Featured Article

Short-term clinical outcomes and long-term survival of minimally invasive direct coronary artery bypass grafting

Shahzad G. Raja[1], Sheena Garg[1], Melissa Rochon[2], Siobhan Daley[3], Fabio De Robertis[1], Toufan Bahrami[1]

[1]Department of Cardiac Surgery, [2]Department of Quality & Safety (Surveillance section), [3]Department of Quality & Safety (Audit section), Harefield Hospital, London, UK

Correspondence to: Shahzad G. Raja. Department of Cardiac Surgery, Harefield Hospital, London, UK. Email: drrajashahzad@hotmail.com.

Background: Minimally invasive direct coronary artery bypass (MIDCAB) grafting is regarded as an alternative to conventional coronary artery bypass grafting (CABG) through full sternotomy, particularly for patients with isolated proximal left anterior descending (LAD) artery stenosis deemed unsuitable for percutaneous coronary intervention. However, the technically demanding nature of the procedure and lack of long-term published outcomes have precluded its universal adoption. We report the comparative short-term outcomes and long-term survival of MIDCAB and conventional CABG through full sternotomy for grafting of isolated LAD.

Methods: From February 1996 to October 2017, a total of 668 patients underwent MIDCAB (n=508) and full sternotomy (n=160) CABG for isolated proximal LAD stenosis. Their data were prospectively entered into the institutional cardiac surgery database (Patients Analysis & Tracking System; Dendrite Clinical Systems, Ltd, Oxford, England, United Kingdom) and analyzed retrospectively. Information on patient deaths was obtained from the institutional database and the National General Register Office for all patients.

Results: The two groups were comparable with respect to preoperative demographics and risk profile. MIDCAB was associated with longer operative time (177±32 versus 141±12 min; P=0.003). The two groups did not significantly differ with regard to other complications including operative mortality. At a mean follow-up of 12.95±0.47 years, survival was also similar.

Conclusions: This large single centre study with longest follow-up validates the status of MIDCAB as an effective strategy for grafting of LAD. However, it fails to show superiority of the minimally invasive approach compared to conventional CABG through full sternotomy.

Keywords: Proximal left anterior descending artery; minimally invasive direct coronary artery bypass grafting (MIDCAB grafting); minimally invasive direct coronary artery bypass (MIDCAB); minimally invasive revascularization; left internal mammary artery (LIMA)

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Introduction

A large area of the myocardium is at risk when the proximal segment of the left anterior descending (LAD) artery has a high-grade stenosis (1). Traditionally, isolated proximal LAD stenosis not amenable to percutaneous coronary intervention has been treated with conventional on- or off-pump coronary artery bypass grafting (CABG) through median sternotomy. For the past five decades, on-pump CABG has enabled cardiac surgeons all over the world to achieve excellent results, despite the ever-increasing risk profile of the patients. However, the majority of complications occurring after on-pump CABG can be attributed to cardiopulmonary bypass and myocardial protection. This is especially true for high-risk patients currently undergoing CABG (2). Off-pump CABG through full sternotomy for single-vessel LAD disease eliminates the risks associated with on-pump CABG on cardiopulmonary

bypass, yet issues associated with full median sternotomy remain a cause for concern.

Minimally invasive direct coronary artery bypass (MIDCAB) grafting involving the surgical revascularization of the LAD artery through a left anterior thoracotomy has been advocated as an acceptable alternative to standard CABG through full sternotomy (3). The minimally invasive nature of the procedure, avoidance of cardiopulmonary bypass, and use of the left internal mammary artery (LIMA) with its well-established long-term patency are some of the widely recognized advantages (4,5). Despite these advantages, certain disadvantages including the technically demanding nature of the procedure, a steep learning curve, and lack of long-term published outcomes have precluded its universal adoption. We undertook this study to compare the short-term outcomes and long-term survival of MIDCAB and conventional CABG through full sternotomy for grafting of isolated LAD.

