individuals who underwent CABG (24-26). With a median follow-up of 4.7 years, a meta-analysis of 28 trials involving 83,695 individuals, found that CR had a greater survival benefit than IR in patients with CABG (risk ratio, 0.76; 95% CI: 0.63–0.90) (27).

A SYNTAX (Synergy Between PCI With Taxus and Cardiac Surgery) trial analysis of all-comers patients with 3VD or left main CAD, consisting of randomly assigned patients and a nested registry, revealed that CR with CABG had a lower risk of all-cause death at 4 years compared with IR [HR, 0.70 (95% CI: 0.49–0.98); P=0.039] (28). In the SYNTAX Extended Survival Study analysis, Takahashi *et al.* found that overall CR had no significant difference in the risk of 10-year all-cause death compared to IR in CABG patients (29).

This difference to the 4-year SYNTAX data (28) was likely due to the fact that the nested CABG registry included patients with more complex anatomy and more clinical comorbidities and these patients were at a much higher risk of death from all causes after CABG with IR instead of CR (29).

Bianco *et al.* reported that surgical CR of all angiographically stenotic arteries was linked with fewer major adverse events and increased mid-term survival in a recent trial that included 3,356 patients with MV CAD who underwent isolated CABG (15). There was no association between IR of non-main-branch vessels and either survival or MACCE (15).

We focused on the prognostic impact of IR on all cause mortality and MACCE in a MV CAD population operated on using minimally invasive, off-pump technique and receiving in mostly arterial grafts. An inquiry was made regarding whether the selection of conduit and the improvement of the surgical procedure throughout the duration of the trial, particularly whether there was a higher utilisation of saphenous vein grafts compared to radial artery grafts at the beginning, could have influenced the survival outcomes. In our study group, we discovered that the choice of bypass graft material was not influenced by time, but rather by individual patient variables. In addition, the proportion of patients who underwent a saphenous vein graft was rather small, totalling 3.2%, with 2.7% in group I and 3.3% in group C. Thus, this discovery further supports the concept that bypass grafting of the LAD with the LITA may counterbalance the long-term prognostic effects of CAD.

In a study of 8,806 individuals, Rastan *et al.* hypothesized that bypass grafting of the LAD with LITA may largely compensate for the prognostic impact of MV CAD (14). The authors found no impact of IR on long-term survival. They also hypothesized that, in diffuse distal CAD of the non-LAD areas, postoperative optimized medication may compensate for surgical IR (14). Off-pump IR using LITA-LAD grafting achieved satisfactory in-hospital and mid-term results in a study of 1,349 isolated off-pump CABG patients conducted by Ji *et al.* (23). Kaplan Meier curves comparing the two groups, complete *vs.* incomplete revascularized, revealed similar cumulative survival free from recurrent revascularization (23).

The authors hypothesise that off-pump IR with LITA grafting to LAD may be a relatively attractive approach in cases when surgical CR is difficult to perform (23). In our study, all patients received a LITA-LAD bypass. IR negatively affected long-term survival in both the unadjusted and adjusted populations. Of the 185 patients in group I, 57 were destined for IR in the form of MIDCAB from the start due to their advanced state of frailty and medical conditions. However, in the aforementioned research, patients in the IR group had a median of 3 bypasses while those in the CR group received a median of 4 bypasses (23). Thus, we can deduce that revascularizing merely the LAD in an MV CAD might not be enough to improve long-term survival.

In our cohort, these cases were immediately flagged during heart-team screening as being too frail and sick to withstand a complete surgical revascularization. In addition, our two groups' early and 1-year survival rates are comparable, providing further support for this strategy in the aforementioned exceptional circumstances.

The rationale for CR is distinct from the feasibility of achieving it (21). Patients with IR may already have a worse long-term perspective, because IR is a potential marker of an increased burden and complexity of coronary and other vascular disease (30). Head *et al.*, using data from the SYNTAX trial population, determined that diffuse disease of small vessels was the primary cause of IR. Other causes included peripheral vascular disease, unstable angina, a higher EuroSCORE, a higher SYNTAX score, the presence of a total occlusion, bifurcation, and a greater number of lesions (21).

Long-term outcomes of complete and IR in a PS-matched group with MV CAD and pre-existing AF were documented by Pasierski *et al.* CR was found to provide long-term benefits, especially for low-risk patients receiving off-pump CABG (22).

