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Predictors and outcomes of conversion to sternotomy in minimally invasive coronary artery bypass grafting

Minimal invaziv koroner arter baypas cerrahisinde sternotomiye dönüşün öngördürücüleri ve sonuçları

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ABSTRACT

Background: This study aims to investigate the risk factors and surgical outcomes of conversion to median sternotomy in minimally invasive direct coronary artery bypass grafting.

Methods: Between January 2017 and July 2022, a total of 274 patients (246 males, 28 females; mean age: 57.0±9.6 years; range, 33 to 81 years) who underwent conventional (n=116) or robot-assisted (n=158) minimally invasive direct coronary artery bypass grafting were retrospectively analyzed. The primary outcome measure of the study was conversion to median sternotomy, and the secondary outcome measures were operative mortality, length of intensive care unit and hospital stay.

Results: Conversion to median sternotomy was required in 26 (9.5%) patients. The most common cause of conversion was intramyocardial left anterior descending artery (27.0%). Among preoperative and operative characteristics, only age was statistically significant risk factor for conversion to sternotomy (odds ratio=1.06, p=0.01). Operative mortality occurred in one patient (0.36%) patient in the entire cohort. The length of intensive care unit and hospital stay was significantly longer in patients requiring conversion to median sternotomy (p=0.002 and p<0.001, respectively). There was no significant difference in other postoperative outcomes between the two groups (p>0.05).

Conclusion: Intramyocardial left anterior descending artery is the most common reason for conversion to sternotomy, and older age increases the risk of conversion. Minimally invasive coronary artery bypass grafting can be performed with satisfactory results, even if it requires conversion to sternotomy.

Keywords: Conversion to open surgery, coronary artery bypass grafting, minimally invasive surgery, sternotomy.

ÖZ

Amaç: Bu çalışmada minimal invaziv direkt koroner arter baypas greftleme cerrahisinde median sternotomiye dönüşün risk faktörleri ve cerrahi sonuçları incelendi.

Çalışma planı: Ocak 2017 - Temmuz 2022 tarihleri arasında konvansiyonel (n=116) ve robot yardımlı (n=158) minimal invaziv direkt koroner arter baypas greftleme yapılan toplam 274 hasta (246 erkek, 28 kadın; ort. yaş: 57.0±9.6 yıl; dağılım, 33-81 yıl) retrospektif olarak incelendi. Çalışmanın birincil sonuç ölçümü, median sternotomiye dönüş ve ikincil sonuç ölçümleri ameliyat mortalitesi, yoğun bakımda kalış süresi ve hastanede kalış süresi idi.

Bulgular: Median sternotomiye dönüş 26 (%9.5) hastada gerekti. En sık dönüş nedeni sol ön inen koroner arterin intramiyokardiyal olması idi (%27.0). Ameliyat öncesi ve ameliyat sırası özellikler arasında yalnızca yaş sternotomiye dönüşün istatistiksel olarak anlamlı risk faktörüydü (olasılık oranı=1.06, p=0.01). Tüm kohortta bir hastada (%0.36) ameliyat mortalitesi meydana geldi. Median sternotomiye dönüş gereken hastalarda yoğun bakım ünitesinde ve hastanede kalış süresi anlamlı düzeyde daha uzundu (sırasıyla, p=0.002 ve p<0.001). İki grup arasında ameliyat sonrası diğer sonuçlar açısından anlamlı bir fark yoktu (p>0.05).

Sonuç: İntramiyokardiyal sol ön inen arter sternotomiye dönüşün en sık nedenidir ve ileri yaş sternotomiye dönüş riskini artırmaktadır. Minimal invaziv koroner arter baypas greftleme, sternotomiye dönüş gerektirse dahi, tatmin edici sonuçlar ile gerçekleştirilebilir.

Anahtar sözcükler: Açık cerrahiye dönüş, koroner arter baypas greftleme, minimal invaziv cerrahi, sternotomi.

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Coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) are the main strategies for coronary revascularization. Despite continuous technological developments in PCI, surgical revascularization provides better clinical outcomes than PCI in various clinical presentations.[1-3] Although CABG has excellent outcomes, the increasing demand by patients for less invasive interventions has inspired surgeons, leading to the development of minimally invasive techniques such as minimally invasive direct CABG (conventional MIDCABG), robotic-assisted MIDCABG (RA-MIDCABG), and totally endoscopic CABG (TECAB) to reduce the invasiveness of conventional CABG, while preserving surgical outcomes.[4-8]

