

Mid-Term Results of Minimally Invasive Direct Coronary Artery Bypass Grafting

Dong Hyun Seo, M.D.¹, Jun Sung Kim, M.D.^{1,2}, Kay-Hyun Park, M.D., Ph.D.^{1,2},
Cheong Lim, M.D., Ph.D.^{1,2}, Su Ryeun Chung, M.D.¹, Dong Jung Kim, M.D.¹

¹Department of Thoracic and Cardiovascular Surgery, Seoul National University Bundang Hospital,

²Department of Thoracic and Cardiovascular Surgery, Seoul National University College of Medicine

Background: Minimally invasive direct coronary artery bypass grafting (MIDCAB) has the advantage of allowing arterial grafting on the left anterior descending artery without a sternotomy incision. We present our single-center clinical experience of 66 consecutive patients. **Methods:** All patients underwent MIDCAB through a left anterior small thoracotomy between August 2007 and July 2015. Preoperative, intraoperative, postoperative and follow-up data—including major adverse cardiovascular and cerebrovascular events (MACCE), graft patency, and the need for re-intervention—were collected. **Results:** The mean age of the patients was 69.4±11.1 years and 73% were male. There was no conversion to an on-pump procedure or a sternotomy incision. The 30-day mortality rate was 1.5%. There were no cases of stroke, although 2 patients had to be re-explored for bleeding, and 81.8% were extubated in the operating room or on the day of surgery. The median stay in the intensive care unit and in the hospital were 1.5 and 9.6 days, respectively. The median follow-up period was 11 months, with a 5-year overall survival rate of 85.3%±0.09% and a 5-year MACCE-free survival rate of 72.8%±0.1%. Of the 66 patients, 32 patients with 36 grafts underwent a postoperative graft patency study with computed tomography angiography or coronary angiography, and 88.9% of the grafts were patent at 9.7±10.8 months postoperatively. **Conclusion:** MIDCAB is a safe procedure with low postoperative morbidity and mortality and favorable mid-term MACCE-free survival.

Key words: 1. Coronary artery disease
2. Coronary artery bypass
3. Minimally invasive surgery

Introduction

Since revascularization of the left anterior descending artery (LAD) was first introduced in the 1960s [1], the applications of coronary artery bypass grafting (CABG) in coronary artery disease have expanded to include minimally invasive direct coronary artery bypass grafting (MIDCAB). MIDCAB has 2 major ad-

vantages over other treatment interventions: one is the use of a small incision through a left antero-lateral thoracotomy without cardiopulmonary bypass, and the other is the fact that it is the best option for grafting the left internal thoracic artery (LITA) to the LAD [2,3]. Those advantages result in better outcomes, with fewer complications in terms of stroke, mediastinitis, and bleeding, as well as lower medical

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Corresponding author: Jun Sung Kim, Department of Thoracic and Cardiovascular Surgery, Seoul National University Bundang Hospital, 82 Gumi-ro 173beon-gil, Bundang-gu, Seongnam 13620, Korea
(Tel) 82-31-787-7140 (Fax) 82-31-787-4050 (E-mail) Junekim73@gmail.com

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costs [2,4]. Recently, LITA-to-LAD MIDCAB has been considered to be the treatment of choice in single-vessel disease in the proximal LAD [5].

However, there are some obstacles hindering the universal use of MIDCAB in specific clinical situations. The fact that thoracotomy is more painful than sternotomy and the need for a learning curve, causing a longer operative time and target vessel misidentification, may be potential pitfalls of MIDCAB [6,7]. In this study, we evaluate the recent MIDCAB results from a single center and discuss the implications of our findings for this approach.

Methods

1) Patients

Between August 2007 and July 2015, a total of 66 patients underwent a MIDCAB operation through a left anterior minithoracotomy at Seoul National University Bundang Hospital, and the procedures were carried out by 3 cardiac surgeons who shared the same operative technique and strategy for MIDCAB. Preoperative, intraoperative, postoperative, and follow-up data were collected, including major adverse cardiovascular and cerebrovascular events (MACCE), graft patency, and the need for re-intervention. The preoperative clinical variables and demographics of the patients undergoing MIDCAB are summarized in Table 1.

The institutional review board of Seoul National University Bundang Hospital approved the present study (B-1511/322-109). And the requirement for informed patient consent was waived due to the retrospective nature of the study.

