Clinical Investigation

Off-Pump Coronary Artery Bypass Grafting and Transmyocardial Laser Revascularization

via a Left Thoracotomy

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Off-pump coronary artery bypass grafting may be combined with adjunctive transmyocardial laser revascularization to optimize revascularization. This approach may be advantageous for high-risk patients, particularly those having undergone previous sternotomies.

From October 2000 through May 2001, 17 patients (9 women and 8 men) underwent off-pump coronary artery bypass grafting and transmyocardial laser revascularization via a left thoracotomy. The patients had a mean age of 63 years and a mean ejection fraction of 0.33. All but 1 patient had undergone previous coronary surgery. In each patient, the heart was approached via a left thoracotomy through the 5th intercostal space, and 37 transmural channels, 1 mm in diameter, were each created with a single pulse of the carbon dioxide laser. Coronary artery bypass grafting was then performed with left internal thoracic artery or saphenous vein grafts. The follow-up period ranged from 2.1 to 9.3 months (mean, 6.2 months).

The patients received 28 bypass grafts (mean, 1.6 grafts). Postoperatively, 2 patients required inotropic support. On day 8, 1 patient died of ventricular fibrillation. After a mean hospitalization of 7.7 days, the remaining patients were discharged, free of angina. At follow-up examination after a mean of 6 months (range, 2–9 months), 15 patients remained free of angina and one had mild angina. None had required further hospitalization.

Performed via a left thoracotomy, off-pump coronary artery bypass grafting plus transmyocardial laser revascularization yielded an acceptable mortality rate, no major morbidity, and substantial angina relief in this carefully selected group of challenging, high-risk patients. ***(Tex Heart Inst J 2003;30:13-8)***

Key words: *Combined modality therapy; coronary artery bypass/methods; coronary disease/surgery; laser surgery/methods; myocardial revascularization/methods; thoracotomy/methods*

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During the past decade, off-pump coronary artery bypass grafting (OPCABG), performed via a minimally invasive approach, has become a valid treatment for patients with coronary artery disease. This approach allows coronary artery bypass grafting (CABG) to be done on the beating heart without the use of cardiopulmonary bypass. Because it avoids the potentially damaging effects of cardiopulmonary bypass, OPCABG is especially useful in patients who have multivessel stenosis in combination with advanced age, severe systemic disease, atherosclerosis of the ascending aorta, or substantial functional impairment of various organs.[1] In this high-risk group of patients, OPCABG is sometimes performed with adjunctive transmyocardial laser revascularization (TMLR), which creates transmyocardial channels to promote blood flow.[2,3] The combined procedure allows complete revascularization, not only of graftable diseased territories but also of areas that are not amenable to conventional grafting.[2]

Recently, surgeons in some centers have been performing OPCABG in combination with TMLR through a left thoracotomy.[2,3] This approach is particularly beneficial for patients who have undergone one or more previous sternotomies, because the left thoracotomy surgical field has fewer adhesions and better posterolateral myocardial exposure. Therefore, the need for prolonged surgical dissection is eliminated. Herein, we summarize our experience with OPCABG plus TMLR, performed via left thoracotomy, in 17 patients.

Patients and Methods

Patients. From October 2000 through May 2001, 17 patients (9 women and 8 men) underwent OPCABG in combination with TMLR via a left thoracotomy approach at our institution. The patients' ages ranged from 44 to 85 years (mean, 63 years). Table I presents the preoperative risk factors, and Table II shows the predicted morbidity and mortality rates, calculated by use of the Cleveland Clinic scoring system for evaluating clinical severity.[4] The decision to perform OPCABG in combination with TMLR was made on the basis of coronary angiography results. The TMLR target areas were chosen preoperatively on the basis of myocardial viability tests and coronary angiography. The study was approved by our hospital's institutional review board. Before surgery, the risks were fully explained, and informed consent was obtained from each patient.

