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Use of Magnetic Resonance Imaging to Assess Myocardial Perfusion after Transmyocardial Laser Revascularization

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ABSTRACT

Background: Transmyocardial laser revascularization (TMLR) is an alternative treatment modality for patients with refractory angina who are not candidates for conventional surgical or percutaneous revascularization. Clinical studies of TMLR have not shown one-to-one correlation between increased myocardial perfusion and improved clinical status.

Methods: Three patients (51, 53, and 70 years old) with severe, diffuse coronary artery disease not amenable to conventional surgical revascularization and with angina (Canadian Cardiovascular Society [CCS] class 3-4) refractory to maximal medical therapy underwent TMLR with a CO_2 laser. Preoperative and postoperative cardiac magnetic resonance imaging (MRI) were performed to assess left ventricular perfusion and wall-motion changes in the laser-treated areas. Postoperative MRIs were performed within 6 months of TMLR and at 12 months. Angina status was assessed with the Seattle Angina Questionnaire.

Results: Postoperative adenosine stress myocardial perfusion imaging with MRI revealed improved overall perfusion and a reduction in subendocardial hypoperfused areas when compared to preoperative images. In all patients, an improvement in CCS class was consistent with an improvement in perfusion.

Conclusions: Cardiac MRI can be used to assess improved subendocardial perfusion after TMLR treatment. In our study, we found that endocardial perfusion was maintained over a 12-month period.

INTRODUCTION

Transmyocardial laser revascularization (TMLR), a procedure in which channels are created in the left ventricular myocardium using a specialized laser, is performed to relieve angina refractory to medical therapy for patients who are not candidates for conventional surgical or percutaneous revascularization [Okada 1986]. Previous studies have demonstrated the efficacy of TMLR in decreasing angina symptoms and improving quality of life in this difficult-to-treat population [Horvath 1997; Allen 1999]; however, the mechanisms responsible for the beneficial effects of TMLR still are not completely understood. Some studies have suggested that the myocardial channels created by TMLR lead to a direct increase in myocardial perfusion, neoangiogenesis, or a combination of both [Spanier 1997]. Other investigators, meanwhile, have proposed that clinical improvement after TMLR is a result of laser denervation of epicardial afferent nerve endings or of a placebo effect [Spanier 1997; Kwong 1998; Kadipasaoglu 1999].

Perfusion studies utilizing positron emission tomography have demonstrated indirect improvement in endocardial blood flow [Frazier 1995; Frazier 1999; van der Sloot 2004]. These indirect methods, however, are not precise in localizing endocardial versus epicardial flow. MRI is currently a well-established, well-validated tool for correlating myocardial perfusion with functional improvement [Martin 1998; Wilke 1998]. The purpose of this limited series was to determine whether cardiac MRI can be used to accurately assess both myocardial perfusion and to correlate that assessment with clinical status after patients undergo TMLR as a sole treatment for angina.

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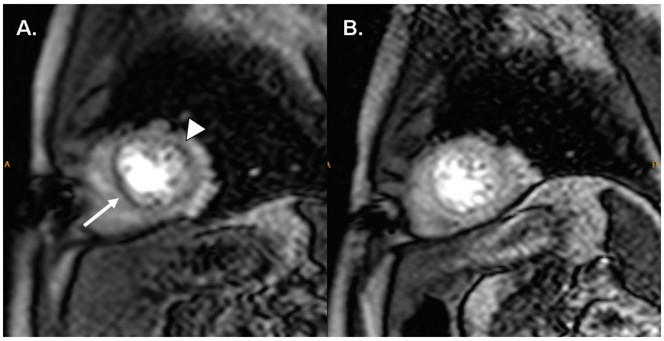
METHODS

Operative Technique

After general anesthesia was induced, a left anterolateral thoracotomy was performed through the 4th intercostal space. The pericardial sac was opened anterior to the phrenic nerve, and the left ventricle was identified. TMLR was performed with the Heart Laser CO_2 system (Laser Engineering, Inc, Milford, MA, USA), which has a peak output of 850 W. The laser was set to operate at a pulse energy of 35 J and a pulse duration of 44 msec. Each laser pulse was synchronized with the R wave on the electrocardiographic signal. Transmyocardial penetration of the laser shots was confirmed by intraoperative transesophageal echocardiography (TEE). Hemostasis was achieved with finger pressure or by placement of epicardial 6/0 polypropylene sutures. A chest tube was placed in the pleural space, and the chest was closed in standard surgical fashion.

