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# Percutaneous Transluminal Myocardial Revascularization With a Holmium Laser System: Procedural Results and Early Clinical Outcome

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**Surgical transmyocardial laser revascularization has been reported to improve clinical outcome in patients with refractory angina who are not candidates for angioplasty or bypass surgery. We investigated the feasibility and safety of a nonsurgical, percutaneous technique for laser channel creation using energy from a holmium:yttrium-aluminium-garnet (YAG) laser. The laser energy was directed through a fiber enclosed in a catheter to the ventricular myocardium creating channels between the blood pool and the myocardium. Thirty-five patients with angina and coronary anatomy not amenable to revascularization with coronary angioplasty or bypass surgery underwent percutaneous transluminal myocardial revascularization. A total of 15 ± 5 channels were formed per patient. There was no procedure-related mortality. One patient developed cardiac tamponade requiring thoracotomy and another a minor self-limiting pericardial effusion. There was no worsening of regional wall motion function in any patient. All patients were discharged alive after a postprocedure hospital stay of 2.1 ± 1.4 days. Mean Canadian Cardiovascular Society (CCS) functional class declined from 3.68 ± 0.4 before procedure to 0.82 ± 0.7 at 30 days ($P < 0.01$). At 3 months, mean angina class was 0.94 ± 0.65 ($n = 35$; $P < 0.01$) and at 6 months, mean angina class was 1.08 ± 0.58 ($n = 26$; $P < 0.01$). One patient required repeat revascularization after 5 months for progression of disease in a degenerated saphenous venous graft supplying different region of myocardium. We conclude that transmyocardial revascularization using holmium:YAG laser by percutaneous technique can be carried out safely with encouraging early results and a very low complication rate. The symptomatic relief seen up to 6 months has been excellent. The long-term effects of this technique on mortality and relief of angina, however, remain to be defined. *Cathet. Cardiovasc. Intervent. 47:287–291, 1999.*** 

**Key words: transmyocardial revascularization; laser myocardial revascularization; percutaneous myocardial revascularization**

## INTRODUCTION

Transmyocardial revascularization (TMR) is a therapeutic strategy designed to enhance myocardial perfusion by creating channels directly into the ischemic myocardium. This procedure is done by using laser energy source to make such channels. This alternative approach to revascularization has been studied [1–5]. Clinical studies have reported angina relief and improved perfusion in many of these patients making this technique potentially promising [6–8]. The mechanism of improvement is not entirely clear but may be a combination of inducement of vessel growth (angiogenesis), direct perfusion, or denervation [9–13]. The surgical approach to TMR, however, has been limited by a high perioperative mortality [6–8]. The adaptation of the holmium:yttrium-aluminium-garnet (YAG) laser, which can create channels in the presence of myocardial blood pool, makes a transcatheter approach possible [14–17]. The percutaneous approach by obviating thoracotomy and achieving the same objective should make the procedure safer and more acceptable.

In order to evaluate the safety, efficacy, and early outcome, we have evaluated a consecutive series of patients undergoing percutaneous transluminal myocardial revascularization (PTMR) as the sole interventional therapy.

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## MATERIALS AND METHODS

This study was conducted to evaluate the feasibility, safety, and early clinical results of PTMR in patients with class III and IV angina not amenable to any other form of revascularization. The trial was approved by the institutional review board and the ethics committee of the hospital.

Between the period June 1997 and May 1998, 35 patients were subjected to PTMR. Patients were included for the study if they met the following criteria: known coronary artery disease not amenable to percutaneous angioplasty or coronary artery bypass graft surgery; patients with Canadian Cardiovascular Society (CCS) functional class III or IV despite intensive medical treatment; patients with inducible ischemia on stress test or unstable angina defined as ischemic ST segment depression at rest; patients with preprocedural echocardiogram demonstrating >9-mm wall thickness of the left ventricular region that was to be lased and an ejection fraction of more than 0.25.

Patients were excluded from the study if they had decompensated congestive heart failure, sustained ventricular tachycardia, ventricular fibrillation, or acute myocardial infarction in the 4 weeks preceding the procedure. Patients with left ventricular aneurysm, left ventricular thrombus, and abnormal aortic arch that in the operator's judgement would not allow safe passage of the catheter were also not included.

### Technique of PTMR

A 9 Fr introducer sheath was introduced in the femoral artery and a 7 Fr introducer sheath in the femoral vein using the standard technique. Heparin 5,000 IU was administered intravenously. A Swan-Ganz catheter was introduced in the pulmonary artery to monitor the pulmonary artery wedge pressure during the procedure. A baseline right atrial pressure was measured in all the patients.