Surgical Technique. During the operation, all patients were monitored with a direct arterial line. General anesthesia was induced, and a double-lumen endotracheal tube was inserted to deflate the left lung. A transesophageal echocardiography transducer was used to evaluate the function of the left ventricle and the cardiac valves. The patient was positioned for a left posterolateral thoracotomy, and the chest was entered through the 5th intercostal space. The inferior pulmonary ligament was then divided. The lung was dissected free of the pericardium and was retracted posteriorly and cephalad. The pericardium was opened posterior and parallel to the left phrenic nerve, and adhesions (if present) were lysed. Then the left internal thoracic artery was harvested, or the greater saphenous vein was harvested from the right leg; in some cases, both were harvested.

Next, TMLR was performed in the target areas of the left ventricle. In every patient, 37 transmural channels, each measuring 1 mm in diameter, were made individually with a single pulse of the carbon dioxide laser (peak power, 850 W). Approximately 1 channel per square centimeter of myocardial surface was created.[5] Transmural penetration by the laser was confirmed with use of transesophageal echocardiography. Bleeding from the channels was stopped by external pressure; occasionally, an epicardial suture was necessary. The minimal energy required for transmural penetration was used.

Silk sutures were placed in the cut edge of the pericardium next to the chest wall and posteriorly, close to the pulmonary veins, to provide a firm surface and to keep the operative field immobilized. If necessary, a β-blocking agent was infused intravenously to reduce the force and rate of cardiac contraction. Sys-

TABLE II. Predicted Risk, Morbidity, and Mortality* (Cleveland Clinic's Clinical Severity Scoring System[4])

Patient Number	Risk Score	Predicted Morbidity (%)	Predicted Mortality (%)
1	7	40	10.0
2	6	30	5.0
3	10	45	10.0
4	10	45	20.0
5	11	45	20.0
6	6	30	5.0
7	11	45	20.0
8	4	15	2.5
9	10	45	20.0
10	10	45	20.0
11	8	40	10.0
12	10	45	20.0
13	10	45	20.0
14	6	30	5.0
15	11	45	20.0
16	7	40	10.0
17	9	40	10.0

*The average (± SD) Cleveland Clinic risk stratification score was 8.6% ± 1.0%; average predicted morbidity rate, 39% ± 1.6%; and average predicted mortality rate, 13% ± 1.6%.

TABLE I. Preoperative Risk Factors in 17 Patients

Variable	No. of Patients (%)
Age >70 years	6 (35)
Hypertension	16 (94)
Diabetes mellitus	12 (71)
Cigarette smoking	10 (59)
Previous MI	12 (71)
Previous CABG	16 (94)
Triple-vessel disease	6 (35.3)
Quadruple-vessel disease	3 (17.6)
LVEF <0.35	12 (71)
CCS class 4 status	13 (76)

CABG = coronary artery bypass grafting; CCS = Canadian Cardiovascular Society angina score; LVEF = left ventricular ejection fraction; MI = myocardial infarction

temic heparin was then administered (2 mg · kg^{-1} · L^{-1}). A coronary stabilizer (Octopus®, Medtronic, Inc.; Minneapolis, Minn) was positioned, and coronary occlusion was achieved by snaring the target vessel proximally with a 5-0 polypropylene suture. After 3 minutes of ischemic preconditioning, the vessel was opened. An appropriate-sized intracoronary shunt or occluder was inserted if necessary. The distal anastomosis was created with a running 6-0 polypropylene suture, with the aid of a carbon dioxide blower/aerosolizer for better visibility. The graft was anastomosed proximally to the descending thoracic aorta, which had been partially occluded with a clamp. At the end of the procedure, the effects of heparin were reversed with protamine, hemostasis was achieved, and the chest was closed in the routine manner.

Postoperatively, the duration of follow-up ranged from 2.1 to 9.3 months (mean, 6.2 months). In analyzing the results, we focused on mortality, morbidity, use of transfusions, use of inotropic agents, duration of intensive care, length of hospital stay, postoperative Canadian Cardiovascular Society (CCS) angina classification, and the need for repeat hospitalization.