Conversion to median sternotomy is the primary salvage method for complications of minimally invasive CABG resulting from inadequate anatomical exposure. Different causes have been reported for the conversion to sternotomy, such as intolerance to one-lung ventilation, inadequate exposure, pleural or pericardial adhesions, left internal mammary artery (LIMA) injury or dysfunction, intramyocardial course of the left anterior descending (LAD) artery, small target vessels, right ventricular perforation, and hemodynamic instability.[9-12]

In the present study, we aimed to investigate the risk factors and surgical outcomes of conversion to median sternotomy in minimally invasive CABG.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital, Department of Cardiovascular Surgery between January 2017 and July 2022. Patients who were operated using conventional MIDCABG and RA-MIDCABG techniques were screened. A total of 274 patients (246 males, 28 females; mean age: 57.0±9.6 years; range, 33 to 81 years), including 158 RA-MIDCABG and 116 conventional MIDCABG, who were operated using minimally invasive techniques were included. Single-vessel CABG (only LAD) was performed in 139 patients, and multi-vessel bypass was performed in 135 patients. The MIDCABG was performed via cardiopulmonary bypass (CPB) in 150 patients.

Demographic, operative, and postoperative data of the patients were evaluated. The primary outcome measure of the study was conversion to median sternotomy. The secondary outcome measures of the study were operative mortality, length of intensive care unit (ICU) stay, and length of hospital stay. Pleural adhesion, pericardial adhesion, patient intolerance to single-lung ventilation, and LIMA dysfunction were classified as early conversion. Intramyocardial LAD, small or diffuse calcified LAD, anastomosis dysfunction, anastomotic bleeding, cardiac injury, and hypotension developing after the pericardium was opened were classified as late conversion.

Diabetes mellitus (DM) was defined as a history of diabetes diagnosed and/or treated by a healthcare provider or preoperatively measured hemoglobin A1c of ≥6.5%. Chronic obstructive pulmonary disease (COPD) was defined as forced expiratory volume in 1 sec (FEV1)/forced vital capacity (FVC) <0.70 on pulmonary function tests or chronic use of inhaled or oral bronchodilator or steroid therapy. Preoperative renal failure was defined as an estimated glomerular filtration rate of <60 mL/min (Kidney Disease: Improving Global Outcomes, Grade ≥3a) or creatine level ≥2 mg/dL. Cerebrovascular disease was defined as focal or global neurological dysfunction caused by brain injury as a result of hemorrhage or infarction. Postoperative renal failure was defined as a creatinine increase >50% relative to preoperative levels or the need for dialysis at least once in the postoperative period. Postoperative stroke was defined as brain death, cerebral infarction, or intracranial hemorrhage within 30 days postoperatively. Operative mortality was defined as death occurring within 30 days postoperatively or before hospital discharge.

Surgical technique

None of the patients who were unsuitable for MIDCABG were operated, such as patients with hemodynamic instability and a history of left thoracotomy, thoracic radiation, and pericarditis. Consultations with pulmonologists and anesthetists were completed after the patients signed the informed surgical consent. Preoperative thoracoabdominal (including common femoral arteries) computed tomography (CT) angiography was performed in patients who were scheduled for CPB via the peripheral cannulation technique for multi-vessel CABG.

Off-pump conventional MIDCABG: After induction of anesthesia, a double-lumen endotracheal tube was placed. External defibrillation pads were placed in the appropriate location. A roller was tucked under the left chest of the patient, the shoulders was fallen, and a 30° right lateral decubitus position was achieved. A 6-cm anterolateral mini-thoracotomy was performed through the fourth intercostal space.

The LIMA was harvested under direct vision using specific retractors (Delacroix-Chevalier, Paris, France). The LIMA was dissected via the semi-skeletonized technique with low-power electrocautery (15-20 W) and Hemoclips up to the left subclavian vein. Systemic heparinization was achieved after LIMA dissection was completed. Then, the LIMA flow and structure were checked. The pericardium was opened, and an appropriate LAD exposure was provided with traction sutures. A tissue stabilizer (Acrobat-i Stabilizer®; Getinge, Sweden) was placed into the anastomosis area. The proximal control was provided with a snare, and an intracoronary (ClearView®; Medtronic Inc., MN, USA) shunt was placed after the arteriotomy. The LIMA-LAD anastomosis was performed using 8/0 prolene sutures.

Off-pump RA-MIDCABG

After anesthesia preparation and positioning similar to conventional MIDCABG, the LIMA was harvested via the Da Vinci® Si™ system (Intuitive Surgical, CA, USA) in RA-MIDCABG. A total of three ports were placed through the second (7 mm), fourth (12 mm), and sixth (7 mm) intercostal spaces. An intrathoracic pressure of 10 mmHg was achieved using carbon dioxide insufflations. The LIMA was dissected up to the left subclavian vein using low-power electrocautery (15-20 W). After the LIMA was check, the Da Vinci® system was removed from the operating table, and the ports were taken out. The camera port was extended 4 cm antero-medially to provide space for manual LIMA-LAD anastomosis. The distal anastomosis technique was performed similarly to the conventional MIDCABG.

