Safety and Effectiveness of Minimal-Access versus Conventional Coronary Artery Bypass Grafting in Emergent Patients

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Background: Myocardial revascularization with a minimal-access incision is used in many patients who undergo an elective coronary artery bypass grafting (CABG) operation. To evaluate whether this method could be used for patients who undergo an emergent CABG operation, we compared patients in whom emergent minimal-access CABG was used as the method of revascularization with patients who underwent emergent conventional CABG.

Methods: From June 1996 to April 1998, 63 patients underwent emergent CABG operation due to unstable angina, percutaneous transluminal coronary angioplasty accident, or critical left main lesion. Ten patients received minimal-access CABG via limited left parasternal incision (MI), and 53 patients received conventional CABG via median sternotomy (CS).

Results: There were 2 deaths in the MI group and 13 deaths in the CS group. We used the Society of Thoracic Surgery computer program to predict the mortality of both groups. The expected hospital mortality of the MI group was significant higher than that of the CS group. The 24-hour drainage amount in the MI group was significant less than that of the CS group. There were no significant differences in cross-clamping time, the duration of extracorporeal circulation, the intensive care unit stay, or the average hospital stay. Total costs of the MI group were similar to those of the CS group, except that the blood transfusion fee was significantly lower (9406 ¡ 1259 vs. 12059 ¡ 3994 New Taiwan dollars, $p = 0.003$).

Conclusion: This technique combines minimally invasive surgical conditions with the safety and cost standards of emergent CABG surgery. Even emergent and high-risk coronary artery disease can be treated using this approach.

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Key words: coronary artery bypass grafting (CABG), minimal invasive surgery, cost-effectiveness.

During the past few years, technical progress with minimally invasive coronary artery bypass grafting (CABG) surgery has extended its clinical use from 1- or 2-vessel disease to left main or 3-ves-

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sel disease, with or without cardiopulmonary bypass support. However, this technique has only been utilized for elective coronary artery bypass surgery. The risks and costs of emergent minimally invasive CABG surgery have not been studied yet. To measure the feasibility and cost-effectiveness of emergent minimally invasive CABG, we reviewed our surgical experience related to 2 groups of patients who underwent either emergent CABG with a minimally invasive incision (group MI) or a conventional median sternotomy (group CS).

METHODS

Patient population

Between June 1996 and April 1998, 63 patients underwent emergent CABG surgery. Surgical indications were acute myocardial infarction with unstable hemodynamic condition (34/63, 54.0%), unstable angina with medical treatment failure (17/63, 27.0%), percutaneous transluminal coronary angioplasty accident (4/63, 6.3%), and critical left main lesion (29/63, 46.0%). An intra-aortic balloon bump were inserted preoperatively in 18 (18/63, 28.6%) patients due to their compromised hemodynamic condition despite large doses of intravenous infusion of inotropic agents; 4 (4/63, 6.3%) of the 18 patients were sent to the operating room under external cardiac massage.

The patients were divided into 2 groups according to the method of operation performed: group MI (n = 10), minimally invasive CABG a via left parasternal incision and group CS (n = 53), traditional CABG via median sternotomy. The operation methods were performed alternatively every other week. One operation method was performed during an entire week, and then the other method was performed in the following week. Patients were randomly assigned to either group according to the time when their operations were performed. All operations were performed by the same doctor (Dr. Lin). Demographic characteristics of both patient groups are shown in Table 1. The demographic profile of MI versus CS patients showed no significant differences in age (61.5 ¡ 11.4 vs. 61.8 ¡ 9.4 years, $p = 0.238$), female gender (10% vs. 34%, $p = 0.129$), hypertension (60% vs. 56.6%, $p = 0.840$), diabetes (20% vs. 37.7%, $p = 0.281$), and previous stroke (0% vs. 18.9%, $p = 0.496$). Preoperatively, an intra-aortic balloon pump was inserted in 3 patients (30%) in the MI group and 15 (28.3%, $p = 0.915$) in CS the group.