Results

The 17 patients received a total of 28 coronary artery bypass grafts (mean, 1.6; range, 1–3 grafts). Four patients received a left internal thoracic artery graft, which was anastomosed to the left anterior descending artery; 2 of these patients also received a saphenous vein graft to the obtuse marginal artery. The other 13 patients underwent a total of 22 saphenous vein graft bypasses to the obtuse marginal artery (Fig. 1), diagonal artery, right coronary artery, or posterior descending branch of the right coronary artery.

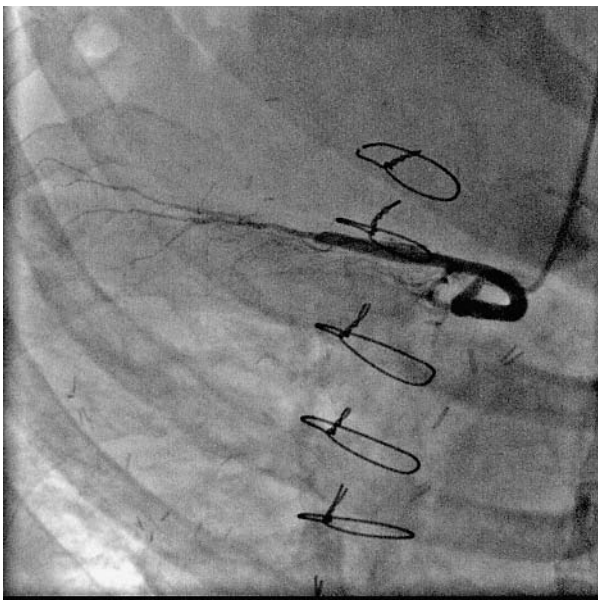


Fig. 1 *Angiogram of a saphenous vein bypass graft from the descending thoracic aorta to the obtuse marginal artery.*

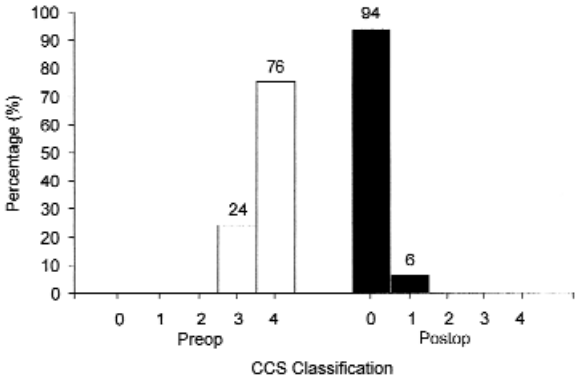


Fig. 2 *Preoperative and 6-month postoperative Canadian Cardiovascular Society (CCS) angina scores.*

Five patients required intraoperative or postoperative blood transfusion. Postoperatively, no reexploration for bleeding was necessary. Inotropic support was needed in 2 patients. On postoperative day 8, 1 patient died of intractable ventricular fibrillation. For the group as a whole, the mean duration of intensive care was 2.3 days (range, 2–4 days), and the mean hospital stay was 7.7 days (range, 6–10 days).

Of the 16 survivors, none had angina at the time of discharge from the hospital. Upon follow-up examination a mean of 6 months after surgery (range, 2–9 months), 15 patients remained free of angina (CCS class 0), and 1 patient had mild angina (CCS class 1). No patient required repeat hospitalization. Figure 2 presents a comparison of the preoperative and postoperative CCS angina scores.

Discussion

OPCABG and Left Thoracotomy. Introduced by Kolesov in 1964,[1] OPCABG has been performed since the beginning of coronary revascularization; however, until the past decade, it had been largely abandoned in favor of cardiopulmonary bypass and cardioplegic techniques. With the advent of minimally invasive coronary surgery and mechanical methods for target-artery stabilization, interest in OPCABG was revived, particularly by Benetti[6] and Buffolo[7] and their associates. The technique's advantages include simplicity, avoidance of the inflammatory response caused by cardiopulmonary bypass, and a decreased need for blood transfusion.

