Minimally Invasive Coronary Artery Bypass Grafting: Dual-Center Experience in 450 Consecutive Patients

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Background—Minimally invasive coronary artery bypass grafting (MICS CABG) is a novel coronary operation that does not require infrastructure and is potentially available to all cardiac surgeons. It aims at decreasing the invasiveness of conventional CABG while preserving the applicability and durability of surgical revascularization. We examined the feasibility and safety of MICS CABG in the first large series of this operation to date.

Methods and Results—All myocardial territories are accessed via a 4- to 6-cm left fifth intercostal thoracotomy. An apical positioner and epicardial stabilizer are introduced into the chest through the subxyphoid and left seventh intercostal spaces, respectively. The left internal thoracic artery is used to graft the left anterior descending artery, and radial artery or saphenous vein segments are used to graft the lateral and inferior myocardial territories. Proximal anastomoses are performed directly onto the aorta or from the left internal thoracic artery as a T-graft. In the first 450 consecutive MICS CABG procedures at our 2 centers, mean \( \pm \) SD age was 62.3 \( \pm \) 10.7 years and 123 patients were female (27%). The average number of grafts was 2.1 \( \pm \) 0.7, with complete revascularization in 95% of patients. There were 34 patients in whom cardiopulmonary bypass was used (7.6%), 17 conversions to sternotomy (3.8%), and 10 reinterventions for bleeding (2.2%). Perioperative mortality occurred in 6 patients (1.3%).

Conclusions—MICS CABG is feasible and has excellent procedural and short-term outcomes. This operation could potentially make multivessel minimally invasive coronary surgery safe, effective, and more widely available. (Circulation. 2009;120[suppl 1]:S78–S84.)

Key Words: bypass ■ coronary disease ■ surgery

An optimal way of performing revascularization for coronary artery disease (CAD) has not yet been identified. Although percutaneous coronary interventions (PCIs) are particularly appropriate for acute ischemic presentations and focal CAD, their long-term durability does not match that of surgical revascularization. On the other hand, coronary artery bypass grafting (CABG) surgery is associated with major morbidity in \( \approx \) 15% of patients, which includes septicemia, infection, stroke, reoperation, hemorrhage, low cardiac output, new-onset hemodialysis, and adult respiratory distress syndrome. Furthermore, atrial fibrillation is seen in up to 50% of patients after CABG. Chronically, poststernotomy patients not uncommonly experience decreased physical functioning, and up to 30% of CABG patients still report pain 1 year after operation. The thoracic invasiveness of CABG has not decreased since the operation was introduced >40 years ago. With the exception of a few specialized centers at which total endoscopic coronary artery bypass is performed in very selected patients, no operation has eliminated the sternotomy and decreased the invasiveness of CABG while preserving key principles of complete revascularization and wide applicability for multivessel or diffuse CAD.

Minimally invasive CABG (MICS CABG) is a surgical procedure based on the anatomic relations between the left internal thoracic artery (LITA), the coronary arteries and their branches, the apex of the heart, and the ascending aorta. The goal of the MICS CABG operation is to allow the surgeon to perform, within a patient’s closed anterior thorax, a revascularization configuration equivalent to that of a regular CABG operation while keeping the procedure minimally invasive, without a sternotomy, and in many cases without the use of cardiopulmonary bypass (CPB). We hereby report on our dual-center experience of 450 consecutive patients treated with this cardiac surgical modality.

Methods

Patient Population

Between 2005 and 2008, 450 patients with CAD referred for CABG underwent MICS CABG at the Staten Island University Hospital or...
at the University of Ottawa Heart Institute. This constitutes both the initial and consecutive group of MICS CABG procedures at each institution. All procedures were performed by J.T.M. at the Staten Island University Hospital and by M.R. at the University of Ottawa Heart Institute.

The preoperative characteristics of the patients are shown in Table 1. The patients ranged in age from 37 to 88 years (mean, 62.3), and 327 were male. Symptomatic multivessel CAD, present in 389 (76.4%) patients, was the most common indication for operation. The median preoperative Canadian Cardiovascular Society angina class was 2.

