Margari *et al. Vessel Plus* 2024;8:38
DOI: 10.20517/2574-1209.2024.37

Vessel Plus

Original Article

Open Access

Check for updates

Early and mid-term results of minimally invasive direct coronary artery bypass (MIDCAB) surgery

Vito Margari[1], **Enrico Squiccimarro**[2,3], **Clemente Pascarella**[1], **Francesco Pio Tupputi**[1], **Carmine Carbone**[1], **Domenico Paparella**[1,2]

[1]Division of Cardiac Surgery, Santa Maria Hospital, GVM Care & Research, Bari 70124, Italy.
[2]Division of Cardiac Surgery, Department of Medical and Surgical Sciences, University of Foggia, Foggia 71122, Italy.
[3]Cardio-Thoracic Surgery Department, Heart & Vascular Centre, Maastricht University Medical Centre, Maastricht 6229 HX, The Netherlands.

Correspondence to: Prof. Domenico Paparella, Division of Cardiac Surgery, Department of Medical and Surgical Sciences, University of Foggia, Viale Luigi Pinto 1, Foggia 71122, Italy. E-mail: domenico.paparella@unifg.it

How to cite this article: Margari V, Squiccimarro E, Pascarella C, Tupputi FP, Carbone C, Paparella D. Early and mid-term results of minimally invasive direct coronary artery bypass (MIDCAB) surgery. *Vessel Plus* 2024;8:38. https://dx.doi.org/10.20517/2574-1209.2024.37

Received: 10 Aug 2024 **First Decision:** 30 Sep 2024 **Revised:** 21 Oct 2024 **Accepted:** 12 Nov 2024 **Published:** 22 Nov 2024

Academic Editor: Jawahar Mehta **Copy Editor:** Fangling Lan **Production Editor:** Fangling Lan

Abstract

Aim: This study aimed to evaluate the early and mid-term outcomes of minimally invasive direct coronary artery bypass (MIDCAB) surgery for isolated left anterior descending artery (LAD) disease, with a primary focus on revascularization-free survival.

Methods: A retrospective analysis was conducted on 155 consecutive patients who underwent MIDCAB at Santa Maria Hospital, Bari, Italy, between May 2017 and December 2023. All patients received a direct anastomosis of the left internal thoracic artery (LITA) to the LAD, with sequential grafting performed for those with concurrent diagonal artery disease. The primary endpoint was revascularization-free survival. The secondary endpoint was in-hospital mortality. Kaplan-Meier survival curves, log-rank tests, and Cox proportional hazards models were employed for statistical analysis.

Results: The median follow-up duration was 36 months [12-48]. No 30-day postoperative deaths occurred. The 5-year revascularization-free survival rate was 84.2% [77.4-91.7], and the overall 5-year survival rate was 90.5% [85.1-96.2]. Predictors of the primary endpoint were preoperative New York Heart Association (NYHA) class III (HR 5.898 [1.187-29.311], P = 0.030) and postoperative atrial fibrillation (HR 3.405 [1.232-9.415], P = 0.018). The incidence of complications was low, with no cerebrovascular events reported.

© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, sharing, adaptation, distribution and reproduction in any medium or format, for any purpose, even commercially, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Conclusion: MIDCAB for isolated LAD disease is safe, with satisfactory postoperative outcomes and excellent mid-term survival. These findings align with existing literature, underscoring the procedure's reproducibility. Further multicenter studies are needed to validate these results and compare MIDCAB versus PCI in treating isolated LAD disease.

Keywords: Minimally invasive direct coronary artery bypass, medium-term outcomes, myocardial revascularization

INTRODUCTION

Coronary artery bypass grafting (CABG) has delivered excellent outcomes in terms of morbidity and long-term mortality, establishing a benchmark for medical therapy and percutaneous coronary intervention (PCI)[1-3]. Despite the advancements in drug-eluting stents (DES) and the development of P2Y12 inhibitors, the significant long-term survival benefits associated with grafting the left internal thoracic artery (LITA) to the left anterior descending artery (LAD) remain unchallenged[4,5]. Less invasive CABG techniques emerged in the 1990s and have nowadays been proven as safe and effective therapeutic options[1]. In particular, the minimally invasive direct coronary artery bypass (MIDCAB), which involves a sternal-sparing, off-pump procedure via a small thoracotomy, typically for LAD revascularization, is a uniquely appealing strategy by reason of its reduced invasiveness and the reported low in-hospital morbidity and mortality, and good long-term survival[6-9]. Notwithstanding, MIDCAB remains underutilized, accounting for only 0.5% of cases in 2022, according to the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS ACDS)[10]. Despite consistent evidence supporting MIDCAB, its adoption has been slow, possibly due to the class 1A recommendations for both CABG and PCI in treating isolated LAD disease in current guidelines[11], and the limited understanding of MIDCAB's reproducibility, which is still primarily documented in specialized centers[6-9].

The aim of this study was to evaluate the early and medium-term outcomes of MIDCAB for isolated LAD disease, providing insights into its safety, reproducibility, and potential benefits. By addressing this gap in knowledge, our findings may help guide clinical decision making and encourage broader adoption of this less invasive approach. We also evaluated the incidence of events at follow-up based on perioperative myocardial damage.

METHODS

This study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki. Approval for the study was granted by the IRCCS Istituto Tumori Giovanni Paolo II - Bari, Review Board (1431/CEL - 03/11/2023). Preoperative, intraoperative, and postoperative data were collected anonymously and recorded in our prospectively maintained institutional database, which is utilized for internal quality control purposes. As such, the requirement for informed consent was waived. Follow-up was performed through direct telephone interviews conducted by adequately trained research personnel.

Study cohort

This retrospective observational cohort study included 155 consecutive elective or in-hospital patients who underwent MIDCAB procedures at Santa Maria Hospital, GVM Care & Research, Bari, Italy, between May 2017 and December 2023. All patients received a direct anastomosis of the LITA to the LAD. Sequential grafting was performed for those with concurrent disease of the diagonal artery.

The primary endpoint of the study was revascularization-free survival during follow-up, while the secondary endpoint was in-hospital mortality. Acute kidney injury was defined as per the Kidney Disease

Improving Global Outcomes (KDIGO) classification.