A 6 Fr pigtail catheter was then advanced into the left ventricle and left ventriculography performed in the 30° right anterior oblique projection. A ventriculogram in 45° left anterior oblique view was also performed if the area to be lased was the posterolateral wall or in left lateral view if the anterior wall was to be lased. The pigtail catheter was then exchanged for a 5- or 7-cm steerable tip deflectable PTMR catheter (Eclipse Surgical Technologies, Sunnyvale, CA) over a 0.038'' curved Amplatz extrastiff guidewire (Cook, Bloomington, IN) shaped to conform to the left ventricular wall. The guidewire was removed and the PTMR catheter aspirated, flushed, and attached to a Touhy Borst Y-adapter. The catheter was continuously flushed with heparinized saline through the other channel of the Y-adapter. The Slim Flex laser fiber

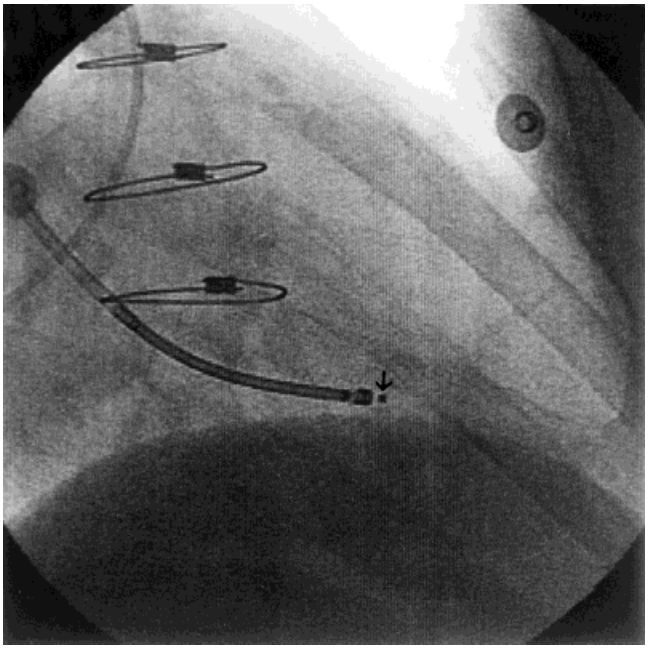

**Fig. 1. The distal marker band of the laser fiber (marked by arrow), which is protruding beyond the tip marker band of PTMR catheter during laser energy delivery.**

(Eclipse Surgical Technologies, Sunnyvale, CA) was introduced into the PTMR catheter and advanced under fluoroscopy into the left ventricular cavity. The PTMR catheter was then advanced to the apex of the left ventricle and deflected to position it against the wall to be lased. The PTMR catheter and the Slim Flex laser fiber were then aligned and the distal marker band of the Slim Flex fiber advanced to a position slightly distal to the tip marker band of the PTMR catheter (Fig. 1). The built in safety mechanism prevented the advancement of fiber beyond a 5-mm depth. The laser was set to deliver 3.5 watts through the 1-mm-diameter optical fiber in a series of three sequential pulses.

The following criteria were used as a suggestion of laser energy delivery to the myocardial wall: production of a ventricular couplet or at least one premature ventricular contraction with each laser pulse train; evidence of laser fiber protruding through the PTMR catheter against the left ventricular wall; audible tones of laser energy firing; and TMR 2000 laser system counter showing that three pulses had been delivered. If all these criteria were met, it was taken as successful channel creation. In the first eight cases, transesophageal echocardiography was also performed during the procedure. The production of bubbles at the time of laser activation in the left ventricular cavity also suggested delivery of laser energy. The use of transesophageal echocardiography was subsequently discontinued because it was not found to be of any additional help.

Laser channels were made starting at the distal portion of the respective wall and then retracting the delivery system serially toward the base of the same wall. The channels were created about 1 cm apart and the position of the catheter verified in both the RAO and LAO views prior to each laser activation. After making the desired channels, the laser fiber was removed. A 0.038'' guidewire was then advanced and the PTMR catheter exchanged for a pigtail catheter. Left ventriculography was performed in the same projection as prior to the procedure. At the end of the procedure, the right atrial pressure was measured again.