Table 1. Patient Demographics

Characteristic	MI Group (N = 10)	CS Group (N = 53)	*p*
Age (yr)	61.5 ¡ 11.4	61.8 ¡ 9.4	0.238
Female	1 (10%)	18 (34.0%)	0.129
Hypertension	6 (60%)	30 (56.6%)	0.840
Diabetes	2 (20%)	20 (37.0%)	0.281
Prior CVA	1 (10%)	10 (18.9%)	0.496
Smoking	7 (70%)	20 (37.7%)	0.059
AMI	6 (60%)	28 (52.8%)	0.678
Pre-op IABP	3 (30%)	15 (28.3%)	0.915
Left main lesion	5 (50%)	24 (45.3%)	0.782
Three-vessel disease	4 (40%)	33 (62.3%)	0.190
PTCA accident	2 (20%)	2 (3.8%)	0.052
LVEF (%)	46.9 ¡ 19.1 (20-79)	52.8 ¡ 19.4 (14-80)	0.201

Abbreviations: CVA: cardiovascular accident; AMI: acute myocardial infarction; IABP: intraaortic balloon pump; LVEF: left ventricular ejection fraction.

Operative techniques

Minimally invasive CABG group

The surgical techniques used in the minimally invasive CABG group have been previously reported,[1, 2] but with some modification. Patients were put in a supine position exposing the left groin and lower limbs, and transesophageal echocardiographic monitoring was set up. In 2 patients who were sent to the operating room under cardiac massage, cardiopulmonary bypass was established first via the left common femoral artery and vein after systemic heparinization (250 units/kg). A left anterior parasternal minithoracotomy, 8-12 cm long, was performed, and the costal cartilage of the third and fourth ribs were resected. Care was taken not to damage the underlying left internal thoracic artery. The internal thoracic arterial graft next to the sternal border was identified and was mobilized from the first to the fifth intercostal space under direct vision. In the meantime, a great saphenous vein graft was harvested from a lower limb.

In the other 8 patients, systemic heparinization was given at this time. The ascending aorta was isolated from the main and left pulmonary arteries, encircled with umbilical tape, and pulled into the operative field. Cardiopulmonary bypass was established through cannulation of the ascending aorta, the main pulmonary artery, and the right atrium. A double-lumen aortic root cannula (DPL, Grand Rapids, MI, USA) was then inserted at the aortic root for delivery of cardioplegic solution and for venting of the left ventricle. A membranous oxygenator (Maxima Plus Oxygenation System, Medtronic, Inc. Cardiopulmonary Division, Anaheim, CA, USA) was used. Systemic hypothermia (rectal temperature 27.4¡ 1.0¢J) was begun immediately after the start of the cardiopulmonary bypass. Topical cooling of the heart was not applied. The aorta was cross-clamped at the distal portion of the ascending aorta. The myocardium was protected by cold blood cardioplegic solution which was infused into the aortic root at this moment and after completing of each distal anastomosis. The heart was soon arrested and cooled, and was decompressed by venting through the aortic root cannula.

The saphenous vein graft was grafted sequentially to the posterior descending branch, the obtuse marginal branch, and the diagonal branch, when there was a proximal lesion, with a running suture under direct vision. The internal thoracic arterial graft was then anastomosed to the left anterior descending artery while rewarming was begun. The anastomotic area was steady and clear due to cardioplegic arrest and aortic cross-clamping, making the anastomosis easy and smooth.

After completion of all distal anastomoses, proximal anastomosis of the saphenous vein graft to the ascending aorta was performed. Warm blood cardioplegia was then infused into the aortic root before removal of the aortic cross-clamp. The sinus rhythm recovered spontaneously, and cardioversion was not necessary in most patients. The cardiopulmonary bypass was terminated after rewarming the patients. An intra-aortic balloon pump or cardiotonic drugs were necessary in some patients with poor ventricular function before the operation. Temporary pacemaker wires and pleural drainage were routinely set up. Hemostasis and closure of incisions were easily achieved.