Patient selection and surgical technique

Patients presented with critical obstructive coronary artery disease affecting the proximal LAD, with some also having diagonal branch disease. A hybrid surgical approach was used for patients with multivessel disease. No exclusions were made based on body weight, chest anatomy, or prior cardiac surgery. Preoperative chest computerized tomography (CT) scans were not routinely used. The cohort included both elective and urgent cases. Under general anesthesia and double-lumen intubation, patients were positioned supine with a support under the left scapula. A left anterior mini-thoracotomy was typically performed through the 5th intercostal space, or the 4th intercostal space when a sequential anastomosis of the LAD and diagonal branch was required. The LITA was harvested proximally from the first rib to 1 cm before bifurcation, using a retractor (ThoraTrak™, Medtronic, USA) to facilitate mobilization. Initially, LITA harvesting was performed under direct vision in the first 100 cases, with subsequent cases utilizing video-assisted thoracoscopy (TIPCAM1™, Karl Storz, Germany). After an initial learning curve of approximately 100 cases, LITA harvesting times aligned with those observed in traditional sternotomy procedures. A superior mini-pericardiectomy was performed, exposing the pulmonary artery, with pericardial suspension sutures placed outside the thoracotomy for optimal LAD exposure. Systemic anticoagulation was achieved with unfractionated heparin, targeting an activated clotting time of 420 s. MIDCAB was conducted off-pump using a transthoracic epicardial stabilizer (Octopus™ Nuvo, Medtronic, USA), often with intravascular shunts. Anastomoses were performed using traditional suturing techniques with 7-0/8-0 polypropylene sutures. Heparin was reversed at the conclusion of the procedure. The first 100 patients underwent postoperative coronary CT to evaluate graft patency and anastomosis. In subsequent patients, intraoperative transit time flowmetry was used to assess the effectiveness of the anastomosis and graft flow.

Statistical analysis

Continuous data were reported as mean with standard deviation or median with interquartile range and compared using *t*-test or Mann-Whitney statistic. Normality was checked with the Shapiro-Wilk test. Categorical variables were reported as frequency and percentage and evaluated with the chi-squared test. Cumulative incidences of events during follow-up were determined with the Kaplan-Meier method, and comparisons of estimates between groups were performed with the log-rank test. Univariate analyses for all demographic information, preoperative comorbidities, and intraoperative procedural characteristics were performed, and variables with a $P < 0.05$ were selected for entry into multivariable stepwise Cox proportional hazards models to identify correlates of the primary outcome. The Cox proportional hazards regression model was used to obtain hazard ratios (HRs) with 95% confidence intervals (CIs) to determine the association of included covariates with the outcome of interest. To provide parsimonious models, a backward elimination approach based on the Akaike Information Criterion was employed. Schoenfeld residuals and log-log plots for survival curves assessed the proportional hazards assumption and investigated its adequacy. The maximum value of Youden's index (sensitivity + specificity-1) was extracted for the postoperative peak of cardiac troponin I (cTnI) within receiver operating characteristic (ROC) analysis for the occurrence of the primary endpoint. All analyses were conducted with RStudio version 2024.04 statistical software. All *P*-values were 2-sided, with $P < 0.05$ being considered significant.

RESULTS

Patient characteristics

From May 2017 to December 2023, 937 patients underwent CABG at our institution, 155 of these underwent MIDCAB. Table 1 presents the preoperative characteristics of the patient cohort. The median age was 69 years [59-75], with 34 patients (21.9%) being female. The most common cardiac risk factors included hypertension (76.1%), obesity (27.1%), diabetes (21.3%), chronic obstructive pulmonary disease

Table 1. Characteristics of MIDCAB patients according to the primary endpoint (mortality and/or revascularization at follow-up)

Variables	Unit	All	No event	Event	*P*-value
Cohort	*n*	155	135 (87.1)	20 (12.9)	
Preoperative data					
Age	years	69 [59-75]	68 [59-74]	71 [64-76.0]	0.357
Female sex	*n*, %	34 (21.9)	29 (21.5)	5 (25.0)	0.948
Body mass index	kg/m^2	27.3 [25.2-30.5]	27.3 [24.8-30.2]	27.65 [26.3-30.7]	0.220
Body surface area (DuBois)	m^2	1.93 [1.80-2.00]	1.93 [1.80-2.00]	1.90 [1.81-1.96]	0.798
EuroSCORE II	%	1.1 [0.7-1.7]	1.1 [0.7-1.6]	1.4 [0.8-2.6]	0.172
Left ventricular ejection fraction	%	55 [50-60]	55 [50-60]	55 [49-55]	0.151
Risk factors	*n*, %				
Heart failure		0 (0.0)	0 (0.0)	0 (0.0)	1.000
Chronic Kidney disease		0 (0.0)	0 (0.0)	0 (0.0)	1.000
Hypertension		118 (76.1)	101 (74.8)	17 (85.0)	0.474
Diabetes		33 (21.3)	26 (19.3)	7 (35.0)	0.189
Obesity		42 (27.1)	35 (25.9)	7 (35.0)	0.560
Peripheral Artery disease		26 (16.8)	21 (15.6)	5 (25.0)	0.463
Atrial fibrillation		13 (8.4)	12 (8.9)	1 (5.0)	0.878
Smoke habit		54 (34.8)	46 (34.1)	8 (40.0)	0.789
COPD		16 (10.3)	12 (8.9)	4 (20.0)	0.258
Previous cardiac surgery		3 (1.9)	3 (2.2)	0 (0.0)	1.000
Pulmonary hypertension	*n*, %				1.000
Absent (PAPs < 31 mmHg)		146 (94.2)	127 (94.1)	19 (95.0)	
Moderate (PAPs 31-55 mmHg)		9 (5.8)	8 (5.9)	1 (5.0)	
Severe (PAPs > 55 mmHg)		0 (0.0)	0 (0.0)	0 (0.0)	
New York heart association	*n*, %				0.009
Class I		126 (81.3)	113 (83.7)	13 (65.0)	
Class II		26 (16.8)	21 (15.6)	5 (25.0)	
Class III		3 (1.9)	1 (0.7)	2 (10.0)	
Class IV		0 (0.0)	0 (0.0)	0 (0.0)	
Dyspnea symptoms (NYHA > I)	*n*, %	29 (18.7)	22 (16.3)	7 (35.0)	0.090
Canadian Cardiovascular Society	*n*, %				0.432
Class I		62 (40.0)	51 (37.8)	11 (55.0)	
Class II		5 (3.2)	5 (3.7)	7 (35.0)	
Class III		73 (47.1)	66 (48.9)	2 (10.0)	
Class IV		15 (9.7)	13 (9.6)	0 (0.0)	
Laboratory data					
Hemoglobin	g/dL	13.8 [13.0-14.6]	13.8 [13.1-14.6]	13.1 [11.9-14.1]	0.058
Hematocrit	%	40.3 [38.4-42.8]	40.3 [38.8-43.0]	39.1 [36.1-40.7]	0.029
Leukocytes	× 10^3/µL	7.8 [6.6-9.3]	7.8 [6.5-9.3]	7.9 [6.7-9.0]	0.737
Neutrophils	× 10^3/µL	5.1 [3.9-6.6]	5.1 [3.9-6.6]	5.1 [4.0-6.0]	0.994
Lymphocytes	× 10^3/µL	1.7 [1.3-2.0]	1.7 [1.3-2.0]	1.8 [1.3-2.2]	0.281
Monocytes	× 10^3/µL	0.6 [0.5-0.8]	0.6 [0.5-0.8]	0.6 [0.5-0.8]	0.529
Thrombocytes	× 10^3/µL	204 [169-252]	205 [170-252]	188 [154-247]	0.606
C-reactive protein	mg/dL	0.51 [0.17-1.01]	0.48 [0.15-0.99]	0.85 [0.26-1.24]	0.150
Creatine phosphokinase	IU/L	87 [66-122]	87 [66-118]	94 [62-127]	0.288
Lactate dehydrogenase	IU/L	183 [164-216]	183 [163-216]	185 [169-211]	0.951
Creatinine	mg/dL	0.90 [0.76-1.08]	0.90 [0.76-1.08]	0.91 [0.77-1.04]	0.866
Glomerular filtration rate	mL/min	77 [58-96]	78 [57-98]	72 [60-88]	0.599
Total bilirubin	mg/dL	0.70 [0.47-0.87]	0.70 [0.47-0.87]	0.70 [0.46-0.83]	0.665
Direct bilirubin	mg/dL	0.22 [0.17-0.26]	0.22 [0.16-0.26]	0.22 [0.17-0.26]	0.864