**Preoperative Evaluation**

Indications for MICS CABG are similar to those for conventional CABG with sternotomy. Absolute contraindications include emergency surgery with hemodynamic compromise, severe pectus excavatum, and severe pulmonary disease. Relative contraindications include hemodynamically significant left subclavian stenosis, hemodialysis arteriovenous fistula on the patient’s left side, redo surgery, morbid obesity, severe left ventricular dysfunction, need for right coronary artery graft with no posterior descending or left ventricular branch target, need for circumflex coronary artery graft with no adequate marginal branch target, and absence of femoral pulses bilaterally.

**Preoperative Patient Characteristics (N=450)**

| SIUH/UOHI | 369/81 |
| Age, y | 62.3±10.7 (range, 37–88) |
| Men/women, n/n | 327/123 |
| Ethnicity, n* | |
| White | 405 (90.0%) |
| Black | 15 (3.3%) |
| Hispanic | 11 (2.4%) |
| Asian | 15 (3.3%) |
| Height, cm | 170.7±10.0 (range, 149–198) |
| Weight, kg | 84.5±19.4 (range, 44–163) |
| CCS angina class, n | |
| No angina | 7 (1.6%) |
| I | 80 (17.8%) |
| II | 156 (34.7%) |
| III | 139 (30.9%) |
| IV | 68 (15.1%) |
| Ejection fraction, % | 41.4±11.3 |
| Three-vessel disease, n | 128 (28.4%) |
| Two-vessel disease, n | 261 (58.0%) |
| Diabetes mellitus, n | 126 (28.0%) |
| Hypertension, n | 357 (79.3%) |
| Tobacco use, n | 265 (58.4%) |
| Cerebrovascular disease, n | 41 (9.1%) |
| Peripheral vascular disease, n | 40 (8.9%) |
| Chronic pulmonary disease, n | 66 (14.7%) |
| Chronic renal insufficiency, n | 42 (9.3%) |
| Prior myocardial infarction, n | 159 (35.3%) |
| Prior PCI, n | 80 (17.8%) |
| Prior CABG, n | 7 (1.6%) |

CCS indicates Canadian Cardiovascular Society; SIUH, Staten Island University Hospital; UOHI, University of Ottawa Heart Institute.

Attention is given on history and physical examination to the detection of possible left subclavian artery stenosis. In cases where such suspicion exists, Doppler, computed tomography, or angiographic examination of the left subclavian–LITA axis is warranted. If use of a radial artery is contemplated, then the ulnar pulse and Allen test must be compatible with its safe use.15 Pulmonary disease, if suspected, is also investigated, because tolerance of single-lung ventilation greatly facilitates the conduct of the operation.

**Operative Procedure**

Patients may be given paravertebral thoracic (T2–T3) blockade. Intubation is performed either with a double-lumen endotracheal tube or with a regular endotracheal tube and a left bronchial blocker to selectively deflate the left lung. Transesophageal echocardiography is routinely used to monitor cardiac function, as well as to help position guide wire–guided femoral venous and arterial cannulas, should CPB be used.

Patients are positioned in a 15° to 30° right lateral decubitus position, with the right arm extended to allow harvest of the radial artery, if applicable. The patient is draped to allow access to the left groin and right thigh/leg for femoral cannulation and saphenous vein harvest, respectively. A 4- to 6-cm incision is made in the left fifth intercostal space, started at the midclavicular line, and extended laterally (Figure 1). In obese patients, the incision can be made slightly larger, and exposure is facilitated by use of a soft-tissue spreader and epicardial tissue stabilizer are inserted through 6-mm incisions in the subxyphoid area and in the seventh intercostal space, respectively. At the end of the procedure, pericardial and left pleural drainage tubes are left at these sites.