Adenosine Stress Perfusion Procedure

First-pass adenosine stress perfusion images were obtained within 6 months and at 12 months by using a 1.5 T MR scanner with an inversion recovery, T1-weighted gradient echo sequence. Parallel imaging was employed in order to shorten the imaging duration (to average 30 to 35 seconds) [Schwitter 2006]. Adenosine (140 μg/kg per min) was administered



Stress perfusion study before and after transmyocardial laser revascularization (TMLR). A, Stress perfusion study before TMLR with hypoperfusion (ischemia) demonstrated by the dark area in the distal septum (arrow) and distal lateral wall (arrowhead). B, Stress perfusion study after TMLR, illustrating marked improvement in perfusion.

through a 20-gauge peripheral cannula for 3 minutes. Subsequently, 0.05 mmol/kg of gadolinium-chelate was administered (4 cc/kg) through an 18-gauge cannula; this was followed by a saline chaser at the same rate. Images were acquired during gadolinium infusion and 3 short-axis slices (including the base, middle, and distal left ventricle, ie, covering 16 segments out of the 17-segment model). Adenosine was stopped after peak left ventricular enhancement. After 15 minutes, a rest-perfusion study was performed using the same parameters, imaging sequence, and gadolinium dose, but without the vasodilator agent. Thereafter, 0.1 mmol/kg of gadolinium was administered in order to perform delayed-enhancement (viability) imaging.

The perfusion data were interpreted visually [Gebker 2007]. (Semiquantitative analyses can also be performed, although these analyses are more time consuming.) For a segment to be called ischemic, there had to be reversible hypoperfusion between the adenosine and rest perfusion sequences with viable myocardium demonstrated by the delayed-enhancement images. In the setting of critical ischemia, hypoperfusion would be seen in the stress and rest images of viable myocardium, usually accompanied by regional wall motion abnormalities related to the area of abnormal perfusion.

RESULTS

Case Reports

Patient #1. Patient #1 is a 51-year-old man with a history of hypertension, hyperlipidemia, and smoking. The patient had an anterolateral myocardial infarction in 1985, after which a 4-vessel aortocoronary bypass graft procedure was performed. The patient remained angina-free for 10 years while receiving maximal medical therapy, but in 1995, he came to the emergency department because of angina symptoms. A coronary angiogram showed patent vein grafts to the circumflex, diagonal branch, left anterior descending (LAD), and right coronary artery (RCA) and posterior descending artery (PDA). There was diffuse disease in the LAD, beyond the graft anastomosis, that was not amenable to angioplasty. The patient subsequently underwent TMLR and received 45 laser shots. He remained symptom-free for 8 years.

In April 2003, the patient was admitted to the emergency department on 2 occasions because of recurrent chest pain. Adenosine stress testing using a multislice perfusion study and MRI confirmed inferoapical reversible ischemia with preserved left ventricular function (ejection fraction [EF], 60%). The patient again underwent TMLR and received 37 laser shots into the apical, inferior, and lateral walls. The postoperative course was uneventful, and the patient was discharged home on postoperative day 4.

The patient's symptoms improved (from Canadian Cardiovascular Society [CCS] class 3 to 1), as did his functional status (from New York Heart Association [NYHA] functional class II to I). There were no interim complications, hospital admissions for cardiac causes, or cardiac interventions. Follow-up cardiac MRI stress perfusion imaging at 1 year continued to show no evidence of a reversible perfusion defect. The hypoperfusion previously identified in the distal inferior and inferolateral walls was no longer evident.

Patient #2. A 53-year-old man with a history of diabetes mellitus and hypertension was referred to our institution in October 2001 for recurrent chest pain. He underwent TMLR to the anterolateral wall as an adjunct to aortocoronary bypass graft surgery (left internal mammary artery [LIMA] to the LAD). The patient remained symptom-free until July 2003, when his angina symptoms returned and continued despite maximal medical treatment. In October 2003, an adenosine stress test with MRI showed anterolateral wall ischemia related to small-vessel disease, possibly secondary to diabetes mellitus. In November 2003, a coronary angiogram showed a patent LIMA-to-LAD anastomosis, with 80% occlusion at its origin. There were no significant stenoses of the RCA and circumflex coronary artery, except for a small ramus branch that had some disease proximally. His ejection fraction was 60%.