Conventional CABG via a median sternotomy

The standard technique for a median sternotomy was used in patients of the MS group.[3] After induction of general anesthesia, transesophageal echocardiographic monitoring was started. The patient was put in a supine position. A cardiopulmonary bypass was established for 2 patients, who were sent to the operating room under cardiac massage, via the left common femoral artery and vein after systemic heparinization. For the other patients, a vertical midline skin incision was made from 1 finger's breadth below the suprasternal notch to a point 1 to 3 cm below the tip of the xiphoid process. The lower part of the incision was carried through the linea alba. The sternum was then split in the midline using an electric saw, and a rib spreader was inserted and opened. The left internal thoracic artery was identified, dissected, and mobilized from the first to the fifth intercostal space. In the meantime, a great saphenous vein graft was harvested. Then the pericardium was opened, and pericardial stay sutures were applied. A cardiopulmonary bypass was established through cannulation of the distal portion of the ascending aorta and the right atrium. A double-lumen aortic root cannula was then inserted at the aortic root for delivery of a cardioplegic solution and venting of the left ventricle. The remaining part of the procedure was the same as that of the minimally invasive group.

Statistical analysis

All statistical analyses were performed with Excel (Microsoft, Seattle, WA, USA) software. P-values <0.01, instead of 0.05, were considered as statistically significant because multiple tests were used in the tables. Discrete variables were analyzed by £q^{2} or Fisher's exact test, and continuous variables were analyzed by the Student's *t* test. All data are presented as an absolute percentage of a mean ¡ standard deviation. We used the Society of Thoracic Surgery Program (Summit Medical Systems, Minneapolis, MN, USA) to register and calculate the predicted mortality of all patients, based on our own registry data.

RESULTS

Operative results

CABG surgery was performed in all patients. Conversion to a full sternotomy was not needed in any patient of the MI group. The length of the skin incision was significantly shorter in patients of the MI group (Table 2). One to 4 distal anastomoses were performed in each patient of both groups without significant difference (MI, 2.6 ¡ 1.2 vs. CS, 3.1 ¡ 1.0, $p=0.487$). The aortic cross-clamp time (MI, 92.4 ¡ 27.3 vs. CS, 83.8 ¡ 33.4 minutes, $p=0.293$), and cardiopulmonary bypass time (MI, 128.4 ¡ 27.1 vs. CS, 131.2 ¡ 70.4 minutes, $p=0.236$) did not signifantly differ between these 2 groups.

In Table 2, we examined the predicted versus observed mortality rates in both groups of patients. By using the Society of Thoracic Surgery program with our previously registered data, the predicted mortality rates for the MI and CS groups were 23.98% and 12.51%, respectively, which shows a significant higher mortality rate for patients in the MI group ($p=0.001$). Actually, the observed in-hospital mortality (20% vs. 24.5%, $p=0.758$) and morbidity (12.5% vs. 22.5%, $p=0.523$) of patients in the MI group did not significantly differ from those of patients in the CS group. The 24-hour drainage amount in the MI group was not significantly less than that of the CS group (193 ¡ 44 vs. 480 ¡ 302, $p=0.012$). Two patients in each group who were sent to the operating room under cardiac massage could not be weaned from the cardiopulmonary bypass and died; another 8 patients of the CS group that could not be weaned from the cardiopulmonary bypass died; while a further 3 patients of the CS group died of myocardial failure in the intensive care unit several days after the emergent operation. One patient in the MI group had minor leg wound infection with conservative treatment only; the other complication which occurred in the MI group was prolonged ventilator support for 7 days in a patient who had a history of chronic obstructive pulmonary disease and a cerebrovascular accident preoperatively. Totally 9 major complication episodes occurred in 7 patients in the CS group: 1 patient who experienced renal failure needed life-long dialysis, 2 had major sternal wound infection which needed operative management, 3 patients had prolonged ventilatory support, and 3 patients had a re-operation for postoperative cardiac tamponade; another 2 minor complications occurred including 1 minor leg wound infection and 1 sternal wound infection, both of which were treated with conservative management. The intensive care unit stay was 5.6 ¡ 3.1 days for patients of the MI group and 5.1 ¡ 4.8 days for those of the CS group without significant difference ($p=0.379$).

