Kakoush et al. Journal of Cardiothoracic Surgery (2025) 20:188
https://doi.org/10.1186/s13019-025-03410-0

Journal of Cardiothoracic Surgery

RESEARCH Open Access

Minimally invasive direct coronary artery bypass versus single internal thoracic artery grafting procedures for multivessel coronary artery disease: a single-center retrospective analysis

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Abstract

Objective To compare two surgical strategies for myocardial revascularization: one by a minimally invasive direct coronary artery bypass (MIDCAB) and the other by a conventional full sternotomy coronary artery bypass grafting (CABG).

Methods We reviewed the early outcomes and overall survival of all the patients treated in our center by the above strategies during 2000–2011.

Results Of 1915 patients, 1752 underwent conventional CABG utilizing a single internal thoracic artery (ITA) graft and 163 underwent a MIDCAB procedure. In the former compared to the latter, the patients were older and the median EuroSCORE was higher. The prevalences were higher of diabetes mellitus, recent myocardial infarction, emergency procedures, the.usage of an intra-aortic balloon pump, redo operations, and peripheral vascular disease; and the prevalences lower of chronic obstructive pulmonary disease and chronic renal failure. The median follow-up was 20 years. Early mortality (30 day) was greater in the conventional CABG group (3.6% vs. 0.6%, $p=0.042$); and 10-, 15- and 20-year survival rates were lower: 55.1% vs. 76.7%, 37.1% vs. 63.7%, and 23.1% vs. 53.4%, respectively, $p<0.001$. In an analysis that compared two matched groups of 134 patients each, early outcomes were similar, but late survival was lower following conventional CABG compared to MIDCAB after 10, 15 and 20 years: 64.7% vs. 74.6%, 44.7% vs. 64.1%, and 28.4% vs. 53.6% respectively, $p=0.004$. In multivariable and univariate analysis, MIDCAB strategy compared to conventional single ITA CABG was associated with better late survival; the hazard ratio was 0.429 (95%CI 0.321–0.574, $p<0.001$) for the whole cohort and 0.559 (95%CI: 0.376–0.831, $p=0.004$), for the matched cohort.

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Conclusions Compared to conventional CABG utilizing a single ITA, the MIDCAB procedure demonstrated early safety and long-term effectiveness for surgical myocardial revascularization of the left anterior descending artery.

Introduction

Coronary artery bypass grafting (CABG) is a well-established surgical strategy for treating multivessel coronary artery disease [1]. Grafting the internal mammary artery to the left anterior descending artery (LAD) was reported to significantly enhance survival and to demonstrate more than 90% graft patency at 15 years; this effectively protects the LAD territory from recurrent ischemic injury [2, 3]. While the traditional CABG approach involves a median sternotomy for surgical access, minimally invasive direct coronary artery bypass (MIDCAB) has emerged as an alternative technique that avoids this need [4]. The MIDCAB procedure involves a small anterolateral thoracotomy to access the LAD, which is then bypassed using the left internal thoracic artery (ITA) as a graft [4]. Typically, the procedure is performed without the need for cardiopulmonary bypass and can be extended to treating lesions in other coronaries using composite grafts and hybrid techniques [5].

In our center, skeletonized bilateral ITA grafting is the routine approach for most patients in need for CABG, while single ITA revascularization is mostly employed in older and sicker patients with presumed lower life expectancy [6]. We also perform MIDCAB procedures in patients with prominent comorbidities and those who require solely LAD revascularization, with or without the combination of percutaneous revascularization. In this report, we sought to compare early and late outcomes of patients with coronary artery disease who underwent either the MIDCAB or conventional CABG procedure utilizing a single ITA-to-LAD graft at our center. In this report, MIDCAB strategy was associated with a better long-term outcome than single ITA CABG.

Methods

The population

This study comprised all the patients with coronary disease who underwent primary isolated CABG in Tel-Aviv Medical Center between January 2000 and December 2011, deploying a single ITA to the LAD, with or without additional non-ITA grafts to other territories. The most recent follow-up date was October 1, 2023. The patients underwent one of two surgical strategies: conventional CABG or a MIDCAB procedure utilizing left ITA to the LAD. Notably, relative contraindications to MIDCAB in our institute include an emergency operation, a patient in critical condition, redo cases (utilizing the ITA) and unstable anatomy (intramyocardial or heavily calcified LAD artery) evaluated by preoperative fluroscopy or cardic gated CT. Patients who received more than one ITA graft were excluded, as were patients who underwent additional procedures during the CABG operation, apart from coronary revascularization. The study was approved by our institutional review board, and informed consent was waived due to the retrospective study design.