**Figure 1.** Schematic representation of anatomic relations in MICS CABG. A left fifth intercostal space anterolateral thoracotomy allows direct visualization of and access to the cardiac apex, the LITA, the LAD, the branches of the circumflex and right coronary arteries, and the ascending aorta. An apical positioner and epicardial tissue stabilizer are inserted through 6-mm incisions in the subxyphoid area and in the seventh intercostal space, respectively. At the end of the procedure, pericardial and left pleural drainage tubes are left at these sites.
is positioned, and a silicone elastomer (Silastic) occluder is placed around the coronary artery to be grafted, proximal to the planned arteriotomy. Coronary anastomoses are performed by using running 7-0 polypropylene. Visualization is obtained by use of an intracoronary shunt and a blower-mister. The flow in each conduit is assessed with a flow probe. At the end of the procedure, a pleural chest tube is placed through the orifice created for the Octopus NS, and a pericardial drain is left in the hole created for the Starfish NS. The left lung is reinfated, and all grafts are inspected under direct vision to rule out kinking or tension. The thoracotomy incision is closed with a single No. 2 stitch around the opened intercostal space. Intramuscular Marcaine is administered, or the On-Q pain relief system (I-Flow, Lake Forest, Calif) is implanted into the thoracotomy. The anterior pectoralis muscle fascia is closed with No. 0 polyglactin 910. The subcutaneous tissues and skin are closed in the usual fashion.

Postoperative Management and Evaluation

Postoperatively, patients are started on daily enterico-coated acetylsalicylic acid 325 mg on the day of operation. Unless contraindicated, antihypertensive medications are resumed on the first postoperative day. All patients are treated with medical therapy as with conventional CABG via sternotomy, including aspirin, $\beta$-blockers, and anticholesterol agents. Patients undergoing MICS CABG with a radial artery graft are prescribed a dihydropyridine calcium channel blockers for 6 months.

In the present series, all patients were followed up for a minimum of 30 days after discharge from the hospital. Death was defined as mortality occurring within 30 days of operation or at any time during hospitalization. Stroke was defined as a permanent, new, focal neurologic deficit occurring either intraoperatively or postoperatively. Respiratory insufficiency was defined as a cumulative requirement for intubation and ventilation of 72 hours or more at any time during the postoperative stay. New-onset renal failure was defined as the need for temporary or permanent renal dialysis of any type. Transfusion rates were determined by the proportion of patients who received at least 1 transfusion of any blood product, and the mean number of units transfused was derived as the total number of packed red blood cell units transfused divided by the number of patients who received a red blood cell transfusion. A known stenotic or occluded graft was defined as an angiographic graft stenosis of >50% or graft occlusion. Sternal wound infection was defined as drainage of purulent material from the wound and was recorded up to 6 months postoperatively.

Results

Operative Characteristics

Of the 450 patients brought to the operating room with the intent to perform MICS CABG, the operation was completed without conversion in 433 (96.2%). Total perioperative mortality occurred in 6 patients (1.3%). Causes of death were multigener failure in 3 patients, sepsis in 2, and tamponade in 1.

Table 2 shows the operative characteristics and postoperative results. The mean number of grafts was $2.1 \pm 0.7$, and 359 patients (79.8%) received 2 or more grafts. Complete revascularization, ie, revascularization of each major myocardial territory subtended by a coronary artery of 1.5 mm or more in diameter with stenosis $\geq 70\%$, was achieved in 427 patients (94.9%). Of these, 17 patients had hybrid revascularization during the same hospital stay, with PCI performed either before ($n=16$) or after ($n=1$) MICS CABG. Rates of return to the operating room, transfusion, stroke, and atrial
fibrillation were low. Excellent wound healing was noted in nearly all patients (Figure 3), with only 1 incident of superficial chest wound infection. Pleural complications were observed almost exclusively in the left thorax.

Procedural Adoption of MICS CABG
Figure 4 displays the surgeon-specific procedural adoption rates of MICS CABG at the 2 centers from which this report originates. Overall, MICS CABG was performed in 450 of 1404 (32.1%) nonemergent coronary bypass patients throughout the study period, and this proportion increased to 142 of 283 patients (50.2%) in 2008.

