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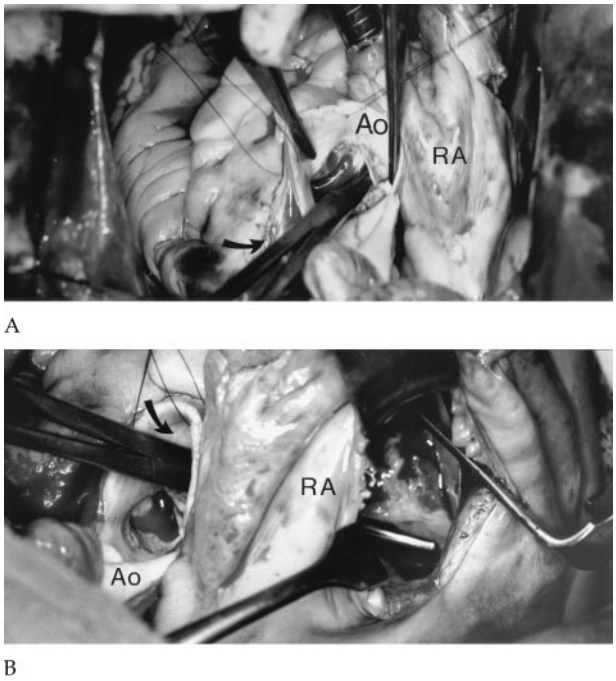


Fig 1. Overholt (arrow) *in the original pathway of the bullet.* (Ao = *aorta;* RA = *opened right atrium.*)

initial volume therapy, has brought a considerable improvement in outcome, even for patients "in extremis" or under cardiopulmonary resuscitation [6]. Secondary lesions are frequent and should be looked for very carefully in the postoperative period with echocardiography and cardiac catheterization. Repair should be carried out electively on symptomatic patients.

Despite a close work-up there are symptomless patients with severe injuries in whom late sequelae develop after many years. Less is known about the natural history of these [7]. Our case delivers an example of the natural history of a combined lesion with traumatic ventriculoatrial defect with associated aortic regurgitation and atrial pseudoaneurysm [3] that developed symptoms after a long period of time. There are only a small number of cases of traumatic ventriculoatrial shunts reported [2], and reports on late sequelae also are rare. Late deterioration may develop as the ventricles dilate or function becomes impaired, as the defect grows, or in the wake of previous tissue damage [2, 7]. In our case we presume the deterioration was brought about by the combination of an increase in pulmonary pressure, a decline in left ventricular compliance, and the onset of atrial fibrillation [8]. We conclude that survivors of gunshot wounds of the heart should be evaluated later for valve lesions, septal defects, and other hemodynamic pathology.

References

1. Cha EK, Mittal V, Allaben RD. Delayed sequelae of penetrating cardiac injury. Arch Surg 1993;128:836–41.
2. Thandroyen FT, Matisonn RE. Penetrating thoracic trauma producing cardiac shunts. J Thorac Cardiovasc Surg 1981;81:569–73.
3. Symbas PN, DiOrio DA, Tyras DH, Ware RE, Hatcher CR. Penetrating cardiac wounds. J Thorac Cardiovasc Surg 1973;66:526–32.
4. Sugg WL, Rea WJ, Ecker RR, Webb WR, Rose EF, Shaw RR. Penetrating wounds of the heart: an analysis of 459 cases. J Thorac Cardiovasc Surg 1968;56:531–45.
5. Tavares S, Hankins JR, Moulton AL, et al. Management of penetrating cardiac injuries: the role of emergency room thoracotomy. Ann Thorac Surg 1984;38:183–7.
6. Ivatury RR, Rohman M, Steichen FM, Gunduz Y, Nallathambi M, Stahl WM. Penetrating cardiac injuries: twenty-year experience. Am Surg 1987;53:300–17.
7. Demetriades D, Charalambides C, Sareli P, Pantanowitz D. Late sequelae of penetrating cardiac injuries. Br J Surg 1990;77:813–4.
8. Borow KM, Alpert JS, Braunwald E. Congenital heart disease in the adult. In: Braunwald E, ed. Heart disease. Philadelphia: Saunders, 1984:1027–34.