The Institutional Review Board of Tel Aviv Sourasky Medical Center approved the study. Approval number: 0258-18-TLV. Due to the retrospective structure of the study and that the data were analyzed anonymously, the IRB (Institutional Review Board of Tel Aviv Sourasky Medical Center) approved a waiver from patient consent. Data from this study are ethically and legally restricted by the institutional Review Board of Tel Aviv Sourasky Medical Center to prevent compromise of patient confidentiality. Any requests for data release should be addressed to Dr. Shmuel Kivity, Chairman of the Tel Aviv Sourasky Medical Center Institutional Review Board (IRB)/Ethics (Helsinki) Committee at: allergy@tlvmc.gov.il..

Funding declaration: The authors received no specific funding for this work..

The surgical procedures

MIDCAB was preferred for patients with: coronary disease with a predominant or single LAD lesion in the setting of advanced age, comorbidities such as chronic obstructive pulmonary disease (COPD), diabetes mellitus, frailty and younger age. The selection of MIDCAB was also influenced by the patient's or referring cardiologist's preference. For the patients with single-vessel disease, MIDCAB was preferred occasionally for those not amendable for percutaneous intervention in the LAD, due to in-stent restenosis or thrombosis of a coronary artery, bifurcation of a lesion involving a major diagonal branch, and complete LAD occlusion, or complex type C lesions. Patients who underwent MIDCAB were operated without extracorporeal circulation, and a single graft was implanted (left ITA) to the LAD. One exception is a patient who converted to full sternotomy with a saphenous vein graft to the LAD. The MIDCAB technique was described in detail by Diegeler and colleagues [7]. In brief, the patient is positioned at 30% elevation of the left thorax, and a limited left anterolateral thoracotomy is performed through the fourth intercostal space. The lung is deflated by either bronchial blockers or by external compression with wet surgical pads. After a small pericardiotomy incision to assure the position and superficiality of the LAD, the ITA is harvested by direct vision [7, 8]. With administration of heparin (200 U/kg), the internal thoracic artery is divided distally and LAD anastomotic site immobilization is achieved with mechanical stabilizers (MIDCAB IMA harvest retractor FC540R and MIDCAB rib retractor FC525R, both of Aesculap Inc., Center Valley, PA 18034, USA). The anastomosis is performed using one running 7 – 0 polypropylene suture on the beating heart. Protamine is applied to partially neutralize the heparin dose, and the surgical wound is closed in a standard fashion.

Data collection and definitions

Patient data were analyzed according to EuroSCORE clinical data standards [9]. Early mortality was defined as mortality occurring within the first 30 days of surgery or the index hospitalization. A cerebrovascular accident was defined as a new permanent neurological deficit and computed tomographic evidence of cerebral infarction. A deep sternal wound infection) was defined as a deep infection involving the sternum or substernal tissues, requiring re-sternotomy. An emergency operation included an operation within 24 h of cardiac catheterization [9] or an operation associated with an acute evolving myocardial infarction (MI), pulmonary edema or cardiogenic shock [10]. Early adverse outcomes were defined as mortality, a postoperative cerebrovascular event, perioperative or early MI, a deep sternal wound infection, and revision for bleeding. Information regarding early outcomes were available from patient medical records and department databases, while late survival information was obtained by accessing data from the Israeli National Registry database.

Statistical analysis

Categorical variables were described as frequencies and percentages. Continuous variables were evaluated for normal distribution using histograms, and reported as means and standard deviations, or as medians and interquartile ranges (IQR). The chi-square test and Fisher's exact test were used to compare categorical variables between the two surgical strategies, and the independent samples t-test and Mann-Whitney tests were applied to compare continuous variables. Follow-up duration was determined by the reverse censoring method. The Kaplan Meier curve was used to describe survival during the follow-up period and to report the median survival time. The log-rank test was used to compare survival between the two surgical strategies. Multivariable Cox regression was applied to evaluate the association between mortality and surgical strategy, while controlling for possible known confounders. Each regression contained three blocks. In the first block, surgical strategy, age, and gender were forced into the regression. In the second and third blocks, pre-operative and operative parameters were considered potential variables for inclusion in the model, using the backward method (the Wald test was used and $p > 0.1$ was the criterion for removal).