2) Indications

We considered MIDCAB in the following circumstances: (1) definitive MIDCAB, for single-vessel disease of the proximal LAD, including restenosis of a previous LAD stent; (2) palliative MIDCAB, for multi-vessel disease with a significant underlying comorbidity such as severe left ventricular (LV) dysfunction (n=12, 18%), stroke (n=14, 21%), malignancy (n=4, 6%), and the expectation of a major operation (n=5, 7.5%); and (3) hybrid MIDCAB, in cases of multi-vessel disease where MIDCAB is performed simultaneously with a percutaneous coronary intervention (PCI) in another area (n=12, 18%). Hybrid MIDCAB

Table 1. Preoperative data of 66 patients

Characteristic	Value
Age (yr)	69.4±11.1
Male sex	50 (73)
Hypertension	45 (68)
Dyslipidemia	21 (32)
Diabetes mellitus	35 (53)
Chronic renal failure	11 (17)
Chronic obstructive pulmonary disease	4 (6)
Cerebrovascular accident	14 (21)
Smoking	35 (53)
Malignancy	4 (6)
EuroSCORE II (%)	1.99±2.05 (range, 0.5–10.5)
Mean EF	53.7
Left ventricular dysfunction (EF < 40%)	12 (18)
3VD	27 (41)
2VD	23 (35)
1VD	16 (24)
Previous percutaneous coronary intervention	26 (39)
Peripheral arterial occlusive disease	6 (9)
Redo open heart surgery ^{a)}	4 (6)
Silent/stable angina	24 (37)
Unstable angina	29 (44)
STEMI/non-STEMI	13 (20)

Values are presented as mean±standard deviation or number of patients (%).

EF, ejection fraction; VD, vessel disease; STEMI, ST-segment elevation myocardial infarction.

^{a)}Coronary artery bypass graft surgery (n=3) and aortic valve replacement (n=1).

was considered for patients with multi-vessel disease who had high-grade proximal disease of the LAD along with favorable lesions for PCI in the left circumflex (LCX) and right coronary artery (RCA) territories. There is no absolute contraindication for MIDCAB, but we generally did not perform MIDCAB in patients who were expected to have severe adhesions of the left hemithorax, poor pulmonary function, or an intra-myocardial course of the LAD based on preoperative computed tomography.

3) Technique

We elevated the left hemithorax to 30°, attached external defibrillation pads, and prepared a double-lumen endotracheal tube. MIDCAB was performed through a 5- to 7-cm anterolateral minithoracotomy in the fourth or fifth intercostal space. Harvesting of the left internal mammary artery (LIMA) was done

under direct visualization with a specially designed retractor while deflating the left lung, and we usually harvested the LITA in a skeletonized fashion as far as the proximal origin of the left subclavian artery. Heparin (1.5 mg/kg) was administered to maintain an activated clotting time over 300 seconds. A standard stabilizer for off-pump CABG (Octopus; Medtronic Inc., Minneapolis, MN, USA) was used. Under a beating heart, the anastomosis to the LAD was performed. The proximal LAD was snared with silastic loops. After the main procedure, we inserted a 24-Fr chest tube into the pleural space and the thoracotomy was closed in layers. If there was no evidence of bleeding, aspirin was started on the day of the operation.

4) Statistical analysis

For statistical analyses, we used IBM SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean±standard deviation or as median values with the range. Kaplan-Meier curves were used to analyze overall survival and freedom from MACCE.

Results

We identified 66 consecutive MIDCAB patients with a mean age of 69.4±11.1 years, 73% of whom were male and 53% of whom had diabetes. The patients' preoperative characteristics are shown in Table 1. Their mean EuroSCORE II was 1.99±2.05 (range, 0.5 to 10.5). Twenty-six patients had normal LV function (ejection fraction >60%), 28 patients had moderate LV dysfunction, and 12 patients had severe LV dysfunction (ejection fraction <40%). Single- and multiple-vessel disease were present in 16 patients (24%) and 50 patients (76%), respectively. Twenty-six patients (39%) had a prior PCI, 3 patients (4.5%) had a prior CABG, and 1 patient (1.5%) had a prior aortic valve replacement. Thirteen patients (20%) had a history of an acute myocardial infarction.

