Journal of the American College of Cardiology
© 1999 by the American College of Cardiology
Published by Elsevier Science Inc.

Vol. 33, No. 4, 1999
ISSN 0735-1097/99/$20.00
PII S0735-1097(98)00676-7

Perioperative Morbidity and Mortality After Transmyocardial Laser Revascularization: Incidence and Risk Factors for Adverse Events

G. Chad Hughes, MD,* Kevin P. Landolfo, MD,* James E. Lowe, MD, FACC,* Robin B. Coleman, RN,* Carolyn L. Donovan, MD, FACC†
Durham, North Carolina

OBJECTIVES The purpose of this study was to describe the incidence and spectrum of perioperative cardiac and noncardiac morbidity and mortality after transmyocardial laser revascularization (TMR) and to identify predictors of these adverse clinical events.

BACKGROUND Clinical studies have demonstrated the efficacy of TMR for relieving angina pectoris, although no study to date has specifically addressed the associated perioperative morbidity and mortality.

METHODS Between October 1995 and August 1997, 34 consecutive patients with end-stage coronary artery disease (CAD) underwent isolated TMR. The majority of patients (94%) had class III or IV angina pectoris, and two patients (6%) had unstable symptoms preoperatively. Patient records were reviewed for fatal and nonfatal adverse cardiac and noncardiac events.

RESULTS Perioperative death occurred in two patients (5.9%) due to cardiogenic shock complicating acute myocardial infarction. Perioperative cardiac morbidity occurred in 16 patients (47.1%); noncardiac morbidity was seen in 12 patients (35.3%). Preoperative unstable angina was the only variable predictive of perioperative death ($p = 0.005$). Cardiac ($p = 0.005$) and noncardiac ($p < 0.001$) morbidity rates were significantly higher for the initial 15 patients undergoing the procedure. Other predictors of perioperative complications included lack of postoperative treatment with a furosemide infusion ($p \leq 0.04$) and preoperative unstable angina ($p = 0.05$).

CONCLUSIONS Perioperative mortality in patients undergoing isolated TMR is low. Transmyocardial laser revascularization patients are at higher risk for adverse perioperative cardiac and noncardiac events, likely reflecting the lack of immediate benefit from the procedure in the setting of severe CAD. These patients merit vigilant surveillance for adverse events and aggressive medical management in the perioperative period. (J Am Coll Cardiol 1999;33:1021–6) © 1999 by the American College of Cardiology

Transmyocardial laser revascularization (TMR) is an emerging technique for the treatment of end-stage coronary artery disease (CAD) not amenable to either percutaneous angioplasty or bypass surgery. Beginning with the initial published results of Frazier et al. (1), multiple studies (2–5) have demonstrated improvements in anginal class after the procedure. Improved perfusion by positron emission tomography (1,2) and single-photon emission computed tomography (3,4), as well as a reduction in ischemic wall motion abnormalities by dobutamine stress echocardiography (6) have been reported as well. However, unlike traditional surgical revascularization, in the majority of patients these clinical improvements have not been observed until at least 3 months postoperatively (1,3,4), making these patients susceptible to perioperative ischemic complications. Despite this, no study to date has specifically addressed the incidence of perioperative mortality as well as cardiac and noncardiac morbidity in this high risk patient population. The purpose of the present study was twofold: to characterize the incidence and spectrum of perioperative cardiac and noncardiac morbidity and mortality after TMR and to identify the predictors of these clinical events.

METHODS

Transmyocardial laser revascularization. Between October 1995 and August 1997, 34 patients at Duke University Medical Center underwent isolated TMR for the treatment of severe, diffuse CAD not amenable to either coronary artery bypass grafting (CABG) or angioplasty. Transmyocardial laser

From the *Division of Cardiovascular and Thoracic Surgery and †Division of Cardiology, Duke University Medical Center, Durham, North Carolina. Presented in part at the American College of Cardiology 47th Annual Scientific Session, March 29–April 1, 1998, Atlanta, Georgia.

Manuscript received August 12, 1998; revised manuscript received October 23, 1998, accepted December 15, 1998.