The two groups were matched according to the probability of a patient undergoing CABG using the MIDCAB strategy. The probability (propensity score) was calculated using a logistic regression model. The following parameters were used to calculate the propensity score: sex, age > 70 years, insulin-dependent diabetes mellitus, non-insulin-dependent diabetes mellitus, COPD, congestive heart failure, emergency procedures, left main disease, unstable angina pectoris, redo procedures, ejection fraction below 30%, chronic renal failure, a recent MI, an old MI, an acute MI, critical condition, peripheral vascular disease, an old cerebrovascular accident, the number of diseased coronary vessels, and percutaneous transluminal coronary angioplasty. Fuzzy matching without replacement was performed. An absolute difference (matching tolerance / caliper) in the propensity score of up to 5% (on a scale of 0 to 100%) was considered acceptable for matching. Standardized differences were calculated to compare the two groups, before and after matching. A standardized difference < 0.1 was considered a negligible difference, and a difference between 0.1 and 0.2 was considered a small difference. The matched groups were compared using the McNamar test for the categorical variables, and the paired t-test and Wilcoxon test for the continuous variables. Stratified Cox regression by pairs was used to compare survival between the matched groups. The regression contained two blocks. In the first block, surgical strategy was forced into the regression. In the second block, operative parameters were considered as potential variables for inclusion in the model. In this block, all the relevant variables were entered into the model and the backward method was applied (the Wald test was used and $p > 0.1$ was the criterion for removal). All the statistical tests were two-sided and $p < 0.05$ was considered statistically significant. In a further sub analysis, we excluded from both groups, patients with relative contraindications for MIDCAB such as redo and emergent procedures. This additional investigation included univariate and multivariable analysis. Statistical analysis was performed with SPSS statistical software (IBM SPSS Statistics for Windows, version 29, IBM Corp., Armonk, NY, USA, 2023) and visualization was performed with R (version 4.3.1, R-Foundation Statistical-Computing, Austria, 2023).

Results

Characteristics of the unmatched cohort

The study comprised 1915 patients of whom 1752 underwent a conventional mid sternotomy single ITA to LAD (CABG procedure) and 163 underwent MIDCAB deploying a left ITA to the LAD. Preoperative and intra-operative patient characteristics are summarized in (Table 1). Compared to the MIDCAB group, for the conventional CABG group, the mean age was older (68.7

Table 1 Preoperative and intraoperative characteristics of patients who underwent SITA CABG and MIDCAB procedures. The data are presented for the unmatched and matched cohorts