Methods

Patients and data collection

The study was conducted in accordance with the principles of the Declaration of Helsinki. The local audit committee approved the study, and the requirement for individual patient consent was waived. We retrospectively analyzed prospectively collected data from the institutional cardiac surgery database (Patients Analysis & Tracking System; Dendrite Clinical Systems, Ltd., Oxford, England, UK) at Harefield Hospital for the period February 1996 to October 2017. This data is annually submitted to the National Institute for Cardiovascular Outcomes Research National Adult Cardiac Surgery Audit registry. Reproducible cleaning algorithms were applied to the database, which are regularly updated as required. Briefly, duplicate records and nonadult cardiac surgery entries were removed, transcriptional discrepancies were harmonized, and clinical conflicts and extreme values were corrected or removed. The data are regularly validated. Further details and definition of variables are available at http://www.ucl.ac.uk/nicor/audits/adultcardiac/datasets. We selected subjects with isolated LAD grafting. MIDCAB was most commonly performed for single-vessel isolated LAD disease when percutaneous coronary intervention was not advisable (ostial involvement or complex lesions), not successful, or not possible (occluded LAD). It also included patients who had undergone stenting of the LAD previously and presented with recurrence of symptoms due to development of in-stent stenosis. Similarly, patients with double vessel disease who had already undergone primary angioplasty and stenting of a non-LAD culprit vessel underwent LAD revascularization by MIDCAB. Finally, patients selected for elective hybrid revascularization underwent MIDCAB followed by stenting of non-LAD lesions. The patients in the full sternotomy group were offered revascularization of the isolated LAD only as the preferred option due to referral of the patients to a surgeon who was not trained to perform MIDCAB. The techniques of MIDCAB and LIMA-to-LAD anastomosis through full sternotomy have been previously described (6).

Variables of interest

Variables of interest included age, gender, hypertension, hypercholesterolemia, previous myocardial infarction within 30 days, previous percutaneous coronary intervention, diabetes mellitus, chronic obstructive pulmonary disease, Canadian Cardiovascular Society class, New York Heart Association class, smoking status, renal status, cerebrovascular disease, peripheral vascular disease, preoperative atrial fibrillation, number of diseased vessels, left ventricle ejection fraction, urgency of operation, and year of operation. Overall risk profile was evaluated by logistic European System for Cardiac Operative Risk Evaluation (EuroSCORE) (7).

Study end points

Short-term outcomes investigated were postoperative complications, including neurological complications, need for intra-aortic balloon pump (IABP; defined as unplanned insertion of IABP intraoperatively or postoperatively because of hemodynamic instability), re-exploration for bleeding, renal complications, surgical site infection, pulmonary complications, gastrointestinal complications, and mortality within 30 days. The long-term outcome of interest was all-cause mortality. All-cause mortality is the most robust and unbiased index because no adjudication is required; thus, inaccurate or biased documentation or clinical assessments are avoided (8). Information on patient deaths was obtained from the institutional database and the National General Register Office for all patients. Data regarding postoperative complications and survival were available for all patients in the study.

Statistical analysis

For baseline characteristics, categorical variables are expressed as number and percent of patients. Continuous variables are reported as mean ± standard deviation (SD) or median and interquartile range (IQR) according to their distribution. Values between groups were compared by unpaired Student *t*-test after testing for normal distribution; otherwise, nonparametric Mann-Whitney *U* tests were used. Fisher exact or chi-square tests were used for categorical variables with nominal scales. Multiple imputation using bootstrapping-based expectation-maximization algorithm and including all pretreatment variables (Amelia R package, http://www. jstatsoft.org/v45/i07/) was used to address missing data. For long-term survival, the Kaplan-Meier method was applied, and differences were assessed by the log-rank test. Kaplan-Meier survival was compared and a curve generated using the survival package (http://CRAN.R-project.org/package=survival) and survplot package (http://CRAN.R-project.org/package=survplot). A probability value of $P<0.05$ was considered statistically significant.