Mid-Term Reintervention
Mid-term follow-up is available for the series’ first 300 initial patients, 2 mid-term graft failures occurred in the remaining 128 patients who had proximal anastomoses onto the aorta, and both involved saphenous vein segments. The fifth intercostal space thoracotomy scar is visible, extending laterally from below the nipple. Also shown are the apical positioner entry site in the subxiphoid area and the epicardial tissue stabilizer entry site in the left seventh intercostal space.

Discussion
The main finding of this report is that multivessel coronary revascularization can be performed minimally invasively in a large number of patients, with wide applicability and excellent procedural outcomes. In our dual-center series of 450

patients undergoing MICS CABG during a period of 3.5 years, we observed a low incidence of perioperative morbidity and mortality and high procedural success with regard to applicability and revascularization completeness. Furthermore, this report includes our entire experience, including our initial one, thus suggesting that this procedure may be implemented and developed without the occurrence of a significant “learning curve” with respect to morbidity and mortality.

**MICS CABG Versus CABG**

The present findings are significant in that for $>40$ years since the introduction of CABG, no diffusible change has occurred to decrease the invasiveness of the operation, and attempts at minimally invasive, multivessel surgical revascularization have succeeded in only low numbers and at highly specialized centers. Although a cost-effectiveness analysis was not performed, MICS CABG does not involve any significant infrastructure acquisition or additional operational costs, thereby potentially facilitating implementation of this new modality at other centers.

To our knowledge, this also constitutes the first large report wherein a minimally invasive multivessel CABG approach compares favorably with the results of the “gold standard” CABG operation. Modern results of conventional CABG include an operative mortality of 2.5%–20 and a 5.2% rate of revascularization within 18 months after the initial procedure.5 It is important to caution, however, that MICS CABG remains a new technique in need of external validation, that its results might not be generalizable to all centers, and that surgical selection bias may have favored the inclusion of patients more likely to benefit from a sternal-sparing CABG approach. In the present study, $>50\%$ of patients had 2-vessel disease; in a related geographic area, Hannan et al5 found 2-vessel CAD in 30% of CABG and in 75% of PCI patients with multivessel CAD. Therefore, referral patterns may have selected a number of patients for MICS CABG who had less severe CAD or who might otherwise have received PCI.

**MICS CABG Versus MIDCAB**

The MICS CABG operation is quite different from a minimally invasive direct coronary artery bypass (MIDCAB) operation, itself associated with excellent results but restricted to the performance of a single LITA-LAD graft.21,22 First, MICS CABG is a multivessel operation that allows for complete revascularization in the presence of 3-vessel or diffuse CAD. Second, the MICS CABG thoracotomy is more lateral and often smaller, allowing for rib spreading with less risk of costochondral or rib injury and for use of the space normally occupied by the left lung (deflated during the procedure) to work within the chest. Third, the LITA can readily be harvested, skeletonized or not, over its entire length, ie, from the level of the subclavian vein down to the bifurcation, as in a conventional CABG operation, thus allowing for optimal selection of the LAD anastomotic site as well as for avoidance of a possible steal phenomenon from LITA side branches.23,24 Fourth, all coronary arteries and their relations can be visualized and identified because the pericardium is opened widely. Fifth, the MICS CABG operation allows for proximal anastomoses to be routinely performed onto the ascending aorta.

**MICS CABG Versus Other Multivessel Minimally Invasive Techniques**

There have been other previous reports of nonsternotomy, off-pump CABG for multivessel CAD. These may be broadly classified as 3 types of interventions: robotic approaches, bilateral MIDCAB-based approaches, and single thoracotomy approaches. Previous series have involved fewer patients than in the present study, and to date, few if any approaches have combined minimal invasiveness, wide applicability for multivessel disease, and preservation of the standard CABG anatomic configuration.