Transmyocardial Laser Revascularization in Allograft Coronary Artery Disease

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We used transmyocardial laser revascularization to treat accelerated cardiac allograft atherosclerosis in 2 patients. One patient received transmyocardial laser revascularization as sole therapy, the other as an adjunct to coronary artery bypass grafting. The systolic function improved in both patients, although the patient who had adjunctive transmyocardial laser revascularization died of systemic infection and renal failure on postoperative day 55. The second patient is alive and well 1½ years after the laser procedure. We discuss 4 other patients who received transmyocardial laser revascularization treatment elsewhere in the United States. Transmyocardial laser revascularization has the potential to become important in the treatment of transplant atherosclerosis. Randomized clinical trials are warranted to assess the efficacy of transmyocardial laser revascularization in this setting.

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Transmyocardial laser revascularization (TMLR) is a relatively new therapy for patients with coronary artery disease (CAD) that is refractory to conventional

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revascularization techniques and maximal medical therapy. Performed on the beating heart through a left anterolateral thoracotomy, TMLR creates transmural channels into the left ventricle that enable blood to perfuse the ischemic regions directly.

Preliminary trials have evaluated the clinical safety and efficacy of TMLR as an alternative to coronary artery bypass grafting (CABG) in patients with end-stage CAD. These studies suggest that most patients who undergo TMLR as sole therapy experience an improvement in anginal symptoms and subendocardial perfusion [1]. Randomized, multicenter trials are under way to compare the efficacy of TMLR with that of medical therapy or repeated CABG. The effectiveness of TMLR as an adjunct to CABG also is being investigated in patients in whom revascularization through CABG may not be complete because of distal atherosclerotic involvement of the arteries.

Accelerated CAD appears to be the leading cause of death among heart transplant recipients who survive the first postoperative year [2]. Although CABG has been successful in a few transplant recipients [3], neither CABG nor percutaneous transluminal coronary angioplasty is used widely to treat these patients. Transmyocardial laser revascularization, however, may offer an adjunctive or alternative means of improving myocardial perfusion. The early histologic data indicate that TMLR creates channels that remain patent for prolonged periods and are resistant to acute occlusion [4]. An alternative theory proposes that the channels become occluded by neovascularized collagen and that angiogenesis ultimately is responsible for the clinical benefits observed [5]. In either case, because of the absence of smooth muscle cells, the new pathways may be protected against factors that influence the development of transplant CAD [6].

We describe 2 patients in whom TMLR was used at our institution to treat accelerated allograft CAD.

Case Reports

Patient 1

A 60-year-old man with shortness of breath on minimal exertion was referred to our institution. His surgical history was significant for two CABG operations, a left ventricular aneurysmectomy in 1982, an orthotopic cardiac transplant in 1987, and an acute anterior-septal myocardial infarction in 1994. A recent cardiac catheterization showed severe triple vessel disease. Stress echocardiography with dobutamine and thallium-201 single-photon emission computed tomography revealed inferior, apical, and septal akinesis with generalized basal hypokinesis and anteroapical stress-induced ischemia. A resting multigated acquisition nuclear scan revealed a left ventricular ejection fraction (LVEF) of 0.29. The patient underwent TMLR, during which 31 channels were created in the anterior, lateral, and inferior coronary distributions. Of these channels, 28 were confirmed as transmural by intraoperative transesophageal echocardiography. The patient tolerated the operation well and had an uncomplicated postoperative course. He was discharged on the sixth postoperative day. A follow-up examination at 18 postoperative months showed that the patient's clinical condition was improved. A resting multigated acquisition scan revealed an LVEF of 0.43. A thallium-201 single-photon emission computed tomographic scan was performed immediately after the treadmill test and revealed septal and anterior scarring and septal and anterior stress-induced ischemia.



Fig 1. Photomicrograph of a heart treated with transmyocardial laser revascularization (patient 2, 55 days after operation) after routine preparation for hematoxylin and eosin staining. A partially patent central channel is surrounded by adjacent scar tissue and healthy myocardium. (×40 before 52% reduction.)

Patient 2

A 54-year-old man had symptoms of pulmonary edema and congestive heart failure that were resistant to diuretic therapy. His medical and surgical history included an orthotopic heart transplant 6 years earlier and subsequent episodes of slow atrial flutter that required cardioversion and amiodarone therapy. Cardiac catheterization revealed severe transplant CAD with diffuse attenuation of the three major coronary arteries. Systolic function was markedly decreased and the LVEF was 0.25. An endomyocardial biopsy showed no evidence of allograft rejection but indicated the presence of chronic ischemia. A thallium-201 single-photon emission computed tomographic scan taken after stress tests indicated apical, anterior, inferior, distal septal, and anterobasal ischemia.