The operative characteristics are shown in Table 2. The mean total operative time was 167 minutes (range, 75 to 405 minutes). There were no iatrogenic injuries to the LITA. Isolated LAD-only revascularization was performed in 58 patients (87.8%). A re-constructed composite graft with the saphenous vein

Table 2. Operative characteristics

Characteristic	Value
Length of operation (min)	167±55 (range, 75–405)
Distal anastomosis	1.15±0.44
1	58 (87.8)
2	7 (10.7)
3	1 (1.5)
Hybrid approach	12 (18)
Incomplete revascularization	17 (26)
Conversion to sternotomy	0
IABP/ECMO support ^{a)}	0
Video-assisted thoracoscopic surgery/robot-assisted	3 (5)
Combined operation ^{b)}	3 (5)

Values are presented as mean±standard deviation or number of patients (%).

^{a)}Intra-aortic balloon pump support and extracorporeal membrane oxygenation support. ^{b)}Abdominal aortic aneurysm (n=2) and lung cancer (n=1).

was used for the anastomosis of additional branches or lengthening of the LITA graft in 8 patients. Twelve patients underwent a hybrid approach for suitable lesions of the LCX and/or RCA using a standard commercial stent immediately after surgery in the hybrid operating room or preoperatively. There were no conversions to an on-pump procedure, sternotomy, or intra-aortic balloon pump or extracorporeal membrane oxygenation support. Robot-assisted MIDCAB and combined operations required longer operative times. If we consider anterolateral minithoracotomy MIDCAB for isolated LAD revascularization (LITA to LAD), the actual mean operative time was 144 minutes.

The in-hospital outcomes are shown in Table 3. The 30-day mortality rate was 1.5% (1 of 66). One 81-year-old patient died due to idiopathic massive gastric bleeding on day 4 after surgery. There were no cerebrovascular events. Atrial fibrillation was observed in 5 patients (7.6%), but there were no cases of perioperative myocardial infarction or low cardiac output syndrome. Two patients (3.0%) had to be re-explored for bleeding. Two patients (3.0%) had a superficial wound problem associated with the thoracotomy. There was 1 case (1.5%) of pulmonary complication and 1 case (1.5%) of acute renal failure. Eighty-one percent of the patients were extubated in the operating room or on the day of surgery. The

Table 3. In-hospital outcomes	
In-hospital outcome	Value
Mortality (30-day)	1 (1.5)
Morbidity	
Stroke	0
Atrial fibrillation	5 (7.6)
Perioperative myocardial infarction/low cardiac output syndrome	0
Bleeding reoperation	2 (3.0)
Wound problems	2 (3.0)
Pulmonary complication	1 (1.5)
Acute renal failure	1 (1.5)
Transfusion, packs of red blood cells	46 (69.7)
Ventilator (hr)	12.0±41.8 (1-336)
Intensive care unit stay (hr)	38.2±69.3 (13-526)
Hospital stay (day)	9.6±8.7 (4-57)

Values are presented as number of patients (%) or mean±standard deviation (range).

Table 4. Follow-up data of 65 patients	
Follow-up data	No. of patients (%)
Mortality	
Cardiac	5 (7.7)
Non-cardiac	2 (3.1)
Morbidity	
Stroke	1 (1.5)
Myocardial infarction	2 (3.1)
Target vessel revascularization	1 (1.5)
Non-target vessel revascularization	3 (4.6)

median stay in the intensive care unit and in the hospital were 23 hours (range, 13 to 526 hours) and 7 days (range, 4 to 57 days), respectively. Twenty patients (30.3%) received no transfusion.

The follow-up data are shown in Table 4. The median follow-up period was 11 months (range, 0 to 90 months). Except for in-hospital mortality, regular follow-up of the 65 survivors was completed in 100% of the patients, and their data were included in the outcome analysis. Among these patients, there were 7 late deaths (10.8%), among which 5 were due to cardiac causes (congestive heart failure). Fig. 1 shows the Kaplan-Meier survival curve of cumulative survival: the calculated 5-year overall survival rate was 85.3%±0.09%. One cerebrovascular event was observed. Two patients (3.1%) had a myocardial infarction due to an occluded LIMA graft and 1 patient was successfully treated with re-intervention on the tar-

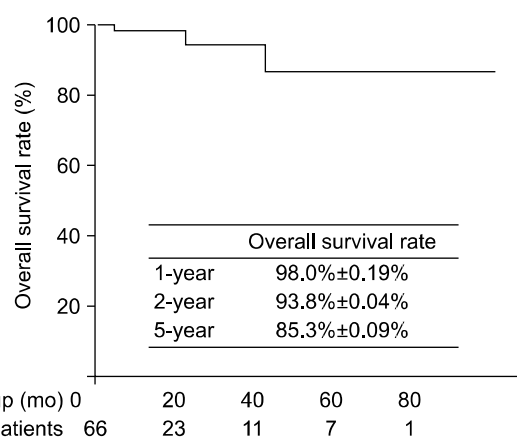


Fig. 1. Kaplan-Meier curve showing mid-term outcomes with a survival rate of 85.3%±0.09%.