On-pump MIDCABG

In addition to anesthesia preparation and positioning similar to the off-pump MIDCABG, transesophageal echocardiography was performed. After 1.5 mg/kg of heparin administration, the right internal jugular vein was cannulated using the Seldinger method, as described in our previous publication.[13] Full systemic heparinization was first achieved, and the right femoral artery and vein were cannulated as described by Şen et al.[14] in a previous study in our clinic. An 8-cm anterolateral mini-thoracotomy was performed through the fourth intercostal space. The LIMA was harvested under direct vision using specific retractors (Delacroix-Chevalier, Paris, France). The LIMA was dissected via the semi-skeletonized technique using low-power electrocautery (15-20 W) and Hemoclips up to the left subclavian vein. Simultaneously, the great saphenous vein and/or the radial artery were harvested. Then, the LIMA flow and structure were checked. The pericardium was opened via a double T-shape incision from the apex to the ascending aorta. The surrounding tissues of the ascending aorta were carefully dissected, and ascending aorta was encircled by a tape. Cardioplegia sutures were placed, and diastolic arrest was achieved with a Chitwood® DeBakey Clamp (Scanlan International Inc., MN, USA) inserted through two intercostal spaces. The inferior vena cava and left pulmonary veins were encircled with tapes during diastolic arrest to ensure proper positioning for anastomosis. Distal anastomosis was performed with 7/0-8/0 prolene sutures. Proximal anastomosis of the saphenous vein grafts was usually performed using an aortic side clamp.

Statistical analysis

Statistical analysis was performed using the R version 4.0.3 software (R Foundation for Statistical Computing, Vienna, Austria). Continuous data were presented in mean ± standard deviation (SD) or median (interquartile range [IQR]), while categorical data were presented in number and frequency. The chi-square test or Fisher exact test was used to analyze data. The Kolmogorov-Smirnov test was used to determine the non-normal distribution. Normally distributed continuous data were analyzed using the Student t-test. Non-normally distributed continuous data were analyzed using the Mann-Whitney U test. Univariate analysis for conversion to median sternotomy was performed using a logistic regression model. A p value of <0.05 was considered statistically significant.

RESULTS

The detailed preoperative and operative characteristics of the patients are given in Table 1. Conversion to median sternotomy was required in 26 (9.5%) patients. The most common cause of conversion was intramyocardial LAD (27.0%). The reasons and timing of conversion to median sternotomy are summarized in Table 2. There was no statistically significant difference between MIDCABG for multi-vessel coronary artery disease (CAD) and MIDCABG for single-vessel CAD in terms of conversion to sternotomy (n=16 [11.9%] *vs.* n=10 [7.2%], respectively; p=0.22). The need for conversion was similar between RA-MIDCABG and conventional MIDCABG techniques (n=15 [9.5%] *vs.* n=11 [9.5%], respectively; p=0.99). The CPB via central cannulation was established in eight patients after conversion to