Aspartate transaminase	IU/L	18 [15-22]	18 [15-22]	18 [17-23]	0.468
Alanine transaminase	IU/L	18 [14-24]	18 [14-24]	18 [15-25]	0.732
Fibrinogen	mg/dL	353 [288-423]	353 [283-420]	353 [310-428]	0.701
Antithrombin III	%	99 [90-106]	99 [90-106]	97 [87-99]	0.188
Partial thromboplastin time	sec	31.0 [28.8-34.2]	31.0 [28.8-34.3]	29.6 [28.4-31.1]	0.159
INR		1.1 [1.0-1.1]	1.1 [1.0-1.1]	1.1 [1.0-1.2]	0.675
Intraoperative data					
Revascularization Strategy	*n*, %				
LITA-LAD		155 (100.0)	135 (100.0)	20 (100.0)	1.000
LITA-LAD-Diagonal		4 (2.6)	4 (3.0)	0 (0.0)	0.981
Hybrid revascularization		12 (7.7)	12 (8.9)	0 (0.0)	0.347
Conversion to sternotomy	*n*, %	6 (3.9)	4 (3.0)	2 (10.0)	0.367
Postoperative results					
Mortality (30-day)	*n*, %	0 (0.0)	0 (0.0)	0 (0.0)	1.000
Duration					
Mechanical ventilation	Hours	4 [3-6]	4 [3-6]	5 [4-6]	0.253
ICU stay	Days	1 [1-2]	1 [1-2]	1 [1-2]	0.963
Complications	*n*, %				
Revision for bleeding		6 (3.9)	6 (4.4)	0 (0.0)	0.733
Acute kidney injury		15 (9.7)	13 (9.6)	2 (10.0)	1.000
Sepsis		0 (0.0)	0 (0.0)	0 (0.0)	1.000
Ex Novo atrial fibrillation		22 (14.2)	15 (11.1)	7 (35.0)	0.012
TIA/stroke		0 (0.0)	0 (0.0)	0 (0.0)	1.000
Myocardial infarction		0 (0.0)	0 (0.0)	0 (0.0)	1.000
Blood transfusion	*n*, %	27 (17.4)	22 (16.3)	5 (25.0)	0.521
ECMO/IABP	*n*, %	0 (0.0)	0 (0.0)	0 (0.0)	1.000
Laboratory data					
Hemoglobin	g/dL	11.8 [10.9-12.8]	11.8 [11.0-12.8]	11.3 [10.5-12.4]	0.152
Hematocrit	%	34.4 [31.7-36.9]	34.5 [31.8-37.1]	33.3 [30.9-36.3]	0.225
Leukocytes	$\times 10^3/\mu L$	10.7 [9.5-14.3]	10.7 [9.5-14.1]	10.7 [9.1-15.2]	0.921
Neutrophils	$\times 10^3/\mu L$	8.9 [7.9-11.7]	8.9 [8.0-11.7]	8.8 [7.3-12.6]	0.612
Lymphocytes	$\times 10^3/\mu L$	0.8 [0.6-1.1]	0.8 [0.6-1.1]	0.8 [0.6-1.3]	0.570
Monocytes	$\times 10^3/\mu L$	0.9 [0.7-1.1]	0.9 [0.7-1.2]	0.9 [0.7-1.1]	0.959
Thrombocytes	$\times 10^3/\mu L$	170 [145-210]	170 [145-210]	185 [153-210]	0.705
C-Reactive protein	mg/dL	6.52 [5.32-6.71]	6.51 [5.03-6.68]	6.54 [6.42-7.15]	0.232
Creatine phosphokinase	IU/L	502 [332-676]	469 [330-641]	627 [422-776]	0.076
Lactate Dehydrogenase	IU/L	190 [169-215]	190 [167-215]	190 [182-216]	0.677
Creatinine	mg/dL	0.85 [0.72-1.03]	0.85 [0.72-1.05]	0.83 [0.77-0.95]	0.717
Glomerular filtration rate	mL/min	79 [63-100]	79 [63-105]	79 [64-94]	0.508
Total bilirubin	mg/dL	0.66 [0.44-0.91]	0.66 [0.46-0.98]	0.57 [0.31-0.80]	0.183
Direct bilirubin	mg/dL	0.26 [0.19-0.32]	0.26 [0.19-0.33]	0.26 [0.15-0.29]	0.210
Aspartate transaminase	IU/L	24 [19-28]	23 [19-28]	26 [23-40]	0.104
Alanine transaminase	IU/L	16 [12-25]	16 [12-25]	18 [14-25]	0.389
Creatine kinase MB fraction	IU/L	6.2 [4.0-12.8]	6.2 [4.0-12.9]	6.7 [4.3-10.2]	0.220
Cardiac troponin I	ng/L	0.61 [0.34-1.49]	0.55 [0.30-1.49]	0.90 [0.33-1.66]	0.616
Cardiac troponin I > 0.87 ng/L	*n*, %	62 (40.0)	51 (37.8)	11 (55.0)	0.221
Thirty-day follow-up					
Pleural effusion	*n*, %	10 (6.5)	9 (6.7)	1 (5.0)	0.995
Wound dehiscence	*n*, %	3 (1.9)	3 (2.2)	0 (0.0)	0.897
Follow-up					