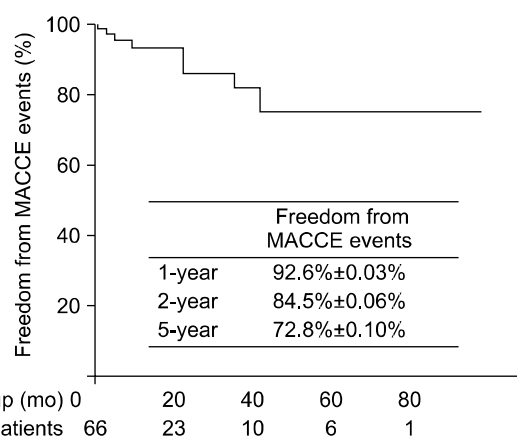


Fig. 2. MACCE-free survival curve: mid-term outcomes with a MACCE-free survival rate of 72.8%±0.1%. MACCE, major adverse cardiovascular and cerebrovascular events.

get vessel. Another 3 patients (4.6%) had a re-intervention due to progressive disease of a non-target vessel during the follow-up period. Fig. 2 shows the calculated cumulative 5-year MACCE-free survival rate of 72.8%±0.1%. Forty-eight percent of the patients (32 of 66), with a total of 36 grafts, underwent a postoperative graft patency study with computed tomography angiography or coronary angiography. Eighty-nine percent of these grafts (32 of 36) were patent at 9.7±10.8 months postoperatively (Table 5).

Discussion

In recent years, MIDCAB is increasingly becoming

Table 5. Results of postoperative computed tomography angiography or coronary angiography in 32 patients with a total of 36 grafts

	Left anterior descending artery	Left circumflex artery	Right coronary artery	Total
Left internal mammary artery	26/28 (93)	-	-	26/28 (93)
Saphenous vein graft	-	4/5 (80)	0/1 (0)	4/6 (67)
Radial artery	1/1 (100)	1/1 (100)	-	2/2 (100)
Total	27/29 (93)	5/6 (83)	0/1 (0)	32/36 (89)

Values are presented as number of patent grafts/number of total grafts (%).

a potential alternative to conventional CABG, particularly among patients with high-grade proximal LAD stenosis that is unsuitable for PCI [8]. MIDCAB has several merits compared to off-pump CABG, including the fact that it is relatively safe and has a shorter recovery period. In addition, it is less likely to require transfusion or result in a wound infection, and it has a preferable course of postoperative physical recovery [9]. It has been confirmed that the early patency rates of MIDCAB patients are comparable to those of patients with anastomoses performed through bypass under cardioplegic arrest [3]. The anastomotic patency rate reported by Cremer et al. [10] was 98%. Furthermore, the overall patency rate of MIDCAB LAD grafting has been reported to be close to that of conventional grafting of the internal mammary artery to the LAD.

Controversy persists regarding whether MIDCAB or PCI is more suitable for isolated high-grade LAD stenosis patients. PCI has the advantages of not requiring general anesthesia, a large incision, or a long hospital stay [11]. However, MIDCAB has demonstrated more promising long-term angina-free and MACCE-free survival rates than PCI. Aziz et al. [12] reported a higher rate of recurrence of angina, incidence of MACCE, and need for repeat revascularization with PCI. In high-grade LAD stenosis patients, CABG showed better outcomes than PCI in terms of MACCE-free survival at a 3-year follow-up in a single-center prospective trial [13]. In 5 years of follow-up in the SYNTAX trial, PCI had a significantly higher incidence of MACCE (46.5% versus 29.0%, $p < 0.0001$) and repeat revascularization (35.3% versus 14.6%, $p < 0.0001$) than CABG [14]. Although the recent European Society of Cardiology/European Association for Cardio-Thoracic Surgery guidelines on myocardial revascularization revised the indications for the treatment of coronary artery disease, CABG still should be recommended as a primary treatment as a

class I indication with a level of evidence of A or B except for 1- or 2-vessel disease without proximal LAD stenosis [15].