	All	Unmatched cohort, *n* (%)				Matched cohort, *n* (%)		
		CABG	MIDCAB	*p* value	SMD	CABG *n* = 134	MIDCAB *n* = 134	SMD
	N = 1915	*n* = 1752	*n* = 163					
Male	1318 (68.8%)	1200 (68.5%)	118 (72.4%)	0.304	0.086	90 (67.2%)	94 (70.1%)	0.064
Age (years), mean (SD)	68.37 (10.71)	68.79 (10.39)	63.88 (12.95)	< 0.001	0.418	66.63 (10.04)	65.16 (13.18)	0.125
Age ≥ 70 years	977 (51.0%)	921 (52.6%)	56 (34.4%)	< 0.001	0.374	53 (39.6%)	54 (40.3%)	0.015
NIDDM	722 (37.7%)	682 (38.9%)	40 (24.5%)	< 0.001	0.313	36 (26.9%)	35 (26.1%)	0.017
IDDM	152 (7.9%)	146 (8.3%)	6 (3.7%)	0.036	0.197	5 (3.7%)	6 (4.5%)	0.038
DM	855 (44.6%)	809 (46.2%)	46 (28.2%)	< 0.001	0.378	41 (30.6%)	41 (30.6%)	0.000
COPD	239 (12.5%)	190 (10.8%)	49 (30.1%)	< 0.001	0.491	37 (27.6%)	32 (23.9%)	0.085
CHF	392 (20.5%)	364 (20.8%)	28 (17.2%)	0.276	0.092	26 (19.4%)	25 (18.7%)	0.019
EF < 30%	159 (8.3%)	155 (8.8%)	4 (2.5%)	0.005	0.280	4 (3.0%)	4 (3.0%)	0.000
CRF	241 (12.6%)	210 (12.0%)	31 (19.0%)	0.01	0.195	27 (20.1%)	21 (15.7%)	0.117
Recent MI	561 (29.3%)	537 (30.7%)	24 (14.8%)	< 0.001	0.387	23 (17.2%)	23 (17.2%)	0.000
Acute MI	372 (19.4%)	350 (20.0%)	22 (13.5%)	0.045	0.174	15 (11.2%)	15 (11.2%)	0.000
MI	1015 (53.0%)	949 (54.2%)	66 (40.5%)	< 0.001	0.277	68 (50.7%)	58 (43.3%)	0.150
UAP	1124 (58.7%)	1017 (58.0%)	107 (65.6%)	0.06	0.157	75 (56.0%)	83 (61.9%)	0.122
EuroSCORE I, median (IQR)	7 (4–9)	7.0 (4.0–10.0)	3.4 (2.1–6.2)	< 0.001	0.578	5.0 (3.0–8.0)	3.6 (2.2–6.5)	0.297
IABP	173 (9.0%)	171 (9.8%)	2 (1.2%)	< 0.001	0.381	3 (2.2%)	2 (1.5%)	0.055
Emergency	360 (18.8%)	360 (20.5%)	0 (0%)	< 0.001	0.719	5 (3.7%)	0 (0%)	0.278
Redo operation	63 (3.3%)	62 (3.5%)	1 (0.6%)	0.045	0.206	0 (0%)	1 (0.7%)	0.123
PVD	476 (24.9%)	464 (26.5%)	12 (7.4%)	< 0.001	0.527	13 (9.7%)	11 (8.2%)	0.052
Old CVA	144 (7.5%)	135 (7.7%)	9 (5.5%)	0.312	0.088	7 (5.2%)	7 (5.2%)	0.000
OPCAB	755 (39.4%)	592 (33.8%)	163 (100%)	< 0.001	1.980	41 (30.6%)	134 (100%)	2.130
Prior PCI	380 (19.8%)	323 (18.4%)	57 (35.0%)	< 0.001	0.380	42 (31.3%)	43 (32.1%)	0.016
LIMA to LAD	1912 (99.8%)	1752 (100%)	160 (98.2%)	> 0.999	0.194	134 (100%)	132 (98.5%)	0.174
Number of diseased vessels	1419 (74.1%)	1259 (71.9%)	160 (98.2%)	< 0.001	0.792	125 (93.3%)	131 (97.8%)	0.218
Bypass number ≥ 3	1145 (59.8%)	1145 (65.4%)	0 (0%)	< 0.001	1.942	101 (75.4%)	0 (0%)	2.474
SEQNUM	882 (46.1%)	882 (50.3%)	0 (0%)	< 0.001	1.424	69 (51.5%)	0 (0%)	1.457
SVG	1166 (60.9%)	1165 (66.5%)	1 (0.6%)	< 0.001	1.947	90 (67.2%)	1 (0.7%)	1.967
GEA	74 (3.9%)	74 (4.2%)	0 (0%)	0.007	0.297	0 (0%)	0 (0%)	0.000
Radial artery	547 (28.6%)	547 (31.2%)	0 (0%)	< 0.001	0.953	47 (35.1%)	0 (0%)	1.039
Left main disease	460 (24.0%)	446 (25.5%)	14 (8.6%)	< 0.001	0.461	13 (9.7%)	14 (10.4%)	0.025

CHF: congestive heart failure, COPD: chronic obstructive pulmonary disease, CRF: chronic renal failure, CVA: cerebrovascular accident, DM: diabetes mellitus, EF: ejection fraction, GEA: gastroepiploic artery, IABP: intra-aortic balloon pump, IDDM: insulin-dependent diabetes mellitus, IQR: interquartile range, MI: myocardial infarction, MIDCAB: minimally invasive direct coronary artery bypass surgery, NIDDM: non-insulin-dependent diabetes mellitus, OPCAB: off-pump coronary artery bypass, PHTN: pulmonary hypertension, PCI: percutaneous transluminal coronary angioplasty, PVD: peripheral vascular disease, SD: standard deviation, SEQNUM: sequential grafts, SITA: single internal thoracic artery, SMD: standardized mean difference, SVG: saphenous vein graft, UAP: unstable angina pectoris

vs. 63.9 years) and the median EuroSCORE was higher (7.00 vs. 3.43). For the latter compared to the former, the prevalences were greater of diabetes mellitus, recent MI, emergency procedures, intra-aortic balloon pump use, redo operations, and peripheral vascular disease; and less for COPD and chronic renal failure (Table 1).