Duration	Months	36 [12-48]	36 [12-51]	36 [24-48]	0.761
Completeness	%	100	100	100	1.000
Follow-Up Events	*n*, %				
Total events		21 (11.4)		21 (100)	
Mortality		14 (7.6)		14 (66.7)	
Cardiac-related mortality		7 (3.6)		7 (35)	
Revascularization (PCI)		7 (3.8)		7 (33.3)	
Revascularization (CABG)		0 (0.0)		0 (0.0)	
Graft failure (LITA-LAD)		3 (1.6)		3 (14.3)	
5-year	%				
Survival		90.5 [85.1-96.2]			
Revascularization-free survival		84.2 [77.4-91.7]			
Cardiac death and graft Revascularization-free survival		94.0 [89.7-98.6]			

COPD: Chronic obstructive pulmonary disease; ECMO: extracorporeal membrane oxygenation; IABP: intra-aortic balloon pump; ICU: intensive care unit; INR: international normalized ratio; LAD: left anterior descending artery; LITA: left internal thoracic artery; PCI: percutaneous coronary intervention.

(COPD) (10.3%), peripheral artery disease (16.8%), and atrial fibrillation (8.4%). Three patients (1.9%) had previously undergone cardiac surgery. The median logistic European System for Cardiac Operative Risk Evaluation (EuroSCORE) II was 1.1% [0.7-1.7]. The majority of patients were classified as New York Heart Association (NYHA) class I (81.3%), while 29 patients (18.7%) experienced dyspnea (NYHA class > I) before surgery. Various preoperative blood chemistry values are also presented in Table 1, which includes a comparison between patients who reached the primary endpoint during follow-up and those who did not. Notably, patients who experienced the primary endpoint had a worse NYHA class (P = 0.009) and lower preoperative hematocrit levels (39.1% [36.1-40.7] *vs.* 40.3% [38.8-43.0], P = 0.029).

Intraoperative data

All patients underwent direct LITA-to-LAD grafting, with 4 patients (2.5%) receiving sequential revascularization involving the diagonal branch. In two cases, LITA elongation was achieved using a segment of saphenous vein. Twelve patients (7.7%) underwent a hybrid procedure, including right coronary artery stenting following the MIDCAB operation. Conversion to sternotomy was necessary in 6 patients (3.9%), due to difficult LITA harvesting in four cases and intramyocardial coronary vessel in two cases. No conversion to cardiopulmonary bypass (CPB) was required, nor were there any instances of hemodynamic instability or ventricular fibrillation.

Postoperative results

No patients died within the first 30 days post-operation. The median duration of mechanical ventilation was 4 h [3-6], and the median length of stay in the intensive care unit (ICU) was 1 day [1-2]. Surgical revision for bleeding was required in 6 patients (3.9%), all of which were resolved by reopening the left mini-thoracotomy, with no need for median sternotomy. Bleeding was typically due to LITA collaterals or chest wall vessels, with no bleeding from the anastomosis observed. Acute kidney injury (Kidney Injury Improving Global Outcomes stage > 1) occurred in 15 patients (9.7%), with renal replacement therapy necessary in five cases (3.2%), and permanent renal failure in 1 patient. No cases of postoperative sepsis were reported. Atrial fibrillation occurred in 22 patients (14.2%) during the postoperative period and was managed with amiodarone infusion followed by oral therapy for 3 weeks. There were no neurological adverse events, no cases of spontaneous myocardial infarction, and no patients required extracorporeal membrane oxygenation (ECMO) or intra-aortic balloon pump (IABP) support. The incidence of postoperative blood transfusion was 17.4%. Postoperative myocardial necrosis was assessed by measuring the peak levels of cardiac Troponin I (cTnI) and creatine kinase MB fraction (CK-MB), with median values of 0.61 ng/L [0.34-1.49] and 6.2 IU/L [4.0-12.8], respectively.

Postoperative CT scans were performed to assess LITA patency and the quality of the anastomosis. A patency defect was identified in 2 patients (2%) [Table 2]. Additionally, 12 patients underwent postoperative coronary angiography to complete revascularization as part of a hybrid procedure, during which no early LITA occlusions were detected [Table 2].

Thirty-day follow-up

Within 30 days post-surgery, 10 patients (6.5%) developed left pleural effusion, of which 4 patients (2.6%) required pleural drainage, and one patient required surgical revision of the pleural cavity. The remaining 5 patients (3.2%) were treated with pharmacological therapy. Thoracotomy wound dehiscence occurred in 3 patients (1.9%), all of whom were female with inframammary incisions. Two patients were treated with vacuum-assisted closure (VAC) therapy, while 1 patient received repeated dressings. No neurological events, either transient or permanent, were reported.

Follow-up

The median follow-up duration was 36 months [12-48], with a 100% completion rate. The primary endpoint was reached by 21 patients (11.4%). Follow-up mortality was reported in 14 patients (7.6%), with cardiac-related mortality accounting for 7 cases (3.6%). Seven patients (3.8%) required rehospitalization for percutaneous revascularization, and in 3 of these patients, a malfunction of the LITA-LAD bypass was identified. No patient required surgical revascularization during follow-up.

The Kaplan-Meier analysis revealed a 5-year revascularization-free survival rate of 84.2% [77.4-91.7] [Figure 1] and an overall 5-year survival rate of 90.5% [85.1-96.2] [Figure 2]. The 5-year survival free from Cardiac Death and LITA-LAD graft failure was 94.0% [89.7-98.6] [Figure 3]. In the multivariable model, preoperative NYHA Class III status (HR 5.898 [1.187-29.311], $P = 0.030$) and postoperative atrial fibrillation (HR 3.405 [1.232-9.415], $P = 0.018$) were identified as significant negative predictors of revascularization-free survival during follow-up [Table 3].

We also examined the optimal cutoff values for peak cTnI levels as a potential predictor of the primary endpoint. ROC curve analysis identified the best cutoff value according to Youden's index at 0.87 ng/L, with a sensitivity of 55% and specificity of 62% [Figure 4]. Comparing groups based on this cutoff, 11 patients (55.0%) in the primary endpoint group and 51 patients (37.8%) in the non-primary endpoint group had cTnI peaks exceeding this threshold ($P = 0.221$).