Kim *et al.* found in a 10-year subgroup analysis of the PRECOMBAT study's outcomes that 68.3% of the PCI group and 70.3% of the CABG group underwent CR. The authors found no statistically significant difference between PCI and CABG in the rates of MACCE and all-cause mortality, regardless of whether revascularization was complete or incomplete (31). CR in our research group enhanced the prognosis in the mid- and long-term, although not to the point of statistical significance.

Due to the complex nature of coronary lesions, CR is often an ideal but unattainable aim, even after careful identification of criteria for CABG. Unfortunately, surgical revascularization is still mostly focused on anatomy, and fractional flow reserve guided revascularization is not regularly performed.

Every patient must get individualized care, and a heart-team plays an essential part in this process by considering the patient's unique medical history, current clinical condition, and coronary anatomy. CR should be considered in making these choices, although it should be understood that in some cases this may not be possible.

The study's most significant limitation is its retrospective nature. Furthermore, though using PS weighting, the study reflects the results of a single center over a rather lengthy period of time; hence, results should be interpreted with caution. Also, the study population was recruited through a thorough process of selection and debate in heart-team. The comparison of IR and CR in minimally invasive off-pump CABG patients was observational, so the results were subject to residual confounding factors. Our surgical team has extensive experience with both off-pump CABG and minimally invasive methods, which may influence the generalizability of our findings. Another possible confounding element is the inferred definition of complete versus IR.

Conclusions

CR had a beneficial effect, although not to the point of statistical significance, on all-cause mortality and MACCE in our CAD study population operated on employing minimally invasive, off-pump CABG approach and receiving in a high majority arterial grafts. Hybrid revascularization strategies allow for IR as long as the PCI step following surgery is performed. Rarely, following careful assessment in a heart-team setting, IR can be advantageous when the cost of establishing CR greatly surpasses the benefit.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-387/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-387/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics committee of the Medical University Tübingen (ethics registration number: 777/2021B02 as of December 6, 2021). Prior to their inclusion in the investigation, all study participants provided written informed consent.

References

1. Van den Eynde J, Bennett J, McCutcheon K, et al. Heart team 2.0: A decision tree for minimally invasive and hybrid myocardial revascularization. Trends Cardiovasc Med 2021;31:382-91.
2. Holzhey DM, Cornely JP, Rastan AJ, et al. Review of a 13-year single-center experience with minimally invasive direct coronary artery bypass as the primary surgical treatment of coronary artery disease. Heart Surg Forum 2012;15:E61-8.
3. Ruel M, Shariff MA, Lapierre H, et al. Results of the Minimally Invasive Coronary Artery Bypass Grafting Angiographic Patency Study. J Thorac Cardiovasc Surg 2014;147:203-8.
4. Lapierre H, Chan V, Sohmer B, et al. Minimally invasive coronary artery bypass grafting via a small thoracotomy versus off-pump: a case-matched study. Eur J Cardiothorac Surg 2011;40:804-10.
5. Ali ZA, Horst J, Gaba P, et al. Standardizing the Definition and Analysis Methodology for Complete Coronary Artery Revascularization. J Am Heart Assoc 2021;10:e020110.
6. Leviner DB, Torregrossa G, Puskas JD. Incomplete revascularization: what the surgeon needs to know. Ann Cardiothorac Surg 2018;7:463-9.
7. Rufa MI, Ursulescu A, Aktuerk D, et al. Minimally invasive strategies of surgical coronary artery revascularization for the aging population. J Cardiovasc Surg (Torino) 2023;64:534-40.
8. Cefalu M, Ridgeway G, McCaffrey D, et al. Twang: Toolkit for weighting and analysis of nonequivalent groups 2021. R package version 2.5, Available online: https://CRAN.R-project.org/package=twang
9. Fay MP, Shaw PA. Exact and Asymptotic Weighted Logrank Tests for Interval Censored Data: The interval R package. J Stat Softw 2010;36:i02.
10. Core Team R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2022. Available online: https://www.R-project.org/
11. Therneau T. A Package for Survival Analysis in R.R package version 3.5-5, 2023, https://CRAN.R-project.org/package=survival