Early outcomes of the unmatched cohort

Before matching, among the patients who underwent MIDCAB compared to conventional CABG, early mortality was lower: 0.6% vs. 3.6% ($p = 0.043$). Rates did not differ between the groups in perioperative MI, strokes and revisions for bleeding. Sternal infections presented in 3.1% of the conventional CABG group and in none of the MIDCAB group (Table 2).

Late outcomes of the unmatched group

While the follow-up time reached 20 years, the median follow-up for the entire cohort was 20 years (IQR 17.52-20). Five-, 10-, 15- and 20-year survival rates for the conventional CABG and MIDCAB groups were 77.9% vs. 89.0%, 55.1% vs. 76.7%, 37.1% vs. 63.7%, and 23.1% vs. 53.4%, respectively, $p < 0.001$. The median survival for the entire cohort was 11.85 years (Fig. 1).

MIDCAB revascularization was associated with better late survival, both in univariate analysis (unadjusted hazard ratio [HR] 0.435 95%CI: 0.345–0.554, $p < 0.001$) and in multivariable analysis (adjusted HR 0.429 95%CI: 0.321–0.574, $p < 0.001$). In multivariable analysis, older age, diabetes mellitus, congested heart failure, chronic renal failure, COPD, peripheral vascular disease, acute

Table 2 Early outcomes of the unmatched cohort following SITA CABG and MIDCAB procedures

	All	Unmatched cohort, *n* (%)			Matched cohort, *n* (%)		
		CABG	MIDCAB	*p* value	CABG *n* = 134	MIDCAB *n* = 134	*p* value
	n = 1915	*n* = 1752	*n* = 163				
Early mortality	64 (3.3%)	63 (3.6%)	1 (0.6%)	0.043	5 (3.7%)	1 (0.7%)	0.219
DSWI	49 (2.8%)	49 (3.1%)	0 (0%)	0.012	4 (3.2%)	0 (0%)	N/A
Post CVA	34 (1.8%)	31 (1.8%)	3 (1.8%)	0.763	4 (3.0%)	3 (2.2%)	> 0.999
Perioperative MI	35 (1.8%)	33 (1.9%)	2 (1.2%)	0.764	0 (0%)	2 (1.5%)	N/A
Revision for Bleeding	62 (3.2%)	60 (3.4%)	2 (1.2%)	0.129	7 (5.2%)	2 (1.5%)	0.18

CVA: cerebrovascular accident, DSWI: deep sternal wound infection, MI: myocardial infarction, MIDCAB: minimally invasive direct coronary artery bypass surgery, N/A: not applicable, SITA: single internal thoracic artery

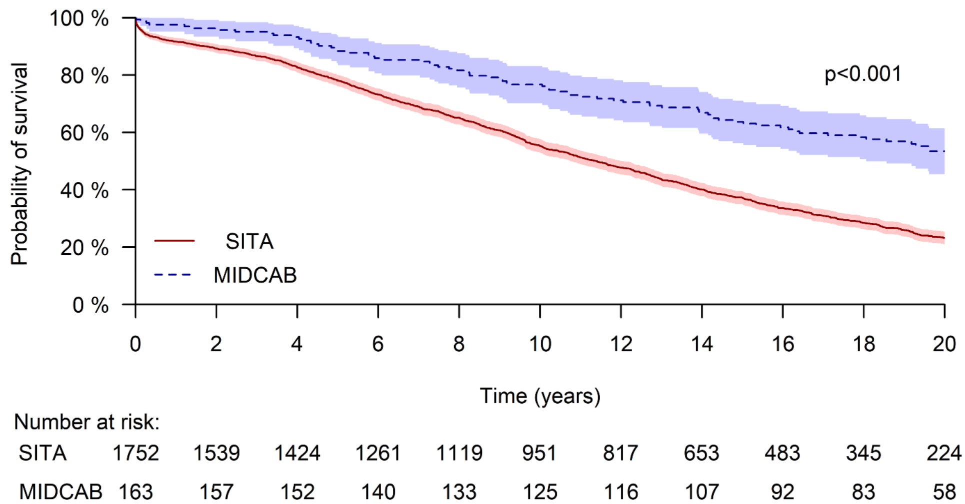

Fig. 1 Kaplan-Meier survival curves for the unmatched cohort

MI and multi-vessel disease were associated with decreased long-term survival after surgery.