DISCUSSION

According to the figures provided by the STS ACDS, CABG has been consistently accounting for over half of all cardiac operations performed per annum[10]. Less-invasive alternatives to CABG via the canonical full sternotomy have been available for decades[12,13], yet their broader adoption has been limited, particularly compared to the more widespread acceptance of less-invasive valve surgeries, and these procedures remain predominantly within the domain of specialized centers.

This study presents the mid-term results of MIDCAB surgery conducted via a left mini-thoracotomy. Our series highlights favorable early postoperative outcomes, including no mortality within 30 days, a low incidence of complications, and a reduced ICU stay, in agreement with the outcomes reported in other

Table 2. Postoperative results imaging control

Planned coronary CT results	100/155 (64%)
% (Anastomoses examined/Occluded or stenotic grafts/anastomoses)	
LITA patency	98% (100/2)
Planned coronary angiography results (hybrid procedure)	
LITA patency	100% (0/12)

CT: Computerized tomography; LITA: left internal thoracic artery.

Table 3. Multivariate cox proportional hazard analyses for the primary endpoint (revascularization-free survival)

Variable	Estimate	Hazard ratio [95%CI]	*P*-value	Estimate	Hazard ratio [95%CI]	*P*-value
	Initial model			Stepwise elimination model		
NYHA class II	0.584	1.794 [0.605-5.320]	0.292	0.672	1.972 [0.690-5.635]	0.205
NYHA class III	1.506	4.510 [0.787-25.837]	0.091	1.775	5.898 [1.187-29.311]	0.030
Preoperative hematocrit (%)	-1.030	0.357 [0.025-5.165]	0.450			
cTnI (ng/L)	0.291	1.338 [0.012-144.153]	0.903			
Postoperative AF	1.177	3.244 [1.153-9.126]	0.026	1.225	3.405 [1.232-9.415]	0.018

AF: Atrial fibrillation; cTnI: cardiac troponin I.

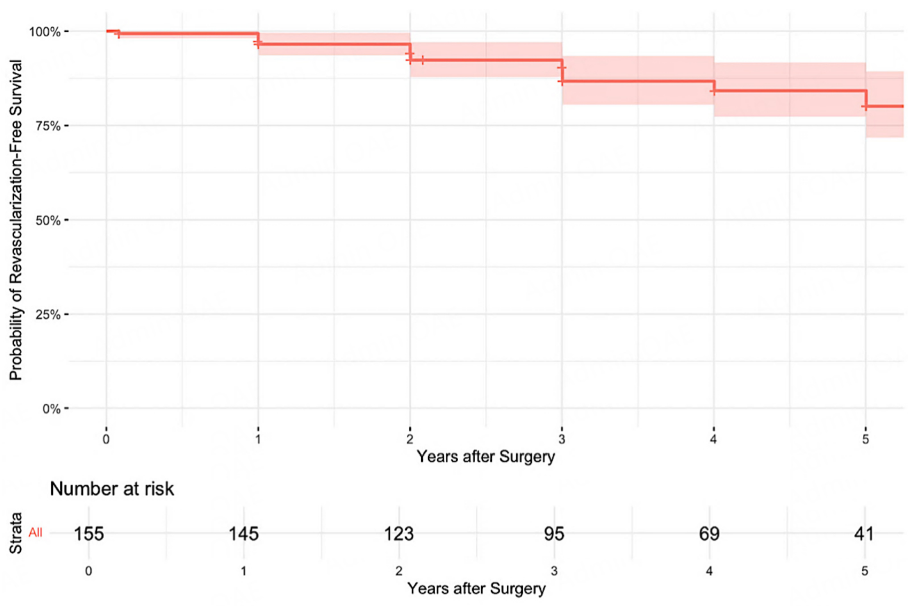

Figure 1. Kaplan-Meier analysis of mid-term revascularization-free survival.

series in the literature[6-9]. This fosters the notion of safety of the MIDCAB procedure, and provides evidence of its reproducibility.

In addition, we report a 2% occurrence of postoperative LITA graft defects, detected using coronary CT scans in each of the first 100 cases and concomitant angiography assessment during hybrid revascularization cases. This finding is in line with observations from other large series, such as those from Brescia, Leipzig, and Ottawa[6,7,9]. However, despite the already limited reports on MIDCAB, even fewer studies have systematically evaluated graft patency using angiography or CT scan[14,15]. This makes comparisons between

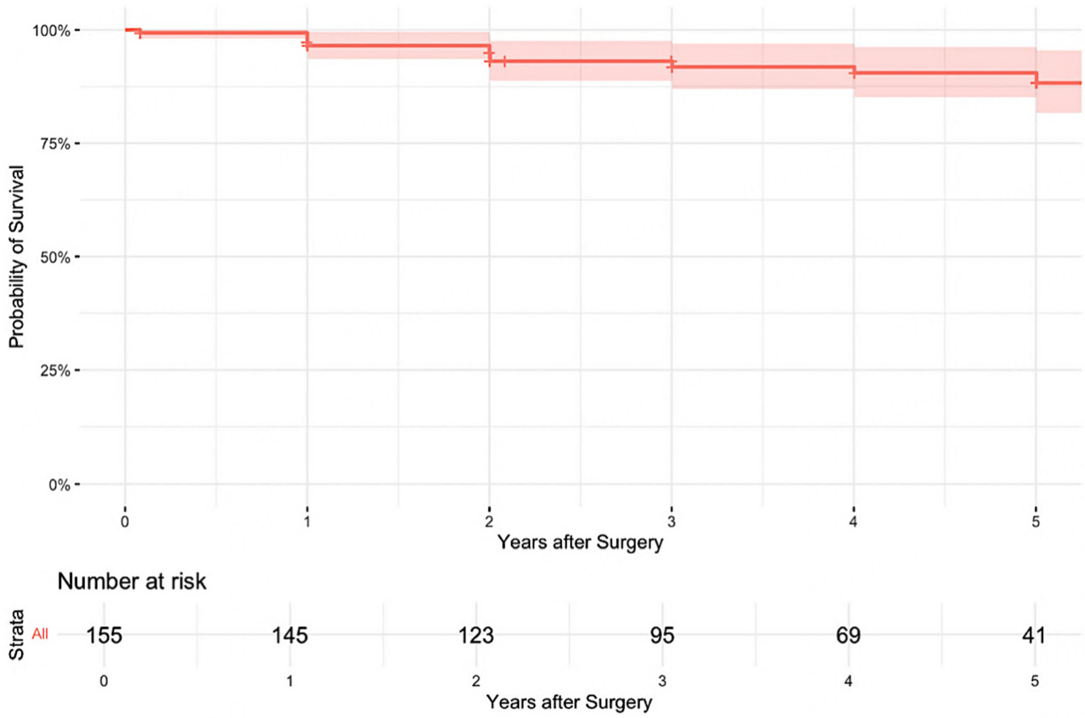

Figure 2. Kaplan-Meier analysis of mid-term mortality.