The patients were observed in the coronary care unit for 24 hr following the procedure. A two-dimensional echocardiogram was performed soon after the procedure to evaluate any changes in the wall motion and to look for any pericardial effusion. All patients had a 12-lead electrocardiogram and sequential creatinine phosphokinase determination to assess for postprocedure myocardial necrosis. A 30-day postprocedure vital status was determined by clinic visit in all the patients. All the patients were again evaluated at 3 months and 6 months. An exercise stress test and two-dimensional echocardiography was scheduled for each patient at 6 month.

## RESULTS

Baseline patient demographics are as shown in Table I. All patients were symptomatic prior to PTMR, with 14 patients in CCS functional class III and 21 patients in class IV. Before PTMR, 21 patients had positive ischemic exercise treadmill test and 14 patients with rest angina could not undertake exercise testing. The patients were mostly male. A history of myocardial infarction was present in 60% and history of congestive heart failure in 17%, prior bypass surgery and/or angioplasty had been done in 66%. Three-vessel coronary disease was present in 63%, two-vessel disease in 29%, and one-vessel disease in 8%. The PTMR was done in the inferior wall (right coronary territory) in 20 patients (58%), in posterolateral wall (left circumflex territory) in 14 patients (40%), and in anterior wall (left anterior descending artery territory) in 2 (6%) patients. One patient required PTMR in more than one coronary artery territory. An average of 15 ± 5 channels were created by the laser. Procedural time from creation of the first to the last channel was 40 ± 9 min with a fluoro time of 14 ± 4 min. The energy was preset at 3.5 watts for each laser activation. Regional wall motion was unchanged immediately following the procedure. Nine patients who were on intravenous nitroglycerine were successfully weaned off the drug within 12 hr. One patient developed cardiac tamponade immediately after the procedure and required pericardiocentesis using a pigtail catheter followed by a thoracotomy. The perforation was closed surgically and the patient recovered completely. An additional patient was found to have a pericardial effusion 6 hr following the procedure without any hemodynamic compromise. The effusion gradually resolved over the next 36 hr and no intervention was required.

**TABLE I. Baseline Patient Demographics**[a]

| | |
|---|---|
| Age (mean years ± SD) | 62 ± 9 |
| Gender (% male) | 83% |
| LV ejection fraction (mean ± SD) | 38 ± 7 |
| Functional class | |
| Class III | 14 (40%) |
| Class IV | 21 (60%) |
| History of | |
| Myocardial infarction | 21 (60%) |
| Congestive heart failure | 06 (17%) |
| Prior coronary bypass surgery | 20 (57%) |
| Prior coronary angioplasty | 09 (26%) |
| Prior bypass and/or angioplasty | 23 (66%) |
| Diabetes mellitus | 10 (29%) |
| Hypertension | 15 (43%) |
| Hyperlipidaemia | 14 (40%) |
| Smoking | 09 (26%) |
| Family history of coronary disease | 14 (40%) |
| Disease severity | |
| Single-vessel disease | 03 (8%) |
| Double-vessel disease | 10 (29%) |
| Triple-vessel disease | 22 (63%) |

[a]N = 35.

There was no procedure-related death. There was no elevation of CPK in any patient. There was no electrocardiographic evidence of myocardial injury. There were no cerebrovascular accidents and there were no sustained supraventricular or ventricular arrhythmias.

All the patients reported an improvement in angina within 48 hr of the procedure. The average length of hospital stay following the procedure was 2.1 ± 1.4 days. At 1 month, of the 35 patients, all of whom were in functional class III or IV before the procedure, 9 were asymptomatic, 18 were in class I, and 8 were in class II; no patient had class III or IV angina 1 month following the procedure. The mean functional class at entry was 3.68 ± 0.4 and it declined to 0.82 ± 0.7 at 30 days. At 3 months, the mean angina class was 0.94 ± 0.65. For 26 patients with functional class available at 6 months, the mean anginal class was 1.08 ± 0.58 (Fig. 2).

Of the 35 patients, 29 (83%) had more than two class improvement in angina at 30 days. At 3 months, this figure was 25 (71%). Of the 26 patients with functional class available at 6 months, more than two class improvement was seen in 19 patients (73%). One patient presented with unstable angina 5 months following the procedure with evidence of ischemia in a different territory than the one subjected to PTMR. Angiography revealed a new lesion in the saphenous venous graft to