Over the years, surgeons have found that the left thoracotomy approach is advantageous in selected patients who have undergone a previous sternotomy, because it avoids the increased risk that a reoperative

sternotomy would pose for such patients. A left thoracotomy is also suitable for patients with poor skin and soft-tissue coverage of the sternum (for example, those who have previously had mediastinitis, sternal wound complications, mediastinal irradiation, or a radical mastectomy). Moreover, because it avoids cross-clamping of the aorta and lifting of the heart, a left thoracotomy is useful for cardiac operations that involve a calcified ascending aorta[8,9] or aortic root replacement. The left thoracotomy approach is also compatible with cardiopulmonary bypass, fibrillatory arrest, moderate hypothermia, femoral or descending thoracic aortic cannulation, and proximal anastomoses made in the descending thoracic aorta or subclavian artery.[8-19] Partial cardiopulmonary bypass allows surgical correction in patients whose condition is unstable.

Moshkovitz and associates, in 1994, were among the first to report the use of OPCABG through a left thoracotomy.[20] In 2000, D'Ancona and coworkers[21] related their experience with reoperative OPCABG through a left posterior thoracotomy in 67 patients who received an average of 1.3 grafts each. Those patients had a 95.5% early freedom from major complications. Perioperative acute myocardial infarction occurred in 2 patients. The actual mortality rate was 4.5% (3 of 67 patients), and the calculated risk-adjusted mortality rate was 2.1%.[21]

Vassiliades and Nielsen[22] used the following approaches in 55 patients undergoing OPCABG procedures: 25 full sternotomies, 21 left posterolateral thoracotomies, 5 lower hemisternotomies, and 4 mini-anterior thoracotomies with thoracoscopic harvesting of the internal thoracic artery. No patient died or had a myocardial infarction within 30 days of the procedure. Sternotomy patients received an average of 2.7 grafts; thoracotomy patients received an average of 1.4 grafts.[22]

Byrne's group[19] used a left thoracotomy in 50 consecutive patients who underwent repeat coronary artery bypass with 1) conventional cardiopulmonary bypass and fibrillatory or circulatory arrest (33 patients), 2) port-access occlusion (Heartport; Redwood City, Calif) with an endoaortic balloon (4 patients), or 3) off-pump beating-heart techniques (13 patients). The 3rd technique (OPCABG) was used in most of Byrne's more recent patients. There were 3 operative deaths (6%): 2 in the conventional group and 1 in the balloon occlusion group; none occurred in the OPCABG group. The median hospital stay was 7 days.[19]

TMLR and CABG. Transmyocardial laser revascularization was introduced in 1981 by Mirhoseini and Cayton,[23] who used a laser to create transmyocardial channels in animals. Five years later, Okada and colleagues[24] performed the same procedure in human beings. Since then, TMLR—either alone or in conjunction with CABG—has been widely used for treating ischemic myocardium.

Randomized, longitudinal, multicenter clinical trials have shown that TMLR, as sole therapy, improves cardiac perfusion and significantly alleviates angina that has been refractory to conventional medical therapy or revascularization.[5] Vincent and coworkers,[25] in one of the largest single-institution series to-date, studied the use of TMLR with and without CABG. They described their experience with 268 patients: 140 underwent TMLR alone, and 128 underwent TMLR plus CABG. The hospital survival rate was 90.3% in the TMLR-only group and 88.2% in the TMLR plus CABG group (overall, 89.2%). At the 12-month follow-up, more than 40% of the TMLR-only patients and more than 80% of the TMLR plus CABG patients were in CCS class 0 or 1. Vincent's group concluded that TMLR reduced pain, increased activity levels, and improved quality of life beyond expectation in these "inoperable" patients.[25]