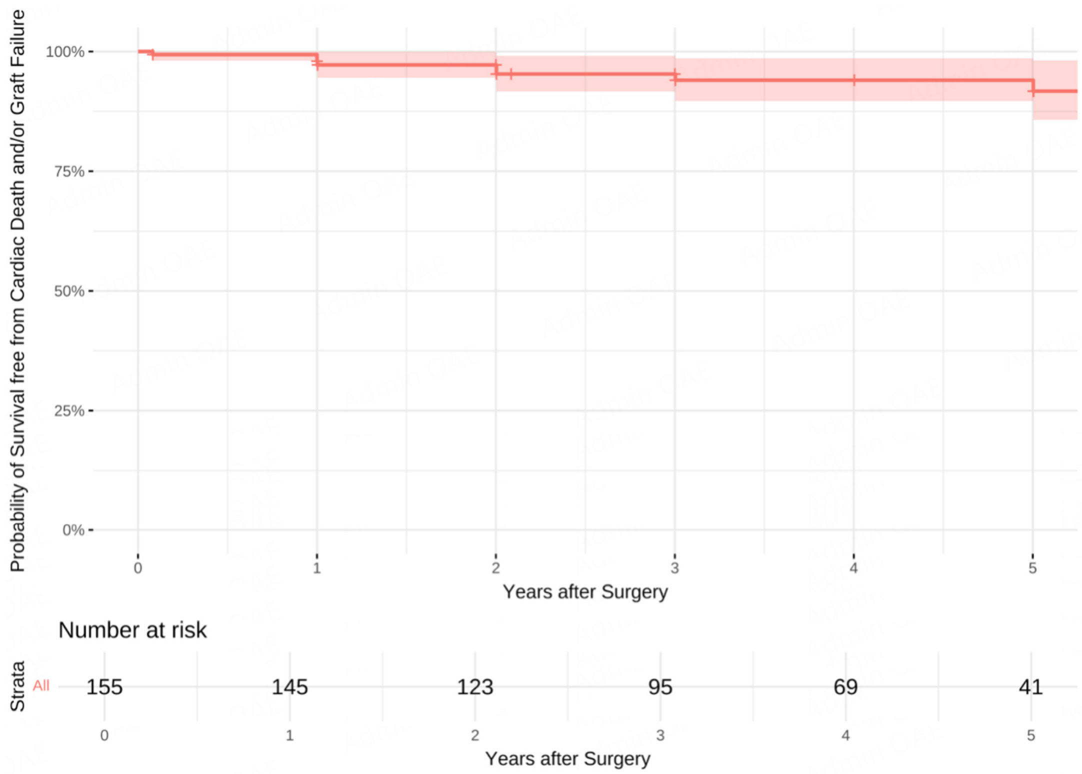

Figure 3. Kaplan-Meier analysis of mid-term cardiac-related mortality and/or LITA-LAD graft failure.

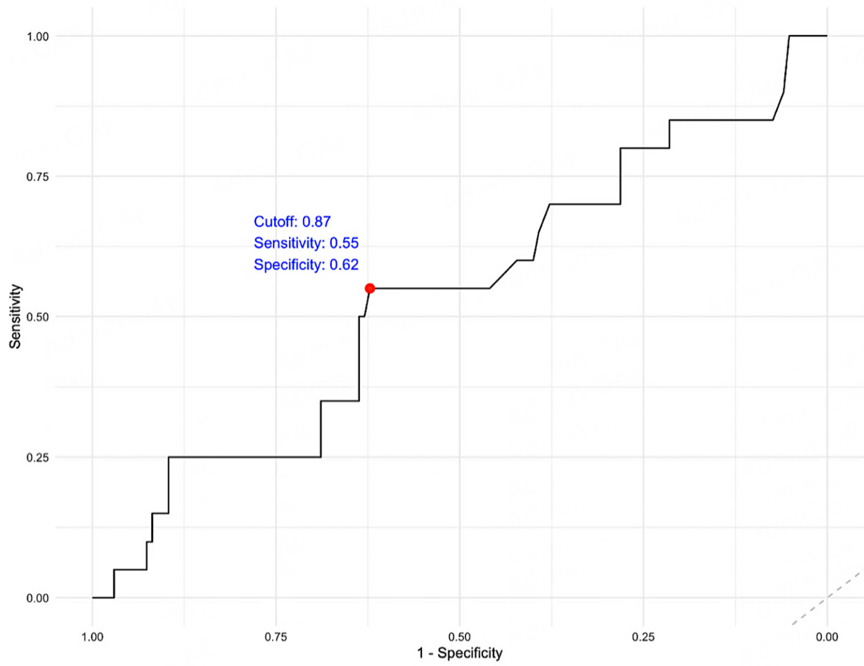

Figure 4. Receiver operating characteristic curve (ROC) for the Primary Endpoint based on the Cardiac Troponin I Cutoff as per Youden J Statistic (0.87 ng/L).

existing case series challenging, highlighting the need for prospective, multicenter studies with standardized imaging controls to provide more robust data.

Other complications were also infrequent in our cohort. Notably, we observed no cerebrovascular events, a significant finding compared to the STS ACSD report, which documented a permanent stroke rate of 1.5% among over 150,000 CABG cases performed in 2021[3]. The absence of aortic manipulation for cross-clamping, arterial cannulation, and proximal anastomoses likely reduces the risk of cerebrovascular complications in MIDCAB. Additionally, the postoperative atrial fibrillation rate in our cohort was 14.2%, substantially lower than the 26% benchmark reported in the STS registry[3]. This lower incidence may be attributed to the reduced surgical trauma of the sternal-sparing approach and the avoidance of CPB, which likely diminishes the inflammatory response and subsequently the risk of postoperative atrial fibrillation.

However, we report three cases of thoracotomy wound dehiscence, resulting in an incidence of 1.9% in our series of 155 cases, higher than the 0.8% rate of deep sternal wound infection or mediastinitis reported by the STS ACSD[3]. These cases involved female patients with inframammary incisions. A recent randomized study comparing periareolar and inframammary approaches in minimally invasive cardiac surgery found that surgical site infections were more common in the inframammary incision group compared to the periareolar approach[16].