Abbreviations and Acronyms

ANOVA = analysis of variance
CABG = coronary artery bypass grafting
CAD = coronary artery disease
IABP = intraaortic balloon pump
MI = myocardial infarction
MUGA = multiple gated acquisition radionuclide ventriculography
TEE = transesophageal echocardiography
TMR = transmyocardial laser revascularization

revascularization was performed through a left anterolateral thoracotomy without cardiopulmonary bypass using an 800-W CO_2 laser (The Heart Laser, PLC Medical Systems, Inc., Milford, Massachusetts). Transmural penetration of laser pulses was confirmed by intraoperative transesophageal echocardiography (TEE). The mean number of transmural laser channels confirmed by TEE was 22 ± 10 per patient, with a range of 10 to 45. Transmyocardial laser revascularization was performed in myocardial regions determined to be ischemic by preoperative thallium scintigraphy. Preoperative ejection fraction was determined in all patients by resting multiple gated acquisition radionuclide ventriculography (MUGA). All patients had cardiac catheterization preoperatively within six months of surgery to assess their native coronary anatomy and bypass graft disease status and to exclude them as candidates for conventional revascularization.

Postoperative medical management consisted of an aspirin (325 mg) the evening of surgery, intravenous nitroglycerin and beta-blockade, as well as immediate resumption of all preoperative cardiac medications. In addition, after the initial 11 patients, all patients received a prophylactic furosemide infusion (5 mg/h intravenous titrated to clinical response, hemodynamics and fluid balance). Patients otherwise received routine postoperative care. Inotropic and intraaortic balloon pump (IABP) support were initiated when necessary for hemodynamic compromise.

Clinical outcomes. The medical records of all 34 patients were reviewed for all fatal and nonfatal adverse perioperative events. All patients were followed by a single cardiologist (C.L.D.) during their entire hospitalization to ensure consistent reporting of clinical events. Perioperative morbidity and mortality were defined as any fatal and nonfatal adverse events occurring during or after operation within 30 days if the patient was discharged or within any interval if the patient was not discharged (7). Specific cardiac events included: angina pectoris, acute myocardial infarction, congestive heart failure, pleural effusion requiring drainage, cardiac arrhythmia requiring treatment and hemodynamic instability or severe ischemia requiring IABP therapy. Noncardiac morbidity included: renal failure (defined as a twofold rise in creatinine over baseline), cerebral vascular accident, pneumonia, sepsis (defined by positive blood cultures) and anemia requiring blood transfusion.

Table 1. Patient Demographics

Patients	34 (13 female)
Mean age (yr)	59.6 ± 9.4
Preoperative class III–IV angina	32 (94%)
Preoperative unstable angina	2 (6%)
Preoperative ejection fraction	51 ± 9%
Diabetes mellitus	24 (71%)
Prior remote MI	26 (76%)
Prior CABG	31 (91%)
Prior redo-CABG	16 (47%)
Hypertension	32 (94%)
Recent smoking (<30 days preoperatively)	6 (18%)
Family history of CAD	21 (62%)
Hyperlipidemia	32 (94%)

CABG = coronary artery bypass grafting; CAD = coronary artery disease; MI = myocardial infarction.

Statistical analysis. Data were entered into a Dell Latitude LM personal computer (Dell Computer Corporation, Austin, Texas) and analyzed using STATISTICA for windows version 5.1 (StatSoft, Inc., Tulsa, Oklahoma). All data are presented as the mean ± SD. One-way analysis of variance (ANOVA) was used to analyze variables associated with fatal as well as nonfatal cardiac and noncardiac events (8). When overall significance was found within the ANOVA, Tukey's honest significant difference test was used to delineate which comparisons were significantly different (8). Statistical significance was considered a p value of <0.05.

The study was approved by the institutional review board of Duke University Medical Center. All subjects gave informed consent before enrollment. All procedures followed were in accordance with institutional guidelines.

RESULTS

Demographics. Patient demographics are presented in Table 1. The study population consisted of 34 patients (13 female) with a mean age of 59.6 ± 9.4 years (range 43 to 75). Thirty-two of the 34 patients had class III or IV angina pectoris; two patients had unstable angina preoperatively requiring intravenous nitrate and heparin therapy. Mean preoperative left ventricular ejection fraction by resting MUGA was 51 ± 9% (range 35 to 71). The range of cardiac medications taken preoperatively is presented in Table 2.

Follow-up results. Mean postoperative length of stay was 9.6 ± 16.4 days; mean intensive care unit stay was 1.9 ± 2.1 days. Mean duration of mechanical ventilation was 0.4 ± 0.3 days. Swan–Ganz catheter use averaged 1.2 ± 1.7 days. Nine patients (27%) required postoperative inotropic support.