Results

Pre-operative demographics

From February 1996 to October 2017, 508 patients underwent off-pump LIMA-to-LAD anastomosis through a left anterior thoracotomy at our institution. These procedures were performed exclusively by three surgeons who were formally trained to perform MIDCAB. During the same period, 160 patients had a LIMA-to-LAD anastomosis via full sternotomy performed by five other surgeons who were not trained to perform MIDCAB. The two groups were similar with respect to preoperative demographics and risk profile. Preoperative data of these patients are shown in *Table 1*. Only 0.3% data was missing.

Intraoperative data

The operative data for the two groups are listed in *Table 2*. The LIMA was harvested through the left anterior thoracotomy incision in 355 patients and endoscopically in 153 patients. The average time of surgery (P=0.003) was significantly shorter in the full sternotomy group. Three MIDCAB patients had to be converted to full sternotomy because of an intramyocardial LAD in one patient, insufficient length of the LIMA in one case, and injury to the LIMA in the third patient. In the full sternotomy group, 104 patients had LIMA-to-LAD anastomosis on cardiopulmonary bypass and 56 patients had off-pump grafting. One patient in the full sternotomy group had to be converted from off-pump to on-pump due to profound ischemia on occlusion of the LAD resulting in hemodynamic instability.

Postoperative complications

There were 10 deaths in the MIDCAB group and four deaths in the full sternotomy group (P=0.81). None of these deaths were due to occlusion or stenosis of the LIMA-to-LAD stenosis. Four (0.8%) patients with recurrent angina within 30 days of the index operation in the MIDCAB group and two (1.3%) in the full sternotomy group underwent symptom-driven angiography that showed significant anastomotic stenosis of more than 50%. The graft occlusion or graft stenosis were treated successfully with percutaneous coronary intervention in all these patients. The two groups did not significantly differ with regard to other complications. All postoperative complications are listed in *Table 3*.

Long-term survival

The mean follow-up time was 12.95±0.45 years. A total of 153 late deaths were recorded, including 40 cases (25%) in the full sternotomy group and 113 cases (22.24%) in MIDCAB group, respectively (P=0.64). The long-term survival was comparable for the two groups (*Figure 1*).

Discussion

This retrospective single centre study compares the perioperative and postoperative outcomes and long-term survival of revascularization of isolated LAD with the MIDCAB and full sternotomy approaches over a 20 years period. The results of our study confirm that MIDCAB is a safe and effective revascularization strategy for patients with isolated proximal LAD disease. In our institution, MIDCAB is performed by highly experienced surgeons with high-volume MIDCAB practice, and outcomes are reflective of this experience. However, there was no significant survival advantage or superiority of MIDCAB in terms of postoperative complications when compared to revascularization of isolated LAD through full sternotomy.