Our in-hospital outcomes are comparable to those of other studies. The mortality rate was 1.5% in our study, due to a single case of massive gastric bleeding. None of our patients had a stroke. The conversion rate from minithoracotomy to sternotomy with cardiopulmonary bypass in our experience was 0%. Two patients (3.0%) had to be re-explored for bleeding; one was bleeding from an intercostal vessel and the other was a hematoma of unknown origin. Our wound problem rate was 3.0%, which was accounted for by cases of superficial wound dehiscence. The ventilation time was very short (median, 4 hours), and 81.8% of our patients were extubated in the operating room or on the day of surgery. However, we did not show a significantly reduced hospital stay (median, 7 days) or transfusion rate (70%). Our indications for MIDCAB included palliative therapy for conditions such as multi-vessel disease with heart failure ($n=12$, 18%), a preoperative bed-ridden state with stroke ($n=14$, 21%), and acute coronary syndrome ($n=42$, 64%), resulting in longer hospital stays and a need for more transfusions. Our follow-up data showed a 5-year overall survival rate of $85.3\% \pm 0.09\%$ and a 5-year MACCE-free survival rate of $72.8\% \pm 0.1\%$, which are acceptable compared with other studies.

Twelve patients (18%) were hybrid cases that underwent the stenting of suitable non-LAD vessels during the same admission by cardiologists. PCI on the culprit lesion prior to MIDCAB was performed for 6 acute coronary syndrome patients; MIDCAB and PCI were simultaneously performed in 5 patients in the hybrid operating room, and 1 patient underwent additional planned PCI on postoperative day 1. These patients showed better outcomes than the other patients, with no early or late mortality and no MACCE. Complete revascularization through a hybrid ap-

proach seems to have been important for the late outcomes of these patients, although this issue must be investigated in a larger study. As we found good clinical outcomes, the hybrid procedure may evolve to become a useful option for multi-vessel disease in high-risk patients [16].

Thirty-two of the 66 patients who had atypical chest pain or agreed to have their grafts evaluated underwent a postoperative graft patency study with computed tomography angiography or coronary angiography. We found that 88.9% of the grafts (32 of 36) were patent at 9.7 ± 10.8 months postoperatively. Isolated LITA-to-LAD grafts were more likely to be patent (26 of 28, 93%) than saphenous vein grafts (4 of 6, 67%) or other grafts (5 of 7, 71%) in our data. Our patency rate is slightly lower than that of other studies because we only investigated less than half of the population (48.5%) who complained of atypical chest pain, and there was a liberal use of saphenous vein grafts and non-LAD territory anastomoses.

Our results showed a favorable graft patency rate of LIMA-to-LAD anastomoses after MIDCAB. Our early re-intervention rate for anastomosis stenosis was 1.5%, whereas Holzhey et al. [16] reported a rate of 3.3%. The low rate of re-intervention was an indicator of graft patency. Although the postoperative follow-up period in our patients was short, the high graft patency rate after MIDCAB may indicate that MIDCAB had substantial benefits in high-risk patients, even among those with multi-vessel disease [17]. This may reflect the safety of MIDCAB, making it a good surgical option for the treatment of coronary artery disease [18].

Based on our findings, we suggest that MIDCAB is a feasible method with acceptable outcomes, including a low rate of stroke, postoperative mortality, morbidity, infections, and transfusions; short intensive care unit and hospital stays; and good graft patency. The good clinical outcomes including excellent survival and a low rate of recurrent angina, myocardial infarction, and re-intervention rates were made possible by the excellent patency of the LIMA-LAD grafts [11].

1) Limitations

This was a study of relatively few patients, and it was an uncontrolled, nonrandomized, single-center, retrospective study. The postoperative follow-up peri-

od in our patients was short. Although 100% of patients were followed up, computed tomography angiography or coronary angiography was not performed to evaluate graft patency in all patients. Additionally, a clinical trial comparing conventional bypass and PCI to MIDCAB has not been conducted.

2) Conclusion

In summary, MIDCAB is a safe and beneficial procedure with low postoperative morbidity, mortality, and acceptable 5-year MACCE-free survival and freedom from re-intervention in selected patients. The results of our study suggest that MIDCAB is a safe and effective therapy capable of achieving effective mid-term revascularization and acceptable clinical outcomes.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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