TMLR and OPCABG. Trehan and colleagues[2] performed TMLR with OPCABG in 56 patients: 51 through a midline sternotomy and 5 through a left anterior thoracotomy. These patients received an average of 1.09 grafts apiece and had a hospital mortality rate of 1.8%. The mean follow-up period was 9.2 months. Myocardial scanning studies showed a stepwise improvement in reversible ischemia, and 91% of the patients were still free of angina at 12 months. Metabolic stress testing showed an average increase in exercise tolerance and metabolic equivalents.[2]

At our hospital, we previously performed TMLR in conjunction with CABG in 21 patients in a randomized, controlled setting as part of a multicenter U.S. trial.[26] Of these 21 patients,* 10 were enrolled in the control arm (CABG only), and the other 11 were enrolled in the combined therapy arm of the study (CABG plus TMLR). During the perioperative period, there was a significant difference between the number of patients in the control group who required mechanical circulatory support (5 required intraaortic balloon pumping and 3 received left ventricular assist devices) versus the number in the combined therapy group (2 required intraaortic balloon pumping; $P < 0.01$). The difference in the number of patients who went into cardiogenic shock (4 in the control group versus 0 in the combined therapy group) was also significant ($P < 0.01$), as was the difference in the number of patients who died (4 in the control group versus 0 in the combined therapy group; $P < 0.01$). The overall results of this trial,[26] which involved a total of 49

* Unpublished observations in patients enrolled from December 1996 through June 1998.

patients from 5 participating centers (including our center and the 21 patients mentioned above), paralleled our single-center experience. The perioperative death rate was 9 of 27 (33%) in the control group versus 2 of 22 (9%) in the combined therapy group (P <0.09).[26] The overall success rate (where failure was defined as perioperative or late death, repeat revascularization, or lack of angina relief) was 13 of 27 (48%) in the control group versus 16 of 22 (73%) in the combination therapy group (P <0.069).*

A 2nd U.S. multicenter, randomized trial[27] was conducted in 263 patients at 24 centers with use of the Ho:YAG laser under the same experimental conditions as those of the 1st trial. This study yielded dramatic differences in mortality rates: 2 of 132 patients (1.5%) undergoing combined therapy died, versus 10 of 131 undergoing CABG alone (7.6%) (P = 0.02).[27] These results suggest that TMLR may be beneficial as an adjunct to CABG in the management of patients who are classified as high risk because of multivessel disease, compromised left ventricular systolic function, intrathoracic adhesions from multiple previous sternotomies, unstable angina at presentation, or other preexisting conditions.

From a purely scientific viewpoint, it may be hard to isolate the effects of TMLR alone (especially the long-term effects) in a combined setting. However, the randomized, controlled design of 2 of these studies[26,27] does permit a cause-and-effect relationship to be drawn between adjunctive use of the laser and, at least, the immediate perioperative outcome as related to the incidence of cardiogenic shock, the need for mechanical circulatory support, and death. Whether the laser allows more complete revascularization in this population with distal diffuse atherosclerotic involvement and jeopardized distal runoff remains to be seen in longer-term follow-up studies.

In the present series, OPCABG in combination with TMLR was performed through a left thoracotomy. Our patients were at high risk: 16 (94%) had undergone at least 1 previous conventional coronary bypass operation, 12 had experienced a previous myocardial infarction, and 6 were older than 70 years. Moreover, the mean ejection fraction in this group of patients was 0.33 (Table I). The average Cleveland Clinic risk stratification score was 8.6% ± 1.0%, with average predicted morbidity and mortality rates of 39% ± 1.6% and 13% ± 1.6%, respectively. The left thoracotomy approach is advantageous because it avoids previous operative sternal adhesions. Harvesting of the left internal thoracic artery, when available, can be performed without difficulty. In addition, the left thoracotomy easily permits TMLR and provides access to the coronary branches of the left posterolateral wall.

In our patients, the use of OPCABG in combination with TMLR resulted in improved angina status, no major complications, and only a single death. Preliminary results indicate that this combined operation, performed via a left thoracotomy, can be a valuable surgical option in a highly selected group of patients who must undergo high-risk, complete myocardial revascularization.

* Unpublished observations in patients enrolled from December 1996 through June 1998.

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