The short-term results of this study are in line with

Table 1 Demographics and risk profile

Variable	MIDCAB (N=508), N (%)	Median sternotomy (N=160), N (%)	P value
Age (year ± SD)	63±12.3	62±11.9	0.79
Male	398 (78.3)	122 (76.3)	0.63
Hypertension	297 (58.5)	88 (55.0)	0.59
Hypercholesterolemia	362 (71.3)	102 (63.8)	0.32
Diabetes	106 (20.8)	36 (22.5)	0.73
Smoking status			0.83
Current smoker	45 (8.9)	17 (10.6)	
Ex-smoker	275 (54.1)	92 (57.5)	
Never smoked	188 (37.0)	31 (19.4)	
Previous MI within 30 days	30 (5.9)	10 (6.3)	0.87
Previous PCI	147 (28.9)	48 (30.0)	0.84
CCS Class			0.76
1	90 (17.7)	24 (15.0)	
2	194 (38.2)	60 (37.5)	
3	148 (29.1)	40 (25.0)	
4	76 (15.0)	36 (22.5)	
NYHA Class			0.89
1	166 (32.7)	50 (31.3)	
2	206 (40.6)	61 (38.1)	
3	116 (22.8)	37 (23.1)	
4	20 (3.9)	12 (7.5)	
COPD	24 (4.7)	7 (4.4)	0.94
PVD	29 (5.7)	10 (6.3)	0.81
Cerebrovascular disease	7 (1.4)	3 (1.9)	0.87
Renal status, Cr >200 μmol/L	1 (0.2)	0	0.97
Preoperative AF	15 (3.0)	4 (2.5)	0.86
Number of diseased vessels			
1	272 (53.5)	117 (73.1)	
2	64 (12.6)	36 (22.5)	
3	172 (33.9)	7 (4.4)	0.001
LVEF			0.89
Good (LVEF >49%)	453 (89.2)	138 (86.3)	
Fair (LVEF 30–49%)	47 (9.3)	18 (11.2)	
Poor (LVEF <30%)	8 (1.6)	4 (2.5)	
Urgency of operation			0.78
Elective	406 (80.0)	126 (78.8)	
Urgent	82 (16.1)	24 (15.0)	
Emergency	20 (3.9)	10 (6.3)	
Year of operation			0.001
1996–2006	183 (36.0)	132 (82.5)	
2007–2017	325 (64.0)	28 (17.5)	
Logistic EuroSCORE	3.8±2.3	3.6±1.9	0.75

AF, atrial fibrillation; CCS, Canadian Cardiovascular Society; COPD, chronic obstructive pulmonary disease; Cr, creatinine; LVEF, left ventricular ejection fraction; MI, myocardial infarction; MIDCAB, minimally invasive direct coronary artery bypass; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; SD, standard deviation.

Table 2 Intraoperative data

Variable	MIDCAB (N=508), N (%)	Median sternotomy (N=160), N (%)	P value
Time of surgery (min ± SD)	177±32	141±12	0.003
Conversion to CPB	0	1 (0.6)	0.81
Conversion to sternotomy	3 (0.6)	0	0.81
Endoscopic LIMA harvest	153 (30.1)	0	0.001
Off-pump	508 (100.0)	56 (35.0)	0.001

CPB, cardiopulmonary bypass; LIMA, left internal mammary artery; MIDCAB, minimally invasive direct coronary artery bypass; SD, standard deviation.

Table 3 Postoperative complications

Variable	MIDCAB (N=508), N (%)	Median sternotomy (N=160), N (%)	P value
Neurological complications	7 (1.4)	2 (1.3)	0.87
Need for IABP	3 (0.6)	2 (1.3)	0.78
Re-exploration for bleeding	16 (3.1)	4 (2.5)	0.73
Renal complications	7 (1.4)	2 (1.3)	0.91
Surgical site infection	12 (2.4)	3 (1.9)	0.84
Pulmonary complications	111 (21.9)	43 (26.9)	0.62
Gastrointestinal complications	12 (2.4)	4 (2.5)	0.91
TVR within 30 days	4 (0.8)	2 (1.3)	0.69
Mortality within 30 days	10 (2.0)	4 (2.5)	0.81

IABP, intra-aortic balloon pump; MIDCAB, minimally invasive direct coronary artery bypass; TVR, target vessel revascularization.

the published results of other groups reporting early mortality (0% to 4.9%), conversion rate to sternotomy (0% to 6.2%), short-term reintervention on target vessel (up to 8.9%), and overall perioperative complication rate (1.6% to 40%) (9-14). The study is unique as it compares long-term survival of MIDCAB and full sternotomy revascularization of isolated LAD at a mean follow-up of 12.95±0.45 years, the longest reported follow-up to date. The excellent outcomes in our study are a reflection of the experience of the surgeons performing MIDCAB. Although the overall operative time for MIDCAB is significantly more than that for full sternotomy procedure, the operative time over the past 10 years for MIDCAB has decreased significantly compared to the operative time prior to 2007 (231±14 versus 132±42 min; P=0.0001). This reduction in operative time is suggestive of the fact that the surgeons performing MIDCAB have traversed their learning curves. Moreover, in our institution, patients needing isolated LAD grafting are preferentially referred to surgeons performing MIDCAB. This approach has translated into improved outcomes, thereby validating the positive volume-outcome relationship (15).