Characteristics and early outcomes of the matched cohort

The matched cohorts comprised two nearly similar groups of 134 patients. The groups did not differ significantly in any of the preoperative characteristics apart from the median EuroSCORE and emergent procedure (by a very small number of patients). The value for the conventional CABG group was less than that of the unmatched cohort, but still higher than for the MIDCAB group: 5.0 (3.0–8.0) vs. 3.6 (2.2–6.5), $p = 0.005$. A higher proportion of patients after CABG than MIDCAB were suspected to have above standard pulmonary artery pressure levels, according to preoperative transthoracic echocardiogram (see Table 1). After matching, differences were not found between the groups in early mortality, and in the incidences of perioperative MIs and strokes (Table 2).

Late outcomes of the matched group

The median follow-up time for the matched cohort was 20 years (IQR19.14-20). Five-, 10-, 15-, and 20-year survival rates for the CABG and MIDCAB groups were 78.3% vs. 88.1%, 64.7% vs. 74.6%, 44.7% vs. 64.1%, and 28.4% vs. 53.6%, respectively, $p = 0.004$; the median survival was 17.85 years (Fig. 2).

In a univariate analysis, MIDCAB revascularization was associated with better late survival (unadjusted HR 0.559 95%CI: 0.376–0.831, $p = 0.004$). The group size was not large enough for multivariable analysis.

In the last sub-analysis, we excluded all redo and emergent patients from both groups, as they were less likely to be referred for MIDCAB. This analysis included 1431 patients: 1271 CABG and 160 MIDCAB (Table 1A in the supplement). We found that the early mortality in the SITA group decreased from 3.6 to 2%, while it remained 0.6% in the MIDCAB group. This difference was not statistically significant, $p = 0.352$ (Table 2 A in the supplement). As in the original analysis, differences between the groups were not found in the other early outcomes (DSWI, post CVA, perioperative MI, and revision for bleeding– Table 2 A supplement). In the multivariate analysis, the survival benefit of MIDCAB was maintained. The adjusted HR was 0.459 (95% CI: 0.335–0.629, $p < 0.001$) (Table 3 A in the supplement).