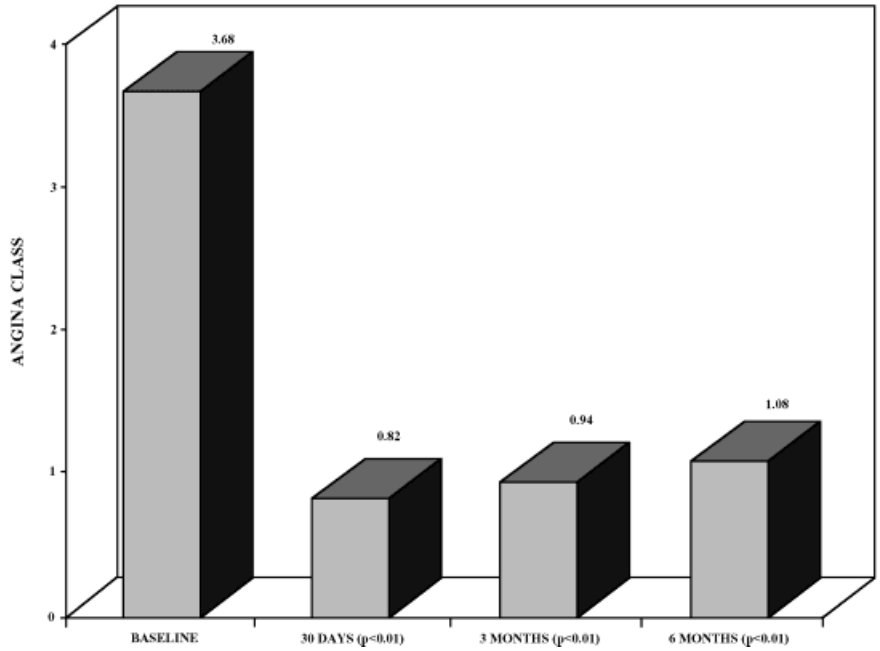


**Fig. 2. Comparison of the angina functional class (CCS) before and after PTMR till 6-month follow-up.**

left anterior descending artery. He was subjected to coronary stenting and became asymptomatic. The left ventricular echocardiography at 6 months showed a left ventricular ejection fraction of 40 ± 9% ($P$ = NS) as compared to the baseline data.

## DISCUSSION

In this feasibility and safety study we report our experience with percutaneously introduced catheter-based transmyocardial revascularization using the holmium:YAG laser system. The procedure can be safely performed, as is evident by the absence of any periprocedural death in this series. This contrasts with a high perioperative mortality of 10%–19% reported in patients undergoing TMR via thoracotomy using carbon dioxide laser systems [6–8]. The symptomatic relief seen in our series was very striking and rapid in onset.

Despite extensive investigations the mechanism of benefit by laser TMR is not entirely clear. The patent channel hypothesis of blood flow to ischemic areas through continued myocardial perfusion as seen in normal reptile hearts [11] has been refuted by recent animal studies [18,19]. Stimulation of angiogenesis and/or enhanced collateral vessel formation by laser-induced myocardial injury is another interesting mechanism reported in animal studies [9,10]. A third proposed mechanism to explain the acute symptomatic relief observed following TMR is damage to myocardial nerve fibers, resulting in an anesthetic effect [12]. It is plausible that a combination of these potential mechanisms may be at work.

The absence of mortality and a very low periprocedural complication rate with the transcatheter technique seems to relate to a markedly lower physiological and structural trauma resulting from the percutaneous approach. This would be particularly important in these ''no option'' patients who are not completely revascularized but yet are subjected to a major surgical procedure. Myocardial perforation leading to cardiac tamponade as seen in one of our patients is a potential complication, which can be minimized by proper case selection and in built safety mechanisms of the delivery systems. The ultrasound-guided delivery catheter (Eclipse, Sunnyvale, CA) and electromechanical mapping guidance (Biosense, Israel/ Johnson & Johnson, NJ) [20] are some attempts in this direction.

Previous reports following TMR have documented both short- and long-term angina relief. Frazier et al. [5] reported a reduction in CCS functional class from 3.70 ± 0.7 to 1.70 ± 0.9. This relief was persistent at 6 months. Similar results have been reported by Horvath et al. [6] in a series of 200 patients. The symptomatic benefit has been accompanied by reduction in the number of perfusion defects, improvement in perfusion by PET scans, and regional wall motion by dobutamine echocardiography [6–8,21]. Our results of PTMR compare favorably with these reports with the additional advantage of a very low morbidity, no mortality, and a very short hospital stay.

## Study Limitations

This is a small uncontrolled study with a limited follow-up. However, randomized multicenter studies currently in progress comparing this method with maximal medical treatment may further substantiate the efficacy of this mode of revascularization in patients disabled with angina and not suitable for other methods of revascularization.

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