The postoperative hospital stay was 9.6 ¡ 3.5 days for patients in the MI group and 10.2 ¡ 3.4 days for those in the CS group, because more complications occurred in the CS group (MI, 12.5% vs. CS, 22.5%, $p=0.523$), without a statistically significant difference ($p=0.331$). Follow-up (Table 3) was completed in all patients of both groups. One late death occurred in the CS group to a patient who had a severe cerebrovascular accident several months after discharge and died of the episode. Echocardiographic examination showed good left ventricular ejection function in patients of both groups (MI, 53.8% ¡ 11.8% vs. CS, 61.0% ¡ 16.0%, $p=0.178$). All patients were found to be in New York Heart Association functional class II or I. All patients of the MI group were satisfied with the cosmetic healing of the minimally invasive parasternotomy wound.

Table 2. Operative Results

Characteristic	MI Group	CS Group	*p*
Length of incisions (cm)	9.2 ¡ 0.3	23.5 ¡ 1.2	<0.001
Number of distal anastomosis	2.6 ¡ 1.2	3.1 ¡ 1.0	0.487
Cross clamping time(min)	92.4 ¡ 27.3	83.8 ¡ 33.4	0.293
Cardiopulmonary bypass (min)	128.4 ¡ 27.1	131.2 ¡ 70.4	0.236
24 hours drainage amount (ml)	193 ¡ 44	480 ¡ 302	0.012
IMA use	10 (100%)	24 (56%)	0.001
Mortality	2 (20%)	13 (24.5%)	0.758
STS predictive of mortality	23.98%	12.51%	0.001
Major Morbidity	1/8 (12.5%)	9/40 (22.5%)	0.523
ICU stay (Days)	5.6 ¡ 3.1	5.1 ¡ 4.8	0.379
Length of post-op stay (days)	9.6 ¡ 3.5	10.2 ¡ 3.4	0.331

Abbreviations: IMA: internal mammary artery; STS: society of thoracic surgery.

Table 3. Follow-up Infromation

Characteristic	MI Group	CS Group	*p*
Period of follow up (month)	19.7 ¡ 4.1	30.4 ¡ 9.8	0.006
Wound complication	1/8 (12.5%)	5/40 (12.5%)	1.000
Late death	0/8	1/40	0.647
Postoperative LVEF (%)	53.8 ¡ 11.8	61.0 ¡ 16.0	0.178

Abbreviations: LVEF: left ventricular ejection fraction.

Cost assessment

Total expenses and costs of each item of every patient in both groups were calculated (Table 4). The total expense (MI, 347,319 ¡ 87,602 vs. CS, 434,360 ¡ 83,583 NT dollars, $p = 0.652$) and ward fee (MI versus CS: 44,300 ¡ 15,225 versus 73,385 ¡ 16,544 NT dollars, $p = 0.853$) of the CS group were much higher than those of the MI group, but without statistical significance. The transfusion fee for blood components for the MI group was significantly less than that of the CS group (9,406 ¡ 1,259 vs. 12,059 ¡ 3,994, $p = 0.003$), due to lower drainage amount during the first 24 hours post-operatively. The difference in costs between these 2 groups comes from the longer duration of postoperative hospital stay in the CS group (CS, 10.2 ¡ 3.4 vs. 9.6 ¡ 3.5 days, $p = 0.331$). Because the daily charge for on ordinary ward in Taiwan is much lower than that in the US, the difference was not statistically significant.