This study is not the first to document the favorable outcomes associated with MIDCAB surgery. Recent case series from Brescia, Leipzig, New York, and Ottawa have reported promising results. Davierwala *et al.* presented data from the largest MIDCAB series globally, covering a 22-year period from 1996 to 2018, with an in-hospital mortality rate of 0.9% among 2,667 patients[7]. The estimated overall survival rates at 10, 15, and 20 years were 77.7% ± 0.9%, 66.1% ± 1.2%, and 55.6% ± 1.6%, respectively[7]. Repossini *et al.* shared findings from a cohort of 1,060 patients who underwent MIDCAB between 1997 and 2016[6]. The early mortality rate was similarly low at 0.8%, with survival estimates at 5, 10, and 15 years being 87.1% [81.0-92.5], 84.3% [77.1-91.4], and 79.8% [72.2-87.3], respectively. Patel *et al.* reported a crude 9-year survival of 96.2% in a retrospective series of 158 MIDCAB patients compared with 158 propensity-matched patients who underwent PCI using a second-generation DES[9]. Interestingly, MIDCAB patients were less likely to require repeat LAD reintervention (13.4% *vs*. 2.5%, $P < 0.0001$). More recently, Guo *et al*. reported on 283 patients prospectively followed up after undergoing MIDCAB at the University of Ottawa Heart Institute over a 17-year period, alongside another 283 patients who underwent minimally invasive multivessel coronary bypass grafting (MICS CABG)[8]. Thirty-day mortality was observed in 1 patient, accounting for an overall mortality rate of 0.2%. The 12-year survival rate was 82.2% ± 2.6%, with no significant differences observed among patients receiving one, two, three, or more grafts[9].

MIDCAB has demonstrated complication rates and long-term patency comparable to conventional sternotomy in multiple studies. A propensity score-adjusted comparison between MIDCAB and sternotomy for isolated LAD revascularization revealed no significant differences in operative mortality and complications[17]. Furthermore, there was no observed improvement in late survival or a reduction in the risk of repeat revascularization[17]. Similar findings were reported by Stanislawski *et al.* in a propensity score matching analysis involving 193 patients who underwent either MIDCAB or off-pump coronary surgery via conventional sternotomy for isolated LAD disease[18]. Notably, all these studies indicated a trend toward improved short-term outcomes with MIDCAB. Recently, the Ruhr-University Bochum in Germany published their experience with 388 elective patients, of whom 229 underwent MIDCAB and 159 underwent off-pump LIMA-to-LAD grafting via full sternotomy[19]. After applying inverse probability of treatment weighting, long-term outcomes did not differ significantly between the groups, with survival rates at 1, 5, and 10 years being 98.4%, 87.8%, and 71.7% for the sternotomy group, and 98.4%, 87.7%, and 68.7% for the MIDCAB cohort, resulting in a non-statistically significant relative risk (RR) of 1.24 [0.87-1.86]. Similar outcomes were observed for other endpoints, such as freedom from stroke, with an RR of 0.52 [0.25-1.09] ($P = 0.06$), and repeat revascularization, with an RR of 0.73 [0.47-1.16] ($P = 0.22$)[19].

MIDCAB has also been compared to percutaneous coronary intervention (PCI) for the treatment of isolated LAD disease, a particularly relevant comparison given the class 1A recommendations for both CABG and PCI in current guidelines. The Leipzig group randomized 130 patients with isolated LAD disease to receive either MIDCAB or sirolimus-eluting stents[20]. After a median follow-up of 7.3 years [5.7-8.3], with 99.3% completeness, there were no significant differences between the groups in the primary composite endpoint of death, myocardial infarction, and target vessel revascularization (22% PCI *vs*. 12% MIDCAB; $P = 0.17$), or in the individual endpoints of death (14% *vs*. 17%; $P = 0.81$) and myocardial infarction (6% *vs*. 9%; $P = 0.74$). However, target vessel revascularization was significantly more frequent in the PCI group (20% *vs*. 1.5%; $P < 0.001$)[20]. More recently, a meta-analysis including 7,710 patients who underwent either MIDCAB surgery or PCI with drug-eluting stents (DES) confirmed these findings. The analysis showed no significant difference in mortality rates (pooled OR 0.92 [0.65-1.32], $P = 0.66$), but a significantly higher rate of target vessel revascularization in the DES group (pooled OR 0.27 [0.16-0.45], $P < 0.0001$) compared to MIDCAB[21]. In this context, the results from Manuel *et al.*, who followed 271 MIDCAB patients for 20 years, demonstrated that patient survival returned to levels comparable to their age/gender/year-matched counterparts in the general population, strongly suggesting that MIDCAB should be considered as an alternative to PCI when advising patients with isolated LAD disease[22].

This study offers valuable insights into MIDCAB outcomes, but several limitations must be acknowledged. Although data were prospectively collected, the retrospective follow-up and single-center design limit the generalizability of the findings. The sample size is relatively small, reducing the study's statistical power and potentially affecting the robustness of the multivariable analyses. Additionally, the median follow-up of 36 months, while adequate for mid-term outcomes, may not fully capture long-term complications or graft failures. Moreover, hard clinical outcomes, such as spontaneous myocardial infarction and stroke, were not systematically assessed during follow-up. Furthermore, there was no formal adjudication of clinical events, which may impact the accuracy of reported outcomes. Information on secondary prevention medications, such as antiplatelet agents and statins, which are associated with long-term prognosis, was also not available, limiting the ability to make comprehensive comparisons with other studies. The evolution in surgical techniques during the study period, from direct vision to video-assisted thoracoscopy for LITA harvesting, introduces variability that could influence outcomes. Additionally, the learning curve associated with the MIDCAB technique may have impacted some results. Furthermore, the study did not assess quality of life, focusing solely on clinical and survival outcomes. Finally, graft patency via coronary CT or angiography was systematically evaluated in only a subset of patients, limiting the ability to generalize these findings.

In conclusion, our study demonstrates that MIDCAB for the treatment of isolated LAD disease is safe and yields satisfactory postoperative outcomes with excellent mid-term results. Our findings align with existing literature, underscoring the reproducibility of results achieved by other institutions. Non-sternotomy approaches represent both the present and future of coronary surgery, offering significant benefits to patients and advancing our specialty. However, it is crucial to acknowledge the technical challenges and steep learning curve associated with these procedures, which require substantial experience and confidence, particularly when addressing complex multivessel disease or multifactorial pathology[23,24]. Future studies with larger, multicenter, and randomized designs are necessary to confirm these results, validate the safety and effectiveness of MIDCAB across diverse patient populations, and provide a more robust comparison with other revascularization strategies.

DECLARATIONS

Authors' contributions

Made substantial contributions to the conception and design of the study and performed data analysis and interpretation: Margari V, Squiccimarro E, Paparella D

Performed data acquisition, as well as providing administrative, technical, and material support: Pascarella C, Tupputi FP, Carbone C

Availability of data and materials

The data supporting their findings are available from the corresponding author upon reasonable request.