12. Lumley T. Survey: analysis of complex survey samples. R package version 4.2, 2023. Available online: https://CRAN.R-project.org/package=survey
13. Lumley T. svyVGAM: design-based inference in vector generalised linear models. R package version 1.2, 2023, Available online: https://CRAN.R-project.org/package=svyVGAM
14. Rastan AJ, Walther T, Falk V, et al. Does reasonable incomplete surgical revascularization affect early or long-term survival in patients with multivessel coronary artery disease receiving left internal mammary artery bypass to left anterior descending artery? Circulation 2009;120:S70-7.
15. Bianco V, Kilic A, Aranda-Michel E, et al. Complete revascularization during coronary artery bypass grafting is associated with reduced major adverse events. J Thorac Cardiovasc Surg 2023;166:104-113.e5.
16. Bell MR, Gersh BJ, Schaff HV, et al. Effect of completeness of revascularization on long-term outcome of patients with three-vessel disease undergoing coronary artery bypass surgery. A report from the Coronary Artery Surgery Study (CASS) Registry. Circulation 1992;86:446-57.
17. van den Brand MJ, Rensing BJ, Morel MA, et al. The effect of completeness of revascularization on event-free survival at one year in the ARTS trial. J Am Coll Cardiol 2002;39:559-64.
18. Osswald BR, Blackstone EH, Tochtermann U, et al. Does the completeness of revascularization affect early survival after coronary artery bypass grafting in elderly patients? Eur J Cardiothorac Surg 2001;20:120-5, discussion 125-6.
19. Kleisli T, Cheng W, Jacobs MJ, et al. In the current era, complete revascularization improves survival after coronary artery bypass surgery. J Thorac Cardiovasc Surg 2005;129:1283-91.
20. Moon MR, Sundt TM 3rd, Pasque MK, et al. Influence of internal mammary artery grafting and completeness of revascularization on long-term outcome in octogenarians. Ann Thorac Surg 2001;72:2003-7.
21. Head SJ, Mack MJ, Holmes DR Jr, et al. Incidence, predictors and outcomes of incomplete revascularization after percutaneous coronary intervention and coronary artery bypass grafting: a subgroup analysis of 3-year SYNTAX data. Eur J Cardiothorac Surg 2012;41:535-41.
22. Pasierski M, Staromłyński J, Finke J, et al. Clinical Insights to Complete and Incomplete Surgical Revascularization in Atrial Fibrillation and Multivessel Coronary Disease. Front Cardiovasc Med 2022;9:910811.
23. Ji Q, Zhao Y, Zhu K, et al. Impacts of incomplete revascularization following off-pump coronary artery bypass grafting on clinical outcomes of patients with triple-vessel lesions: insights from a single-center study of propensity-matched data. J Thorac Dis 2019;11:1325-35.
24. Buda AJ, Macdonald IL, Anderson MJ, et al. Long-term results following coronary bypass operation. Importance of preoperative actors and complete revascularization. J Thorac Cardiovasc Surg 1981;82:383-90.
25. Lawrie GM, Morris GC Jr, Silvers A, et al. The influence of residual disease after coronary bypass on the 5-year survival rate of 1274 men with coronary artery disease. Circulation 1982;66:717-23.
26. Jones EL, Craver JM, Guyton RA, et al. Importance of complete revascularization in performance of the coronary bypass operation. Am J Cardiol 1983;51:7-12.
27. Zimarino M, Ricci F, Romanello M, et al. Complete myocardial revascularization confers a larger clinical benefit when performed with state-of-the-art techniques in high-risk patients with multivessel coronary artery disease: A meta-analysis of randomized and observational studies. Catheter Cardiovasc Interv 2016;87:3-12.
28. Farooq V, Serruys PW, Garcia-Garcia HM, et al. The negative impact of incomplete angiographic revascularization on clinical outcomes and its association with total occlusions: the SYNTAX (Synergy Between Percutaneous Coronary Intervention with Taxus and Cardiac Surgery) trial. J Am Coll Cardiol 2013;61:282-94.
29. Takahashi K, Serruys PW, Gao C, et al. Ten-Year All-Cause Death According to Completeness of Revascularization in Patients With Three-Vessel Disease or Left Main Coronary Artery Disease: Insights From the SYNTAX Extended Survival Study. Circulation 2021;144:96-109.
30. Taggart DP. Incomplete revascularization: appropriate and inappropriate. Eur J Cardiothorac Surg 2012;41:542-3.
31. Kim T, Kang DY, Kim S, et al. Impact of Complete or Incomplete Revascularization for Left Main Coronary Disease: The Extended PRECOMBAT Study. JACC Asia 2023;3:65-74.

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