Table 4. Cost Assessment (in New Taiwan dollars)

Characteristic	MI Group	CS Group	*p*
Total amount	347,319 ¡ 87,602	434,360 ¡ 83,583	0.652
Operative fee	83,070 ¡ 12,688	82,364 ¡ 17,698	0.793
Ward fee	44,300 ¡ 15,225	73,385 ¡ 16,544	0.852
Lab fee	41,199 ¡ 8,689	49,141 ¡ 8,855	0.143
Transfusion fee	9,406 ¡ 1,259	12,059 ¡ 3,994	0.003

Note: In 2000, the average exchange rate was US$1.00: NT$ 31.87

DISCUSSION

In the past decade, CABG surgery has seen several major changes, especially in the minimally invasive surgical procedures,[4] although conventional CABG via a median sternotomy remains the golden standard. Minimally invasive approaches with less surgical trauma and greater benefits have been adopted by an increasing number of surgical specialties.[5-9] Our previous experience demonstrated that a minimally invasive coronary surgery technique could be safely and cost-effectively performed on patients who received elective surgery.[1,2] However, whether the technological advances allow minimally invasive CABG surgery to be performed on patients requiring emergent surgery had not been studied before.

In this report, the MI group was about the same age (61.5 ¡ 11.4 vs. 61.8 ¡ 9.4 years, $p = 0.238$) and had a similar proportion of females (10% vs. 34.0%, $p = 0.129$) as did the CS group undergoing conventional emergent CABG surgery. The MI group had a higher proportion of patients who smoked, and who had hypertension, recent myocardial infarction, or impairment in LV function (Table 1). According to our previous data which was processed with the Society of the Thoracic Surgery computer program, the expected mortality for the MI group was 23.98%, whereas that of the CS group was 12.51% ($p = 0.001$). The actual observed mortality rate for the MI group was 20% (2/10, 2 patients sent to the operating room under cardiac massage who died), which was similar to that of the CS group (24.5%, $p = 0.758$). Although the CS group had a higher rate of sternal wound infection and re-operation for cardiac tamponade, the morbidity of the MI group was similar to that of the CS group but without a statistically significant difference (12.5% vs. 22.5%, $p = 0.523$).

The major differences in our emergent minimally invasive coronary surgical techniques and those of emergent conventional or minimally invasive CABG surgery[10,11] are described here. The first difference was the avoidance of a median sternotomy. The first priority of an emergent CABG surgical procedure is the maintenance of adequate peripheral perfusion and preservation of as much cardiac function as possible. This can be accomplished by extracorporeal circulatory support with or without an intra-aortic balloon pump instead of a median sternotomy. For those patients with compromised hemodynamic condition, as our patients in this series, beating-heart direct-vision CABG surgery can not be performed without cardiopulmonary bypass support. With the operative method we present, access to the left anterior descending artery, diagonal branches, obtuse marginal branches, and posterior descending branch is easy while the heart is relaxed, decompressed, arrested, and protected. Because of the avoidance of a median sternotomy, devastating sternal wound infection and difficult sternal wound hemostasis after prolonged cardiopulmonary bypass were avoided, which significantly reduced the drainage amount during the first postoperative day and ameliorated the need, risk, and expense of blood transfusions. In this way, minimally invasive CABG surgery can be easily expanded to applications in surgical revascularization for the emergent patients.

The second difference was avoidance of a groin incision for cannulation of the femoral artery and vein in some selected patients. In minimally invasive cardiac surgery, a simple femorofemoral or femoro-atrial cardiopulmonary bypass established satisfactory perfusion of all vital organs, including the brain.[1,12-17] The possibility of vascular complications in the lower limbs, although slight, is always present. Aorto-atrial cardiopulmonary bypass is familiar to most cardiac surgeons. In our series, an aortopulmonary arterial-right atrial cardiopulmonary bypass was performed in 8 patients, indicating that this technique can be performed in minimally invasive cardiac surgery to avoid a groin incision and its possible complications.