Perioperative mortality. Perioperative death occurred in 2 patients (5.9%). Both deaths resulted from complications of perioperative myocardial infarction (MI). The first patient died of progressive cardiogenic shock on postoperative day 8. Autopsy revealed recent (within one week) infarction of

Table 2. Preoperative Cardiac Medications

Medication	Number of Patients Taking (%)
Aspirin	34 (100%)
Beta-blockers	31 (91%)
Nitrates	33 (97%)
Calcium channel blockers	30 (88%)
Diuretics	19 (56%)
ACE inhibitors	23 (68%)
Antilipid drugs	31 (91%)

ACE = angiotensin-converting enzyme.

the anterolateral papillary muscle in addition to a right ventricular infarction. The second patient suffered a perioperative MI and required IABP placement on the day of surgery. His postoperative course was complicated by progressive hemodynamic deterioration due to ongoing ischemia. The patient died on postoperative day 51. No autopsy was performed.

Perioperative cardiac morbidity. Perioperative cardiac morbidity is outlined in Table 3. Overall, perioperative cardiac events including angina pectoris, acute MI, congestive heart failure, pleural effusion requiring drainage, cardiac arrhythmia requiring treatment or need for IABP occurred in 16 of the 34 patients (47.1%). Although all patients were treated with intravenous nitroglycerin for at least the first 24 h postoperatively, 12 of 34 patients (35%) complained of angina pectoris, and three of 34 (9%) sustained acute myocardial infarction defined by new regional wall motion abnormalities by two-dimensional echocardiography in conjunction with ST changes consistent with myocardial injury. Of the six patients with postoperative arrhythmia, there were two episodes of atrial fibrillation, one episode of junctional rhythm, two episodes of ventricular tachycardia successfully treated with DC cardioversion and one terminal episode of ventricular fibrillation. Of the two episodes of ventricular tachycardia, one occurred intraoperatively and was secondary to inadequate grounding of the electrocautery device, and the second occurred on postoperative day 7 in a patient suspected to have acute MI. Nearly one third of patients had perioperative congestive heart failure (defined by pulmonary congestion on chest X ray in the presence of arterial hypoxemia) requiring an intensification of their medical management. Both patients requiring postoperative IABP sustained perioperative MI.

Table 3. Perioperative Cardiac Morbidity

Angina pectoris	12 patients (35%)
Acute MI	3 patients (9%)
CHF	10 patients (29%)
Effusion	2 patients (6%)
Arrhythmia	6 patients (18%)
IABP	2 patients (6%)

CHF = congestive heart failure; IABP = intraaortic balloon pump; MI = myocardial infarction.

Table 4. Perioperative Noncardiac Morbidity

Renal failure	4 patients (12%)
CVA	1 patient (3%)
Pneumonia	4 patients (12%)
Sepsis	2 patients (6%)
Transfusion	8 patients (24%)

CVA = cerebrovascular accident.

Perioperative noncardiac morbidity. Perioperative noncardiac morbidity is outlined in Table 4. Noncardiac complications were seen in 12 patients (35.3%). Four patients had a twofold or greater rise in their creatinine postoperatively, although no patient required dialysis. One patient suffered a mild postoperative ischemic stroke with associated facial droop and unilateral extremity weakness, which was attributed to an embolic event in the setting of new onset atrial fibrillation. The patient's neurologic symptoms were almost completely resolved at the time of her discharge on postoperative day 14. Four patients developed postoperative pneumonia requiring antibiotic therapy. Two patients had sepsis with positive blood cultures postoperatively. The first patient had methicillin-resistant staphylococcal sepsis complicating postoperative pneumonia; the second patient had enterococcal sepsis also from a pulmonary source.

Risk factor analysis. One-way ANOVA and Tukey's honest significant difference test (8) were used to analyze risk factors for death and cardiac and noncardiac morbidity. Of the variables analyzed (Table 5), only preoperative unstable angina was predictive of perioperative death (Fig. 1). Early experience with TMR (defined as the initial 15 patients undergoing the procedure) (Fig. 2) and lack of immediate postoperative therapy with a furosemide infusion (Fig. 3) predicted perioperative cardiac and noncardiac morbidity (Table 6). Preoperative unstable angina was also a risk factor for adverse noncardiac events (Table 6).