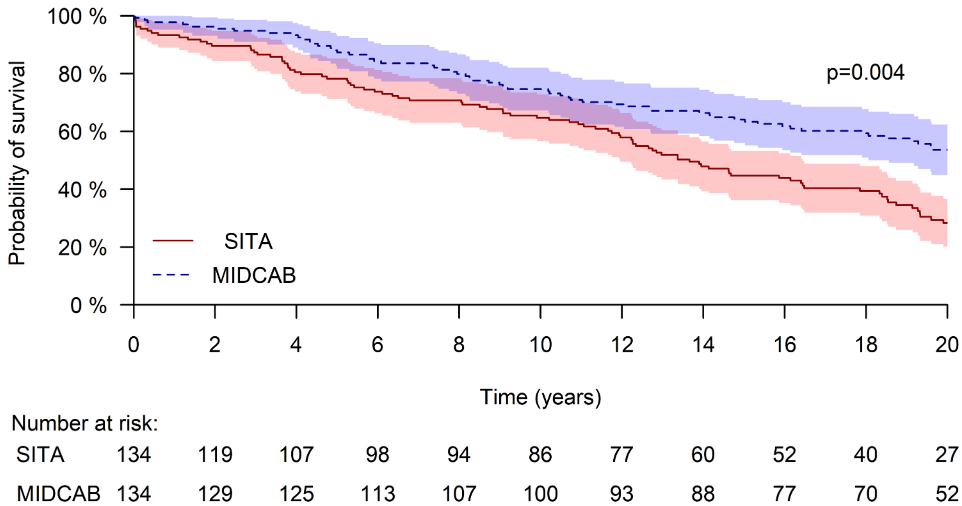

Fig. 2 Kaplan-Meier curve of survival for the matched cohort

Discussion

This study delineated long-term follow up of 20 years in 1915 patients, of whom 1751 underwent CABG and 163 underwent a MIDCAB procedure, all with a single left ITA to the LAD. A propensity analysis was done to create two matched cohorts of 134 patients each. Early findings of major adverse cardiovascular events were similar in both the matched and unmatched groups (except for early mortality, which was higher in the unmatched and sicker CABG group). For both the matched and unmatched cohorts, the MIDCAB group demonstrated higher survival rates at 5-, 10-, 15-, and 20-year follow-up; while in multivariable analysis, the MIDCAB procedure was significantly associated with improved survival. MIDCAB was first described in 1967 by Kolesov (left ITA to the myocardium) [11], and was later reintroduced by Calafiore and colleagues in 1996 [12]. The procedure was standardized and further established as a well-known and reproducible procedure with the reports of Diegeler et al. and Boonstra et al. [7, 8]. Advancements included the precise incision site (left anterior mini-thoracotomy, 4th intercostal), skeletonization of the left ITA and the development of myocardial stabilizers for LAD revascularization, with or without intracoronary shunts. Currently, MIDCAB can be performed also by a thoracoscopic ITA harvest or with robotic assistance, all with widespread acceptance and excellent results [13, 14].

Jegaden et al. compared three minimally invasive CABG techniques among 160 patients. Port-Access CABG (PA-CABG), minimally invasive direct CABG (MIDCAB), and Totally Endoscopic Off-Pump CABG (TECAB). Overall, they revealed that minimally invasive LAD grafting was both effective and safe. However, totally endoscopic off-pump CABG was associated with a higher incidence of early bypass failure and re-interventions (10% compared to 1.8% in MIDCAB and 0% in port-access CABG). This suggests that MIDCAB may be the most reliable minimally invasive technique for isolated LAD grafts, and that it offers the best cost-effective option in that setting [15]. Nonetheless, additional studies are needed to elucidate differences in MIDCAB strategies.

Repossini et al. described 1060 patients after MIDCAB; 647 of them (61%) with multivessel coronary disease received a left ITA to LAD, with or without completion of a percutaneous coronary intervention]16]. The authors reported graft patency rates of 96.8% by angiogram or computed tomography scans in 696 patients during the first 10 years of follow up. The 5-, 10- and 15-year survival rates were 87.1%, 84.3% and 79.8% (the median follow up was 11 years). These findings support the safety and excellent short- and long-term survival rates of MIDCAB operations.

The MIDCAB advantage over CABG has been speculated to be more prominent in the elder, more frail population. Among almost 700 individuals who underwent MIDCAB procedures, including 235 aged over 70 years (mean age 74.5), the 30-day mortality rate was 2.5%; and the survival rate was 89.9% at 1.5 years, and 79.7% at five years. Multivessel disease and male sex were identified as significant independent predictors of overall mortality in the elderly (over age 70 years). Although survival was better among younger patients (under age 70 years), the differences were not statistically significant ($p=0.088$). This suggests that MIDCAB is a reasonable option for all ages [17]. However, among 72 octogenarian patients compared to more than 1000 younger patients, Hoffmann G. et al. reported higher early mortality (5.6% vs. 0.8%, $p=0.006$) and higher incidence of major adverse cardiovascular events (5.6% vs. 1.3%, $p=0.024$). The 1-, 3-, and 5-year survival rates for the octogenarian group were

89%, 78%, and 63%, respectively; and the median survival at 6.7 years was satisfactory [18].

Few reports have tried to stratificate the risks and outcomes between MIDCAB and the conventional CABG procedures. An early report by Dickes et al. compared MIDCAB vs. CABG outcomes by four surgical risk categories. Patients after MIDCAB had lower levels of blood transfusions, inotropic support and ventilator time; but longer length of stay. However, the study included only 64 patients and a short follow up of up to one year [19].

Among 3,648 octogenarians who underwent on-pump CABG, off-pump CABG or MIDCAB (only 96 patients), early mortality was higher among those with left main disease who underwent on-pump CABG compared to the other procedures. However, the 10-year survival rates were similar across all the subgroups, during a mean follow up of 3.7 years [20]. Raja et al. reported results of 668 patients with isolated LAD disease, of whom 508 underwent MIDCAB and 160 full sternotomy CABG [21]. The characteristics of the patients were similar, except for more extensive coronary artery disease in the latter group. Other than longer surgical time for those who underwent MIDCAB, the authors failed to demonstrate the superiority of either surgical approach in early outcomes or in long-term survival.