Table 1. Preoperative and operative characteristics of the patients

	All patients (n=274)	Robotic-assisted MIDCABG (n=158)	Conventional-MIDCABG (n=116)		On-pump MIDCABG (n=150)	Off-pump MIDCABG (n=124)		MIDCABG for multiple-vessel CAD (n=135)	MIDCABG for single-vessel CAD (n=139)	
	n (%) Mean±SD	n (%) Mean±SD	n (%) Mean±SD	*p*	n (%) Mean±SD	n (%) Mean±SD	*p*	n (%) Mean±SD	n (%) Mean±SD	*p*
Age (year)	57.0±9.6	57.1±9.6	56.8±9.5	0.81	58.0±9.4	55.9 ±9.7	0.07	57.8±9.1	56.3±10.0	0.19
Sex										
Male	246 (89.8%)	135 (85.4 %)	111 (95.7%)	0.01	140 (93.3%)	106 (85.5%)	0.04	127 (94.1%)	119 (85.6%)	0.03
COPD	69 (25.2%)	40 (25.3%)	29 (25.0%)	0.99	34 (22.7%)	35 (28.2%)	0.33	29 (21.5%)	40 (28.8%)	0.21
Diabetes mellitus	110 (40.1%)	59 (37.3%)	51 (44.0%)	0.32	72 (48.0%)	38 (30.6%)	0.01	65 (48.1%)	45 (32.4%)	0.01
Renal failure	12 (4.4%)	5 (3.2%)	7 (6.0%)	0.37	9 (6.0%)	3 (2.4%)	0.24	8 (5.9%)	4 (2.9%)	0.25
Cerebrovascular disease	11 (4.0%)	5 (3.2%)	6 (5.2%)	0.54	7 (4.7%)	4 (3.2%)	0.76	8 (5.9%)	3 (2.2%)	0.13
EF (%)	55.0±8.2	54.9±8.2	55.0±8.3	0.9	54.7±7.9	55.3±8.6	0.56	55.0±8.2	55.0±8.2	0.99
CABG for single-vessel CAD	139 (50.7%)	118 (74.7%)	21 (18.1%)	<0.01	23 (15.3%)	116 (93.5%)	<0.01	0	139 (100 %)	NA
Off-pump	124 (45.3%)	103 (65.2%)	21 (18.1%)	<0.01	0	124 (100%)	NA	8 (5.9%)	116 (83.5%)	<0.01
CPB time (min)	114.8±49.7	72.1±25.8	135.4±45.2	<0.01	114.8±49.8	-	NA	123.2±45.2	60.1±43.8	<0.01
ACC time (min)	57.1±26.0	39.6±19.7	64.2±24.9	<0.01	57.1±26.0	-	NA	61.4±24.2	24.3±12.4	<0.01

MIDCABG: Minimally invasive direct coronary artery bypass grafting; CAD: Coronary artery disease; SD: Standard deviation; COPD: Chronic obstructive pulmonary disease; EF: Ejection fraction; CPB: Cardiopulmonary bypass; ACC: Aortic cross-clamp; NA: Not applicable.

Table 2. The reasons and timing of conversion to median sternotomy

	n	%
Early conversion	11	42.3
Pleural adhesions	5	19.2
Pericardial adhesions	1	3.8
Single-lung ventilation not tolerated	2	7.7
LIMA dysfunction	3	11.5
Late conversion	15	57.7
Intramyocardial LAD	7	27.0
Small or diffuse calcified LAD	2	7.7
Anastomosis dysfunction	1	3.8
Anastomotic bleeding	1	3.8
Ventricular perforation	1	3.8
Aortic injury	1	3.8
Left pulmonary artery injury	1	3.8
Hypotension	1	3.8

LAD: Left anterior descending artery; LIMA: Left internal mammary artery.

sternotomy. There was no statistically significant difference between planned on-pump MIDCABG and planned off-pump MIDCABG in terms of conversion to sternotomy (n=16 [11.3%] *vs*. n=10 [7.6%], respectively; p=0.31).

Univariate analyses were performed to identify risk factors for conversion to median sternotomy. Among preoperative and operative characteristics, only age statistically significantly increased the risk of conversion (odds ratio [OR]= 1.06, 95% confidence interval [CI]: 1.01-1.11; p=0.01). Table 3 demonstrates the univariate analysis results of conversion to median sternotomy.

Operative mortality occurred in one (0.36%) patient in the entire MIDCABG cohort. This patient had a diagnosis of COPD. The LIMA was successfully taken down using the conventional MIDCABG technique in the patient. After completing the two-vessel CABG (LIMA-LAD, aorta-right coronary artery) anastomosis with the on-pump technique, the patient became hypotensive following weaning from CPB. Conversion to median sternotomy was performed. The CPB was re-initiated with central cannulation, and distal coronary anastomoses were re-anastomosed. The patient was able to wean from CPB with intra-aortic balloon pump support. There was no problem in the control angiography of the patient, and operative mortality occurred within 11 days postoperatively due to low cardiac output syndrome. There was no statistically significant difference in the operative mortality, new-onset atrial fibrillation, acute renal failure, re-exploration, prolonged inotrope use (>24 h), postoperative myocardial infarction, and postoperative stroke between the patients who required conversion to median sternotomy and those who did not. The length of ICU and hospital stay was significantly longer in patients requiring conversion to median sternotomy (1 *vs*. 1, respectively; p=0.002 and 5 *vs*. 6, respectively; p<0.001). Postoperative outcomes are shown in Table 4.

DISCUSSION

In the present study, the rate of conversion to sternotomy was found to be 9.5%. Conversion was

Table 3. Univariate analysis for conversion

	Univariate analysis		
	OR	95% CI	*p*
Age	1.06	1.01-1.11	0.01*
Sex			
Male	0.86	0.24-3.07	0.82
Diabetes mellitus	1.85	0.82-4.16	0.13
Renal failure	1.98	0.41-9.58	0.39
COPD	1.46	0.52-4.03	0.46
Ejection fraction	0.98	0.93-1.02	0.29
CABG for single-vessel coronary artery disease	0.58	0.25-1.32	0.19

OR: Odds ratio; CI: Confidence interval; COPD: Chronic obstructive pulmonary disease; CABG: Coronary artery bypass grafting.