DISCUSSION

Transmyocardial laser revascularization is an emerging technique for the treatment of end-stage coronary artery disease. When the technique was first described for use in humans (9), the mechanism of action was hypothesized to be direct myocardial perfusion with left ventricular blood via the laser channels. However, histologic studies in both humans (10–12) and animal models (13) have failed to demonstrate long-term channel patency. Subsequent basic scientific studies (14–18) have cast doubt on this hypothesis as well, with direct myocardial perfusion via TMR channels yet to be demonstrated. Clinical studies of TMR (1,3,4) have shown a delay in the clinical benefits of the procedure, with improvements in anginal class often not evident until at least 3 months postoperatively. Consequently, unlike CABG,

Table 5. One-Way Analysis of Variance of Potential Risk Factors for Perioperative Death After Transmyocardial Laser Revascularization

Variable	Patients Dying (Mean Value)	Patients Surviving (Mean Value)
Age (yr)	64.5	60.5
Female	0%	43.8%
Diabetes	50.0%	71.9%
EF <40	0%	12.5%
Unstable angina	50.0%*	3.1%
Recent smoking	0%	18.8%
Prior MI	100%	75.0%
Prior CABG	100%	90.6%
Prior redo-CABG	50%	46.9%
# grafts patent	1.0	1.8
Pre-op beta-blocker	100%	90.6%
Pre-op calcium channel blocker	100%	87.5%
Pre-op diuretic	0%	59.4%
Pre-op ACE inhibitor	50.0%	68.8%
Post-op furosemide infusion	100%	65.6%
First 15 patients	50.0%	43.8%

*$p = 0.005$.
ACE = angiotensin-converting enzyme; CABG = coronary artery bypass grafting; EF = ejection fraction; MI = myocardial infarction; op = operative.

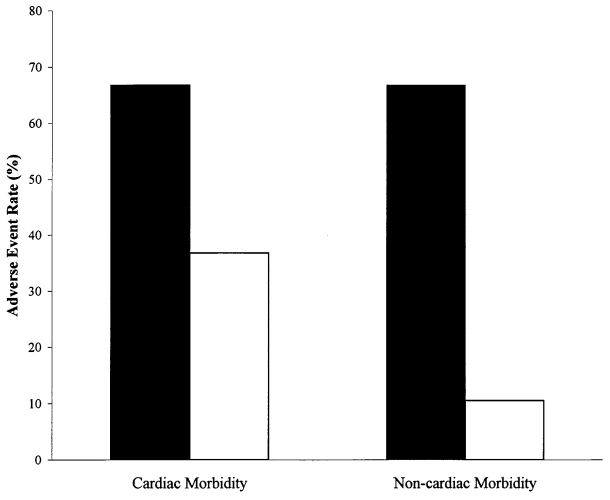

Figure 2. Graph of perioperative adverse cardiac and noncardiac event rates in the first 15 **(solid bars)** versus the final 19 **(open bars)** patients undergoing transmyocardial laser revascularization at our institution. Patients among the initial 15 treated had significantly higher rates of both cardiac ($p = 0.005$) and noncardiac ($p < 0.001$) morbidity.

which provides an immediate increase in myocardial perfusion, patients undergoing TMR do not benefit immediately, yet are subjected to all of the associated perioperative stress. This situation places these patients at high risk for perioperative morbidity and mortality. Despite this, no study to date has specifically addressed the incidence, spectrum and risk factors for perioperative mortality as well as cardiac and noncardiac morbidity after isolated TMR.

Perioperative mortality. This study demonstrates that perioperative mortality after transmyocardial laser revascularization is low. The perioperative mortality rate of 5.9% seen in this study compares favorably with those of other TMR patient series, which have reported mortality rates ranging from 0% (5) to 20% (3), with the largest published