The third difference was the establishment of cardioplegic arrest with cold blood cardioplegia.[1,16] With the growing enthusiasm of beating-heart coronary bypass grafting surgery, cardioplegic arrest is still the standard method of myocardial protection,[18-20] which gives a steady, motionless, and bloodless operative field, and is a very familiar method for most cardiac surgeons to ensure a patent anastomosis. A double-lumen aortic root cannula was easily inserted at the aortic root for delivery of a cardioplegic solution and for venting of the left ventricle.

The fourth difference was the use of the internal thoracic artery as the bypass graft in all patients of the MI group, which was significantly higher than that of the CS group (100% vs. 56%, $p=0.001$). The use of an arterial graft as the conduit to ensure a better long-term patency rate has been widely accepted for elective CABG patients. Because of the unstable hemodynamic condition of emergent surgical patients, the use of the internal thoracic artery as a conduit might not be performed in every case as in the CS group (56%). With the minimally invasive surgical techniques we present, every internal thoracic artery of MI group patients was exposed and was routinely used as a conduit because the left parasternal incision was just above the thoracic artery.

Emergent CABG surgery can be easily and safely accomplished with a minimally invasive technique as we present. Compared with conventional emergent CABG surgery, the minimally invasive technique has the same quality as the conventional method by using (1) a left parasternal minithoracotomy, (2) an aorto-pulmonary artery-right atrial or femorofemoral cardiopulmonary bypass, and (3) cold-blood cardioplegic arrest. The left internal thoracic artery was grafted to the left anterior descending artery in all patients with the minimally invasive technique, which was used more frequently than the conventional method ($p=0.001$). All patients in the MI group were satisfied with the cosmetic results of the limited thoracotomy incisions. The postoperative length of stay in the MI group (9.6 days) was similar to that of uncomplicated elective CABG performed through a median sternotomy (8.2 days) (1) and was shorter than that of CS group (10.2 days). Postoperative drainage and blood transfusions were reduced with the left parasternal incision, as were the costs and risks of blood transfusions. However, at the present time, the number in this series is too small for meaningful statistical analysis between these 2 groups.

Our experience demonstrates that emergent CABG surgery can be accomplished using a minimally invasive technique which we present here in, with the same safety, quality, and expense as the conventional method and with better cosmetic results.

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微創冠狀動脈繞道手術與傳統手術法施行於急症病患的安全性及效益比較

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背 景： 微創開心術已被廣泛的運用在許多接受常規冠狀動脈繞道手術的病患身上。為評估此種手術方法是否可以施行於緊急冠狀動脈繞道手術的病患，我們比較了使用傳統正中開胸術及微創開胸術下，緊急冠狀動脈繞道手術的結果。

方 法： 自1996年6月至1998年4月，63位病患因不穩定型心絞痛、冠狀動脈氣球擴張術併發症、或嚴重左主冠狀動脈狹窄接受緊急冠狀動脈繞道手術。10位病患接受經由左側胸骨旁切口的微創冠狀動脈繞道手術，其他53位病患則接受傳統正中胸骨切開術。

結 果： 在微創冠狀動脈繞道手術組中有2位病患死亡，在傳統正中胸骨開心術組中有13位病患死亡。我們使用美國胸腔學會的電腦程式，推算兩組病患的預估死亡率，發現微創冠狀動脈繞道手術組的病患預估死亡率較高。兩組病患手術結果的比較，發現在主動脈橫夾時間、體外循環時間、加護病房住院時間、及術後住院期間均無顯著差異。但在術後24小時胸管引流量上，微創冠狀動脈繞道手術明顯較少。在整體醫療費用上，兩者並無顯著差異。但微創冠狀動脈繞道手術所需的輸血費用明顯較低。

結 論： 使用微創冠狀動脈繞道手術並不會增加手術的風險及醫療費用，且可以達成傳統冠狀動脈繞道手術的安全及成果。此種術式可以同樣安全、有效的使用於緊急及高危險群的冠狀動脈繞道手術病患。
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關鍵字： 冠狀動脈繞道手術，微創開心術，效益。

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