Table 4. Postoperative outcomes

	Non-conversion (n=248)				Conversion (n=26)				
	n	%	Median	IQR1-IQR3	n	%	Median	IQR1-IQR3	*p*
Operative mortality	0	0.0			1	3.8			0.09
New-onset atrial fibrillation	32	12.9			6	23.1			0.22
Acute renal failure	2	0.8			0	0.0			0.99
Re-exploration	22	8.9			3	11.5			0.71
Prolonged inotrope use (>24 h)	9	3.6			1	3.8			0.99
Postoperative myocardial infarction	3	1.2			1	3.8			0.10
Postoperative stroke	3	1.2			1	3.8			0.33
ICU stay (day)			1	1-1			1	1-2	0.002
Hospital stay (day)			5	4-6			6	5-8	<0.001

IQ: Interquartile range; ICU: Intensive care unit.

required in 3.8% to 12.4% of patients in previous studies.[7,9-11] Similar to the results of Christidis et al.,[9] the most common cause of conversion was intramyocardial LAD in our study. In contrast, van der Merwe et al.[10] showed that the most common causes of conversion were lung adhesions (36.7%) and LIMA dysfunction (36.7%). The main finding of our study is that older age is the only univariate risk factor for conversion. History of preoperative clinical conditions such as COPD, DM, and renal failure were not found to be risk factors for conversion. In the same study conducted by van der Merwe et al.,[10] preoperative renal failure was the only risk factor for conversion. In their study, patients with preoperative renal failure comprised 20% of the total MIDCABG population. In the present study, the definition of renal failure was probably stricter, and patients with preoperative renal failure accounted for 4.4% of the total MIDCABG population.

In our study, patients requiring conversion to median sternotomy only had longer ICU and hospital stays. On the other hand, the median ICU stay was similar, and median hospital stay was only one day longer than in patients not requiring conversion. This finding highlights the importance of a low conversion threshold for patient safety and satisfactory surgical outcome. Rodriguez et al.[12] demonstrated that sternotomy conversion did not lead to poor surgical outcomes such as operative mortality, new-onset atrial fibrillation, and re-exploration for bleeding, similar to our study.

The main advantages of MIDCABG are postoperative early rehabilitation and fewer sternal complications compared to median sternotomy.[15] Conversion to sternotomy is performed, when the patient safety or revascularization success is in doubt.[10] Although conversion to sternotomy is undesirable by the patient, it should not be seen as a failure.[13] Conversion to sternotomy in the MIDCABG procedure varies according to the learning curve, the experience of the surgical team, and the conversion threshold.[16] There is a risk of conversion to sternotomy with every MIDCABG, and the risk of conversion must be included in the surgical plan, and appropriate precautions must be taken. We believe that our study results are encouraging for surgeons who routinely perform CABG with median sternotomy and are willing to add MIDCABG techniques to their surgical expertise. Cardiac surgeons who are at the beginning of the MIDCABG learning curve can avoid catastrophic outcomes by rapidly converting to sternotomy in case of complications.

Although conversion to sternotomy is a part of MIDCABG, successful preoperative patient assessment has been shown to reduce the risk of conversion. Coronary angiography evaluation for LAD-related problems more specific to MIDCABG should be performed. Similarly, it has been shown that defining the morphological features of LAD by performing preoperative coronary CT angiography significantly reduces conversion to median sternotomy.[17-20]

Nonetheless, this study has some limitations. First, the operations were performed by more than five different surgeons. While some of these surgeons had more than 10 years of MIDCABG experience, some were at the beginning of the learning curve. Therefore, conversion rate was slightly higher than that has been previously published for MIDCABG. Second, preoperative coronary CT angiography was not routinely performed for intramyocardial LAD evaluation. Third, flow measurement or intraoperative angiography could not be performed to assess anastomotic quality. Finally, this study did not investigate long-term clinical outcomes. Further studies comparing the long-term results of CABG via median sternotomy to CABG via minimally invasive surgery are needed.

In conclusion, intramyocardial left anterior descending artery is the most common reason for conversion to sternotomy, and older age increases the risk of conversion. Minimally invasive direct coronary artery bypass grafting can be performed with satisfactory results, even if it requires conversion to sternotomy.

Ethics Committee Approval: The study protocol was approved by the Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital Ethics Committee (date: 06.12.2022, no: 2022-68). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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