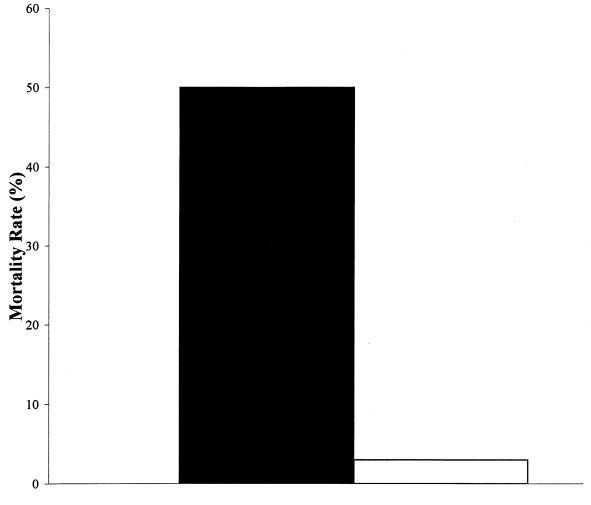

Figure 1. Graph of perioperative mortality rates in patients with and without unstable angina preoperatively. The rate in patients with unstable angina was 50% versus 3% in those without unstable angina. Using one-way analysis of variance, unstable angina was the only variable of those studied that was associated with an increased risk of perioperative mortality ($p = 0.005$). **Solid bar** = unstable angina; **open bar** = stable angina.

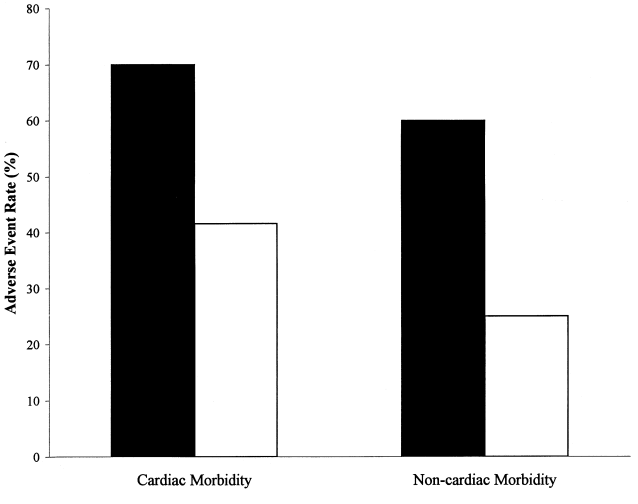

Figure 3. Graph of perioperative adverse cardiac and noncardiac event rates in patients receiving **(open bars)** and not receiving **(solid bars)** a furosemide infusion beginning in the immediate postoperative period. Patients not receiving a furosemide infusion had significantly higher rates of both cardiac ($p = 0.04$) and noncardiac ($p = 0.02$) morbidity.

Table 6. One-Way Analysis of Variance of Potential Risk Factors for Perioperative Cardiac and Noncardiac Morbidity After Transmyocardial Laser Revascularization

Variable	Patients With Cardiac Morbidity (Mean Value)	Patients Without Cardiac Morbidity (Mean Value)	Patients With Noncardiac Morbidity (Mean Value)	Patients Without Noncardiac Morbidity (Mean Value)
Age (yr)	62.3	59.3	62.3	59.9
Female	31.3%	50.0%	41.7%	40.9%
Diabetes	81.3%	61.1%	66.7%	72.7%
EF <40	6.3%	16.7%	0%	18.2%
Unstable angina	12.5%	0%	16.7%*	0%
Recent smoking	18.8%	16.7%	25.0%	13.6%
Prior MI	68.8%	83.3%	91.7%	68.2%
Prior CABG	87.5%	94.4%	91.7%	90.9%
Prior redo-CABG	37.5%	55.6%	41.7%	50.0%
# grafts patent	1.8	1.8	1.6	1.9
Pre-op beta-blocker	87.5%	94.4%	83.3%	95.5%
Pre-op calcium channel blocker	93.8%	83.3%	100%	81.8%
Pre-op diuretic	62.5%	50.0%	50.0%	59.1%
Pre-op ACE inhibitor	81.3%	55.6%	58.3%	72.7%
Post-op furosemide infusion	50.0%†	83.3%	41.7%‡	81.8%
First 15 patients	68.8%§	22.2%	91.7%‖	18.2%

*p = 0.05. †p = 0.04. ‡p = 0.02. §p = 0.005. ‖p < 0.001. Abbreviations as in Table 5.

series to date quoting a perioperative mortality of 9% (4). Both deaths in the present study were secondary to cardiogenic shock after perioperative MI, consistent with prior studies (2–4), which have found the majority of perioperative deaths to be cardiac in nature.