Rogers et al. studied the early (procedure to discharge) benefits of MIDCAB vs. off-pump CABG by prospective randomization of 180 patients to either surgical strategy. Although the primary end point of this trial was the length of hospitalization, the results were inconclusive, 6 vs. 5 days to discharge, $p=0.53$. Other pre-specified secondary endpoints demonstrated possible benefits of MIDCAB over off-pump CABG; specifically, reductions were observed in inflammatory response, intubation times and in the number of postoperative arrhythmias. However, these advantages were offset by longer operations, fewer grafts, inferior postoperative lung function tests, a greater need for analgesics and higher costs in the MIDCAB group. Mid- or long-term follow was unavailable and protocol violations including conversions to open procedures or to pump procedures yielded even more vague and inconsistent conclusions [22].

As a single-center observational retrospective analysis, our study bares definite inherent limitations. First, complete follow-up of major adverse cardiac events after the index hospitalization were unavailable. Consequently, data were not collected about cardiac mortality, the need for late re-interventions, and late myocardial infarctions and strokes. These outcomes could have unveiled potential advantages of one of the surgical strategies. Another limitation is that we could not elaborate or differentiate cardiac and non-cardiac deaths. Moreover, there was no information to distinguish between patients who underwent incomplete revascularization and those who were fully revascularized. Also, the types and severity of the coronary lesions, and data regarding later postoperative planned or unplanned completion of a percutaneous coronary intervention for other coronary lesions were unavailable. Additionally, due to the luck of clear guidelines or criteria for MIDCAB or conventional CABG, the surgical strategy was selected subjectively, by a surgeon, or less frequently by a heart team, mostly during the index hospitalization. This precludes ruling out selection bias. Notably, all the MIDCAB procedures were performed by two experienced surgeons from our group, and the conventional CABG by 10 surgeons some of them were residents under supervision. As a final point, even after our matching process, differences remained in the EuroSCORE grading between the two groups. While the EuroSCORE is mostly used to determine the risks of early adverse outcomes, the above differences (although reduced after the matching) may have affected the late outcome.

In conclusion, findings of this study support the safety and efficacy of MIDCAB in the short and long term (20 years) for patients with single- or multi-vessel disease. The clinical outcomes were at least comparable to those of patients who underwent conventional CABG utilizing a single ITA to LAD (with or without additional non-ITA grafts). However, the EuroSCORE differed and a selection bias cannot be ruled out. Although additional studies may further illuminate the differences between the two surgical strategies, our findings support the use of MIDCAB for myocardial revascularization as an acceptable strategy compared to conventional single ITA, in selected cases.

Abbreviations

CABG	Coronary Artery Bypass Graft
COPD	Chronic Obstructive Pulmonary Disease
HR	Hazard Ratio.
IQR	Interquartile Range ITA-Internal Thoracic Artery
LAD	Left Anterior Descending Artery
MI	Myocardial Infarction
MIDCAB	Minimally Invasive Direct Coronary Artery Bypass

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13019-025-03410-0.

Supplementary Material 1

Author contributions

Conceptualization: M.K., A.G., J.K. and Y.B.G.; Data curation: M.K., A.G. and O.S.; Formal analysis: O.S. and T.Z.B.; Funding acquisition: Y.B.G.; Investigation: M.K., A.G., O.S., J.K. and Y.B.G.; Methodology: A.F., N.D., D.P. and Y.B.G.; Project administration: O.S.; Resources: Y.B.G.; Software: O.S. and T.Z.B.; Supervision: A.F., D.P. and Y.B.G.; Validation: M.K., A.G., A.F. and N.T.; Visualization: D.P., J.K. and Y.B.G.; Writing– original draft: M.K., A.G., T.Z.B. and Y.B.G.; Writing– review & editing: M.K., A.G., D.P. and Y.B.G.

Data availability

Some restrictions will apply.Data from this study are ethically and legally restricted by the Institutional Review Board of Tel Aviv Sourasky Medical Center to prevent compromise of patient confidentiality. Any requests for data release should be addressed to Dr. Shmuel Kivity, Chairman of the Tel Aviv Sourasky Medical Center Institutional Review Board (IRB)/Ethics (Helsinki) Committee at: allergy@tlvmc.gov.il..

Declarations

Competing interests

The authors declare no competing interests.

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Received: 26 September 2024 / Accepted: 31 March 2025
Published online: 11 April 2025

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