Financial support and sponsorship

None.

Conflicts of interest

Paparella D is an Editorial Board member of the journal *Vessel Plus*. while the other authors have declared that they have no conflicts of interest.

Ethical approval and consent to participate

The research was performed in accordance with the Declaration of Helsinki. Approval for the study was granted by the IRCCS Istituto Tumori Giovanni Paolo II - Bari, Review Board (1431/CEL-03/11/2023).

Consent for publication

The ethics committee waived the need for informed consent to participate in the study.

Copyright
© The Author(s) 2024.

REFERENCES

1. Head SJ, Kieser TM, Falk V, Huysmans HA, Kappetein AP. Coronary artery bypass grafting: part 1-the evolution over the first 50 years. *Eur Heart J* 2013;34:2862-72. DOI PubMed
2. Llerena-Velastegui J, Zumbana-Podaneva K, Velastegui-Zurita S, et al. Comparative efficacy of percutaneous coronary intervention versus coronary artery bypass grafting in the treatment of ischemic heart disease: a systematic review and meta-analysis of recent randomized controlled trials. *Cardiol Res* 2024;15:153-68. DOI PubMed PMC
3. Kim KM, Arghami A, Habib R, et al. The society of thoracic surgeons adult cardiac surgery database: 2022 update on outcomes and research. *Ann Thorac Surg* 2023;115:566-74. DOI
4. Loop FD, Lytle BW, Cosgrove DM, et al. Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. *N Engl J Med* 1986;314:1-6. DOI
5. Cameron A, Davis KB, Green G, Schaff HV. Coronary bypass surgery with internal-thoracic-artery grafts-effects on survival over a 15-year period. *N Engl J Med* 1996;334:216-9. DOI
6. Repossini A, Di Bacco L, Nicoli F, et al. Minimally invasive coronary artery bypass: twenty-year experience. *J Thorac Cardiovasc Surg* 2019;158:127-38.e1. DOI
7. Davierwala PM, Verevkin A, Bergien L, et al. Twenty-year outcomes of minimally invasive direct coronary artery bypass surgery: the Leipzig experience. *J Thorac Cardiovasc Surg* 2023;165:115-27.e4. DOI
8. Guo MH, Toubar O, Issa H, et al. Long-term survival, cardiovascular, and functional outcomes after minimally invasive coronary artery bypass grafting in 566 patients. *J Thorac Cardiovasc Surg* 2024;168:1080-8.e2. DOI
9. Patel NC, Hemli JM, Seetharam K, et al. Minimally invasive coronary bypass versus percutaneous coronary intervention for isolated complex stenosis of the left anterior descending coronary artery. *J Thorac Cardiovasc Surg* 2022;163:1839-46.e1. DOI
10. Wyler von Ballmoos MC, Kaneko T, Iribarne A, et al. The society of thoracic surgeons adult cardiac surgery database: 2023 update on procedure data and research. *Ann Thorac Surg* 2024;117:260-70. DOI
11. Vrints C, Andreotti F, Koskinas KC, et al. 2024 ESC guidelines for the management of chronic coronary syndromes: developed by the task force for the management of chronic coronary syndromes of the European Society of Cardiology (ESC) *Endorsed by the European Association for Cardio-Thoracic Surgery (EACTS)*. *Eur Heart J* 2024;45:3415-537. DOI
12. Kolesov VI, Potashov LV. [Surgery of coronary arteries]. *Eksp Khir Anesteziol* 1965;10:3-8. PubMed
13. Calafiore AM, Angelini GD. Left anterior small thoracotomy (LAST) for coronary artery revascularisation. *Lancet* 1996;347:263-4. DOI PubMed
14. Garg S, Raja SG. Minimally invasive direct coronary artery bypass (MIDCAB) grafting. *AME Med J* 2020;5:19. DOI
15. 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;147:203-9. DOI
16. El Adel M, Nady MA, Amin A, Khairy M. A randomized controlled trial (PAMI trial) on our new trend periareolar minimally invasive (PAMI) technique versus inframammary approach for minimally invasive cardiac surgery. *Cardiothorac Surg* 2022;30:29. DOI
17. Raja SG, Benedetto U, Alkizwini E, Gupta S, Amrani M; Harefield Cardiac Outcomes Research Group. Propensity score adjusted comparison of MIDCAB versus full sternotomy left anterior descending artery revascularization. *Innovations* 2015;10:174-8. PubMed
18. Stanislawski R, Aboul-Hassan SS, Marczak J, et al. Early and long-term clinical outcomes after minimally invasive direct coronary artery bypass grafting versus off-pump coronary surgery via sternotomy in isolated proximal left anterior descending artery disease: a propensity score matching analysis. *J Card Surg* 2020;35:3412-9. DOI
19. Sharaf M, Zittermann A, Sunavsky J, et al. Early and late outcomes after minimally invasive direct coronary artery bypass vs. full sternotomy off-pump coronary artery bypass grafting. *Front Cardiovasc Med* 2024;11:1298466. DOI PubMed PMC
20. Blazek S, Rossbach C, Borger MA, et al. Comparison of sirolimus-eluting stenting with minimally invasive bypass surgery for stenosis of the left anterior descending coronary artery: 7-year follow-up of a randomized trial. *JACC Cardiovasc Interv* 2015;8:30-8. DOI
21. Raja SG, Uzzaman M, Garg S, et al. Comparison of minimally invasive direct coronary artery bypass and drug-eluting stents for management of isolated left anterior descending artery disease: a systematic review and meta-analysis of 7,710 patients. *Ann Cardiothorac Surg* 2018;7:567-76. DOI PubMed PMC
22. Manuel L, Fong LS, Betts K, Bassin L, Wolfenden H. LIMA to LAD grafting returns patient survival to age-matched population: 20-year outcomes of MIDCAB surgery. *Interact Cardiovasc Thorac Surg* 2022;35:ivac243. DOI PubMed PMC
23. Nisivaco S, Kitahara H, Bhasin R, Patel B, Coleman C, Balkhy HH. A decade of robotic beating-heart totally endoscopic coronary bypass (TECAB) at a single institution: outcomes with 10-year follow-up. *J Thorac Cardiovasc Surg* 2024:S0022-5223(24)00682. DOI
24. Squiccimarro E, Margari V, Paparella D. Bilateral mini-thoracotomy for combined minimally invasive direct coronary artery bypass and mitral valve repair. *Eur J Cardiothorac Surg* 2022;62:ezac306. DOI PubMed