The patient underwent TMLR, receiving a total of 37 laser shots to the anterolateral wall of the left ventricle, as confirmed by TEE. The postoperative course was uneventful, and the patient was discharged home on postoperative day 6. An adenosine stress multislice myocardial perfusion study was performed postoperatively, and the patient had an appropriate hemodynamic response, without significant complications. Perfusion imaging revealed no significant reversible or fixed perfusion defects. All of the left ventricular myocardium showed normal enhancement, during both stress and rest. The postoperative EF was 62%. The patient's symptoms improved (from CCS class 3 to 1), as did his functional status (from NYHA functional class III to II). Follow-up cardiac MRI stress perfusion imaging at 1 year continued to show no evidence of a reversible perfusion defect.

Patient #3. In April 2003, a 70-year-old man was admitted to our hospital with a history of 3 coronary artery bypass graft (CABG) operations (1984, 1989, and 1992) and CCS class 4 angina symptoms unresponsive to maximal medical treatment. Cardiac catheterization revealed a patent LIMA to LAD, a patent vein graft to the RCA, and an occluded vein graft to the severely diseased circumflex artery, which was filling from collateral branches. His EF was 65%.

Echocardiography showed an aortic valve area of 1 cm^2. In October 2002, adenosine stress myocardial perfusion imaging with MRI showed subendocardial hypoperfusion involving the anterolateral wall of the base and the lateral wall at the mid and distal thirds of the left ventricle. The lateral wall was hypokinetic. MRI viability imaging revealed subendocardial scar formation of the proximal two-thirds of the lateral wall.

The patient underwent aortic valve replacement (On-X 19-mm heart valve, Medical Carbon Research Institute, LLC, Austin, TX, USA) via a median sternotomy and TMLR to the anterolateral wall with 20 laser shots, confirmed by perioperative TEE. The postoperative course was uneventful.

The patient's symptoms improved (from CCS class 4 to 1), as did his functional status (from NYHA functional class III to I). When an adenosine stress multislice myocardial perfusion study was performed, the patient exhibited an appropriate hemodynamic response, without significant complications. The study revealed subendocardial hypoperfusion of the basilar anterolateral wall and the lateral wall in the middle and apical thirds of the ventricle; however, these regions of hypoperfusion were smaller than they were on previous examination. His postoperative EF was 62%. Follow-up cardiac MRI stress perfusion imaging at 1 year continued to show no evidence of a reversible perfusion defect. The patient has remained symptom-free.

DISCUSSION

In this study, the cardiac MRI was used to assess subendocardial perfusion after treatment with TMLR. Cardiac MRI is unique in that it allows direct visual assessment and analysis of endocardial and epicardial perfusion. Because it is generally believed that improved perfusion results from direct communication of the laser channels with the ventricular cavity, allowing improved endocardial perfusion, we felt that cardiac MRI would be useful in analyzing the effectiveness of laser revascularization. Previous studies with thallium perfusion and positron emission tomography (PET) have consistently shown improved overall perfusion, but they could not assess endocardial perfusion with the direct accuracy of cardiac MRI. [Frazier 1995; Allen 1999; Frazier 1999; Rimoldi 1999; Schofield 1999].

As is the case for every investigational device, most of the preliminary studies primarily focus on the safety and efficacy of TMLR [Hattler 1999; Horvath 2001; Allen 2003]. A randomized, prospective study of treated patients versus randomized, untreated controls did demonstrate improved overall perfusion with the use of a CO_2 laser [Frazier 1999]. Direct assessment of improved endocardial perfusion has not been easily assessed, however. Studies with PET have demonstrated improved endocardial/epicardial perfusion ratios [Frazier 1995], but PET technology is expensive and is unavailable in usual, current clinical practice. Perfusion MRIs, which were used in this study, were able to show consistent improvement in endocardial perfusion. The ability of MRI to show perfusion may be useful not only postoperatively to determine the impact of TMLR on endocardial perfusion, but may also be of value in further follow-up studies, particularly if a patient's symptoms recur.

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