The only variable predictive of perioperative death in this study was the presence of unstable angina preoperatively. This finding is similar to that of Lowe et al. (19), who reported a total 6-month mortality of 6.5% in patients with end-stage coronary disease initially randomized to TMR versus a total mortality of 34.6% in patients with unstable angina crossing over to TMR from medical management. The authors of that multicenter prospective randomized trial of TMR versus medical management recommended TMR be offered to medically refractory patients with class III or IV angina but not unstable angina. Unstable angina represents an ischemic syndrome characterized by acute plaque rupture and thrombus formation with a high risk of subsequent myocardial infarction. Consequently, unstable angina is considered a contraindication to TMR because of the increased risk of MI and death.

Mortality for patients with a preoperative resting ejection fraction less than 40% was not increased in this study. Likewise, the mortality rate for patients receiving diuretics or angiotensin-converting enzyme inhibitors preoperatively was not significantly elevated either. This finding contrasts with those of Frazier et al. (1), who found an increased risk of adverse events in patients being treated for congestive heart failure preoperatively. However, only four of the 34 patients in our series had an ejection fraction less than 40%, and although there were no deaths in this group, the number of patients is too small to draw any meaningful conclusions. More recent studies of TMR have excluded patients with an ejection fraction less than 30% (5).

Perioperative morbidity. This study is the first to fully characterize the incidence and spectrum of perioperative morbidity and mortality after TMR. The incidence of cardiac (47.1%) and noncardiac (35.3%) morbidity observed in this study is consistent with other series in the literature (1–4,20), which have reported adverse perioperative events in approximately one third of patients. Our incidence of cardiac morbidity is slightly higher than other series, likely because we included symptomatic ischemia, including angina pectoris, as an adverse cardiac event. The incidence of perioperative angina pectoris in the present study was 35%, and accounted for the largest proportion of cardiac morbidity.

One-way ANOVA revealed a significantly increased incidence of adverse cardiac events among the first 15 patients undergoing TMR in our series. Cardiac morbidity was seen in two thirds of this group versus approximately one third of the final 19 patients. The major reason for the decrease in cardiac morbidity in the final 19 patients was a significant decrease in the incidence of congestive heart failure. Of the 10 patients with perioperative congestive failure requiring an intensification of medical therapy, 7 were among the first 15 patients to undergo TMR. These early complications led to more aggressive medical therapy in the immediate postoperative period, including the use of higher doses of intravenous nitroglycerin, an intravenous furosemide infusion and supplemental intravenous beta-adrenergic blocking agents to minimize ischemia. Our current postoperative medical regimen includes an aspirin the evening of surgery, intravenous nitroglycerin and beta-

blockers for at least the first 24 h postoperatively and immediate resumption of all preoperative cardiac medications. As noted, a prophylactic furosemide infusion is initiated in the immediate postoperative period and continued for at least 24 h. The rationale for the furosemide infusion is that we hypothesize that myocardial edema exists postoperatively after laser injury of the myocardium, leading to diastolic dysfunction and congestive heart failure. The present study found that patients not receiving a prophylactic furosemide infusion had an increased incidence of cardiac events. Because all of the patients not receiving a furosemide infusion were among the first 15 patients to undergo TMR, this likely contributed substantially to the higher incidence of cardiac morbidity in these patients.

The noncardiac morbidity rate was also significantly lower among the final 19 (11%) versus the initial 15 patients (67%), and among patients not receiving a prophylactic furosemide infusion postoperatively. Three fourths of the cases of both postoperative pneumonia and renal failure occurred in the initial group of 15 patients undergoing TMR. This increased incidence of both pneumonia and renal failure is potentially related to the higher rate of congestive heart failure seen in this group of patients as well. Patients with unstable angina preoperatively also had a higher incidence of noncardiac complications.

In summary, patients undergoing isolated TMR for treatment of end-stage coronary artery disease are at increased risk for perioperative cardiac and noncardiac morbidity as compared with conventional bypass surgery. However, as evidenced by the change in adverse event rates observed in our final 19 versus our initial 15 patients, an acceptable morbidity rate can be achieved through aggressive medical management in the early postoperative period. This should include aspirin, intravenous nitroglycerin, intravenous beta-blockade and a furosemide infusion, as well as early resumption of all preoperative cardiac medications. This study also demonstrated that the mortality rate of isolated TMR is low, although patients with unstable angina and significantly impaired myocardial function should not be considered candidates for the procedure. Hopefully, by adopting the guidelines outlined, the risk of perioperative morbidity and mortality with isolated TMR can be minimized.