The coronary anatomy was deemed suitable for CABG, which was performed using a reverse saphenous vein graft to the left anterior descending coronary artery, the obtuse marginal branch of the left circumflex artery, and the posterior descending branch of the right coronary artery. Transmyocardial laser revascularization was performed as adjunctive therapy. Of the 45 channels created in the anterolateral, posterior, and posterolateral regions of the left ventricle, 20 were confirmed as transmural.

The postoperative course was complicated by prolonged ventilator support and infection that resulted in sternal dehiscence requiring wound exploration, debridement, and mobilization of the omental flap to the

Table 1. Transmyocardial Laser Revascularization Modality and Follow-up in Patients With Allograft Coronary Artery Disease

Patient No.	Adjunct to CABG	Location	Follow-up	Improved LVEF	Improved Symptoms
1	No	Houston	18 mo	Yes	Yes
2	Yes	Houston	55 days	Yes	Dead (multiorgan failure)
3	No	Milwaukee	10 days	Yes	Dead (arrhythmia)
4	Yes	Milwaukee	12 mo	No	Yes
5	No	Chicago	3 mo	No	No
6	Yes	Chicago	12 mo	No	Yes

CABG = coronary artery bypass grafting; LVEF = left ventricular ejection fraction.

substernal space on postoperative day 10. On postoperative day 33, a multigated acquisition scan showed an LVEF of 0.45 and moderate left ventricular dysfunction. Renal failure and cardiac arrhythmia further worsened the patient's status, and the patient died on postoperative day 55. Cardiac autopsy revealed patent channels that were partially occluded by fibrosis but connected to what appeared to be native microvasculature (Fig 1).

Comment

Transplant CAD is the leading cause of late death in transplant recipients. Unfortunately, transplant CAD cannot be reliably predicted, diagnosed, or treated. Unlike native heart CAD, transplant CAD is most prominent in intramyocardial vessels and is histologically similar to postangioplasty restenosis and saphenous vein bypass graft occlusive disease [6]. No medical therapy is known to prevent, curtail, or reverse allograft CAD; the only available therapy is retransplantation, which is suitable for only a few patients. However, allograft survival after retransplantation can be relatively short. Moreover, the number of patients awaiting transplantation continues to grow while the donor pool remains small. For these reasons, alternative therapies such as TMLR must be considered to reduce long-term mortality and prolong survival.

Both patients presented here experienced improved systolic function after TMLR. The LVEF increased from 0.29 to 0.43 in the first patient and from 0.25 to 0.45 in the second patient. However, functional improvement was not accompanied by perfusional increase in the first patient and the potential effect of TMLR on LVEF could not be isolated from that of CABG in the second patient. The second patient's death does not seem to have resulted from cardiac-related events, but rather was precipitated by preoperative renal dysfunction concomitant with diabetes mellitus and postoperative systemic infection. Transmyocardial laser revascularization has been used in 6 transplant recipients at the three United States centers participating in the present study, and may have been used in additional patients at other centers unbeknownst to us. Of the 6 known patients, 3 have undergone TMLR as an adjunct to CABG and the other 3 have undergone TMLR alone (Table 1). The overall clinical success rate is 50% and the overall mortality rate is 33%. Unfortunately, among the survivors, it has been difficult to show improved perfusion (and cardiac function, with the exception of patient 1) within this limited series.

At present, the mode of action of TMLR remains unknown. It is possible that the mechanism of increased perfusion in TMLR is mediated by left ventricular blood carried through patent channels. However, the patency of channels observed in postmortem micrographs remains open to interpretation and is highly controversial [7, 8]. Laser-induced angiogenesis may contribute to the more effective distribution of the additional blood. However, it seems unlikely that angiogenesis alone, in the absence of patent channels with endocardial connections, could account for the additional blood in the region simply through the already compromised epicardial coronary arteries.

Transmyocardial laser revascularization, with or without CABG, has the potential to become an important therapeutic alternative for transplant CAD. Randomized clinical trials are warranted to assess the efficacy of TMLR in cardiac transplant recipients who have CAD.