The popularity of the LIMA as a conduit for revascularization of the heart has increased steadily over the past three decades. With more data available concerning the long-term patency of this conduit, virtually every patient is afforded the advantage of this surgical procedure (16). The published experience of LIMA usage clearly shows that patients who receive in-situ LIMA graft to the LAD have improved long-term survival, have fewer recurrent symptoms, and have fewer late cardiac-related events (17,18). These benefits can be attributed to the improved long-term patency of the LIMA (16-18). Performance of the LIMA-to-LAD anastomosis through a small left

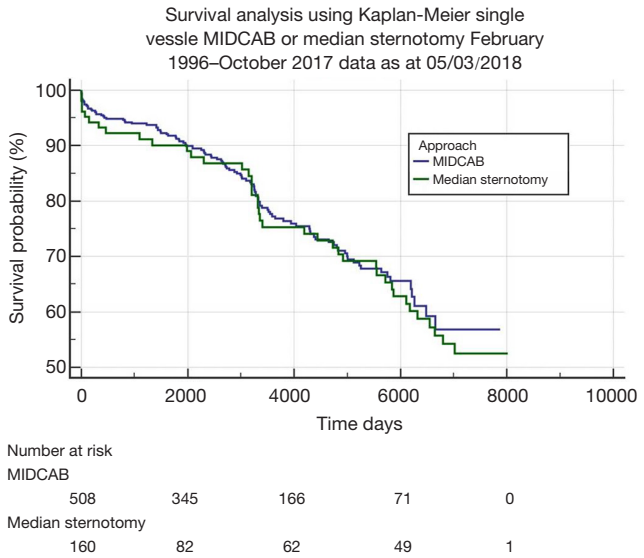

Figure 1 Kaplan-Meier survival curves of MIDCAB and isolated LIMA-to-LAD grafting through median sternotomy groups. MIDCAB, minimally invasive direct coronary artery bypass; LIMA, left internal mammary artery; LAD, left anterior descending.

anterior thoracotomy in MIDCAB offers the advantage of improved long-term survival with minimum morbidity. Five-year survival ranges between 80% and 95% in different publications including high risk and elderly patients (19-21). The 5-year survival of our patients after MIDCAB of 93.6%, the 10-year survival of 76.2% and 15-year survival of 67.5% is comparable with other studies (13,14,19-21).

The main limitation of our study is that no follow-up data were available to compare the groups with respect to the cause of death (cardiac versus non-cardiac), recurrence of angina, need for repeated revascularization, and graft patency. Therefore, we can only speculate about the mechanism beyond the equipoise between MIDCAB and isolated LAD grafting through full sternotomy on long-term survival. Other limitations of this study include its retrospective nature and inherent potential for errors in data collection. Last but not least, we did not specifically look for the impact of cumulative years of experience or other factors such as learning curve or fellowship training of the surgeons performing MIDCAB on outcomes.

Conclusions

MIDCAB is a very attractive operation for the patient due to its minimally invasive nature, excellent cosmesis and a speedy recovery. Although, it is a challenging operation for surgeons, especially those in the learning curve phase, it can be performed very elegantly and effectively by highly experienced surgeons, with not only good short and mid-term results but also excellent long-term outcomes. Our large single centre study with longest follow-up validates the status of MIDCAB as an effective strategy for grafting of the LAD. However, it fails to show superiority of the minimally invasive approach compared to conventional CABG through full sternotomy.

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None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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