Reprint requests and correspondence: Dr. Carolyn L. Donovan, Box 3606, Duke University Medical Center, Durham, North Carolina 27710. E-mail: Donov001@mc.duke.edu.

REFERENCES

1. Frazier OH, Cooley DA, Kadipasaoglu KA, et al. Myocardial revascularization with laser. Preliminary findings. Circulation 1995;92 Suppl II:II-58–65.
2. Cooley DA, Frazier OH, Kadipasaoglu KA, et al. Transmyocardial laser revascularization: clinical experience with twelve-month follow-up. J Thorac Cardiovasc Surg 1996;111:791–9.
3. Horvath KA, Mannting F, Cummings N, et al. Transmyocardial laser revascularization: operative techniques and clinical results at two years. J Thorac Cardiovasc Surg 1996;111: 1047–53.
4. Horvath KA, Cohn LH, Cooley DA, et al. Transmyocardial laser revascularization: results of a multicenter trial with transmyocardial laser revascularization used as sole therapy for end-stage coronary artery disease. J Thorac Cardiovasc Surg 1997;113:645–54.
5. Milano A, Pratali S, Tartarini G, et al. Early results of transmyocardial revascularization with a holmium laser. Ann Thorac Surg 1998;65:700–4.
6. Donovan CL, Landolfo KP, Lowe JE, et al. Improvement in inducible ischemia during dobutamine stress echocardiography after transmyocardial laser revascularization in patients with refractory angina pectoris. J Am Coll Cardiol 1997;30: 607–12.
7. Edmunds LH Jr, Clark RE, Cohn LH, et al. Guidelines for reporting morbidity and mortality after cardiac valvular operations. Ann Thorac Surg 1988;46:257–9.
8. Godfrey K. Comparing the means of several groups. In: Bailar JC III, Mosteller F, editors. Medical Uses of Statistics. 2nd ed. Boston: NEJM Books, 1992:233–57.
9. Mirhoseini M, Fisher JC, Cayton M. Myocardial revascularization by laser: a clinical report. Lasers Surg Med 1983;3: 241–5.
10. Burkhoff D, Fisher PE, Apfelbaum M, et al. Histologic appearance of transmyocardial laser channels after 4 1/2 weeks. Ann Thorac Surg 1996;61:1532–4.
11. Krabatsch T, Schaper F, Leder C, et al. Histological findings after transmyocardial laser revascularization. J Card Surg 1996;11:326–31.
12. Gassler N, Wintzer HO, Stubbe HM, et al. Transmyocardial laser revascularization. Histological features in human nonresponder myocardium. Circulation 1997;95:371–5.
13. Hughes GC, Lowe JE, Kypson AP, et al. Neovascularization after transmyocardial laser revascularization in a model of chronic ischemia. Ann Thorac Surg 1998;66:2029–36.
14. Hardy RI, James FW, Millard RW, Kaplan S. Regional myocardial blood flow and cardiac mechanics in dog hearts with CO_2 laser-induced intramyocardial revascularization. Basic Res Cardiol 1990;85:179–97.
15. Landreneau R, Nawarawong W, Laughlin H, et al. Direct CO_2 laser "revascularization" of the myocardium. Lasers Surg Med 1991;11:35–42.
16. Whittaker P, Kloner RA, Przyklenk K. Laser-mediated transmural myocardial channels do not salvage acutely ischemic myocardium. J Am Coll Cardiol 1993;22:302–9.
17. Kohmoto T, Fisher PE, Gu A, et al. Does blood flow through homium:YAG transmyocardial laser channels? Ann Thorac Surg 1996;61:861–8.
18. Kohmoto T, Fisher PE, Gu A, et al. Physiology, histology, and 2-week morphology of acute transmyocardial channels made with a CO_2 laser. Ann Thorac Surg 1997;63:1275–83.
19. Lowe JE, Landolfo KP, Aranki S, et al. Transmyocardial laser revascularization (TMR) versus medical management in patients unamenable to conventional revascularization (abstr). Presented at the American College of Cardiology 46th Annual Scientific Session, March 16–19, 1997, Anaheim, California.
20. Smith JA, Dunning JJ, Parry AJ, Large SR, Wallwork J. Transmyocardial laser revascularization. J Card Surg 1995;10: 569–72.