References

1. 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.
2. Beiber CP, Hunt SA, Schwinn DA, et al. Complications in long-term survivors of cardiac transplantation. Transplant Proc 1981;8:207–11.
3. Frazier OH, Vega JD, Duncan JM, et al. Coronary artery bypass two years after orthotopic heart transplantation. J Heart Lung Transplant 1991;10:1036–40.
4. Mirhoseini M, Shelgikar S, Cayton M. New concepts in revascularization of the myocardium. Ann Thorac Surg 1988;45:415–20.
5. Fisher PE, Khomoto T, DeRosa CM, Spotnitz HM, Smith CR, Burkhoff D. Histologic analysis of transmyocardial channels: comparison of CO_2 and holmium:YAG lasers. Ann Thorac Surg 1997;64:466–72.
6. Turek LP, Radovancevic B, Frazier OH. Allograft vascular disease. In: Frazier OH, Macris MP, Radovancevic B, eds. Support and replacement of the failing heart. Philadelphia: Lippincott-Raven, 1996:261–96.
7. Burkhoff D, Fisher PE, Applebaum M, Kohmoto A, DeRosa C, Smith CR. Histologic appearance of transmyocardial laser channels after 4½ weeks. Ann Thorac Surg 1996;61:1532–5.
8. Cooley DA, Frazier OH, Kadipasaoglu KKA, Pehlivanoglu S, Shannon RL, Angelini P. Transmyocardial laser revascular-

ization. Anatomic evidence of long-term channel patency. Tex Heart Inst J 1994;21:220–4.

INVITED COMMENTARY

With this publication Frazier and associates are the first to report transmyocardial laser revascularization (TMLR) in the treatment of cardiac transplant graft coronary disease, in a small number of patients (6) treated at three institutions. Three such patients have been treated at Columbia-Presbyterian, and there are undoubtedly more elsewhere, as Frazier and associates acknowledge. Limited conclusions are possible. Perioperative mortality was 33%, and symptoms were improved in 50%, which are worse results than those obtained in large series of nontransplant patients similarly treated. If confirmed in a larger experience this would be discouraging indeed, but it must certainly be measured against the dismal lack of alternatives in such patients. Not surprisingly, Frazier and associates choose to emphasize instead the increase in left ventricular ejection fraction (LVEF) observed in 50% of their patients. This finding also differs from what has been reported in nontransplant patients; in none of the large series has LVEF changed significantly from baseline. Regardless of one's choice among the theoretical mechanisms of action, it is difficult to understand how transplant patients would be more greatly benefited. The mean LVEF in the larger series is 0.40 to 0.49, and 2 of the 3 patients presented here had LVEF low enough (0.29 and 0.25) to exclude them from most existing trials, which may have served to provide greater opportunity for observation of improvement. Claims for TMLR-mediated improvement in LVEF are also clouded in 1 of the patients by the presence of bypass grafts to all three major territories, completely overlapping with the distribution of channels. This, of course, is an analytic obstacle faced by any trial of TMLR combined with coronary bypass.

Frazier and associates are to be commended for their concise and even-handed discussion of the controversies surrounding mechanism and channel patency. They go as far as to describe the channel in Figure 1 as "partially patent." Similar photomicrographs have been described in the past as "patent," and have been used in support of the direct perfusion hypothesis, despite the fact that what was originally a 1-mm channel has been reduced to something measured in micrometers, surrounded by more than 1 mm of healing scar. Frazier and associates also contribute an interesting speculation that TMLR channels might be protected against graft coronary disease because of the absence of smooth muscle cells. Although the antigens involved are thought to be almost entirely endothelial, it is tempting to think that the absence of smooth muscle cells to remodel in response to the endothelial stimulus would be protective. On the other hand, the stromal cells participating in the healing reaction are pluripotent, and it would not be surprising to find that some differentiate to express functions and responses of smooth muscle cells. Further experience may answer some of these questions and bolster the preliminary evidence offered here that TMLR might give hope to a very difficult group of patients with few other options.

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Combined TMR and Mitral Valve Replacement via Left Thoracotomy

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Transmyocardial laser revascularization is an emerging technique for treatment of patients with coronary artery disease not amenable to standard revascularization by either percutaneous transluminal coronary angioplasty or coronary artery bypass grafting. Transmyocardial laser revascularization is typically performed as an isolated procedure on the beating heart, although it has been performed as an adjunct to conventional coronary artery bypass grafting in nongraftable territories. We report the use of transmyocardial laser revascularization in combination with mitral valve replacement via a left lateral thoracotomy for treatment of ischemic mitral regurgitation.

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The patient is a 56-year-old woman who initially presented in February 1996 with a non–Q-wave inferoposterior myocardial infarction. Cardiac catheterization revealed inferior-posterior wall akinesis and an ejection fraction of 0.45 with 3+ mitral regurgitation. Coronary angiography demonstrated severe three-vessel coronary artery disease. Coronary artery bypass grafting was performed with anastomosis of the left internal mammary artery to the left anterior descending artery and saphenous vein grafting to the right coronary artery. Because of diffuse disease, the left circumflex system could not be bypassed. The patient underwent simultaneous mitral valve annuloplasty with a Carpentier-

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