Among robotic approaches, Bonatti et al17 and Schachner et al18 reported in 85 patients who underwent totally endoscopic coronary artery bypass with the daVinci telemanipulation system between 2001 and 2006. The mean CPB time was 114 minutes, and the aortic endooclusion time was 65 minutes. There was a significant learning curve, including injury to the LITA in 6%.20 In an experience involving 12 centers, totally endoscopic coronary artery bypass was performed in 98 patients requiring single-vessel LAD revascularization. Average CPB time was 117 minutes, cross-clamp time was 71 minutes, and overall freedom from reintervention or angiographic failure at 3 months was 91%. Multivessel robotics was used by Srivastava et al27 in 150 patients, with a mean number of grafts per patient of 2.6. In their experience, all coronary arteries could be reached by the use of bilateral internal thoracic arteries, with the use of in situ or composite grafts.

Other multivessel alternatives include bilateral MIDCAB28 or endo-ACAB, for which Vassiliades29 reported, in 52 patients, the use of bilateral thoracoscopic internal thoracic artery harvesting followed by a right-sided thoracotomy to reach anterior coronary vessels, including the right coronary artery and the LAD. However, bilateral thoracotomy incisions were necessary to also reach posterolateral vessels, and no grafting of the posterior interventricular branch could be performed.

With respect to thoracotomy approaches, techniques including complex arterial configurations have been previously reported in up to 27 patients.30,31 In 2 other publications, single-center thoracotomy multivessel grafting with a configuration similar to that in the present series was reported in as many as 255 patients.27,32 Although the thoracotomies were larger (allowing central cannulation via the right atrial appendage and aorta) and used external sternotomy off-pump CABG instruments through the incision, the authors noted good results, including low mortality and an incidence of atrial fibrillation that ranged between 5.5% and 8%.

**Selection of Patients for MICS CABG**

Preoperative assessment of prospective MICS CABG patients is important to identify those with an unsuitable anatomy; those with peripheral, ascending aortic, or subclavian artery disease; or those who are unlikely to tolerate single-lung ventilation. Mild to moderate thoracic hyperinflation is not a contraindication to MICS CABG, as it is often associated...
with very good exposure. On the other hand, several considerations may be important for surgeons who are beginning to perform MICS CABG. Patients with severe cardiac hypertrophy, especially when concentric in distribution and associated with diastolic dysfunction, may not allow for adequate exposure of the lateral and inferior coronary arteries, and CPB assistance or conventional CABG may be a better option for these patients. Patients with previous chest trauma or rib fractures on the left side should not be offered MICS CABG early in one’s experience. Early attempts at grafting the circumflex coronary distribution should preferably include patients who have at least I well-developed marginal branch target. Finally, as with standard off-pump surgical revascularization, patients with significant ischemia or instability associated with manipulation of the heart should be treated with pump assistance or, if unsuitable, with sternotomy and on-pump CABG.

Limitations

This report is observational and bias in the selection of patients is likely, especially in the earlier part of the experience. Even in the last year of the present series, nearly 50% of our CABG patients still underwent CABG via sternotomy owing to a number of logistical, surgical, and patient selection reasons. Selection bias may therefore have remained throughout the study period and favored the selection of patients who were more likely to benefit from the avoidance of a sternotomy.

Mid-term follow-up is incomplete and ongoing; therefore, no inference can be made regarding the late durability of this revascularization procedure. On the other hand, MICS CABG has evolved to allow for a graft configuration that is anatomically similar to conventional CABG, and chronic-phase results could be equivalent, provided that all technical aspects of the minimally invasive procedure are mastered. Although no adverse events were observed, the use of peripheral CPB occurred in nearly 8% of patients in this series and should be considered to carry an inherent risk of complications.

Conclusions

In this large cohort of adult patients undergoing MICS CABG, applicability, revascularization completeness, morbidity profile, and safety were excellent and were maintained despite rapid procedural adoption. This suggests that a novel minimally invasive surgical alternative to CABG exists, may be widely applicable, and might be associated with at least as good procedural outcomes. However, randomized, controlled trials will be necessary to compare MICS CABG with CABG with respect to survival, long-term patency, and physical functioning.

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