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Preliminary Results of Intraoperative Excimer Laser Angioplasty: Phase 1: An Adjunct to Coronary Artery Bypass Surgery

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The excimer laser underwent phase I clinical trials at three centers to determine its safety for intraoperative coronary laser angioplasty as an adjunct to coronary artery bypass grafting. A 308-nm Xenon-Chloride, pulsed-wave excimer laser was used to perform angioplasty in 30 patients undergoing coronary artery bypass surgery. Forty vessels (30 patients) were treated, in which the extent of occlusion ranged from 30% to 100%, with complete occlusion in 40% of all vessels. Improvement in vessel luminal caliber was achieved in 33 (79%) vessels, with perforations occurring in 4 (12%) vessels, 2 of which required surgical repair. The lumens of the remaining 8 (19%) vessels were not enlarged, and 2 (5%) of these vessels were perforated. Luminal enlargement was most often achieved in totalled occluded vessels in which 16/17 (94%) were recanalized. No patients died within 30 days postoperatively. Five patients demonstrated biochemical and electrocardiographic evidence of myocardial injury 48 hr postoperatively, and one patient died of cardiac arrest 139 days postoperatively. On the basis of these results, we believe that excimer laser angioplasty can be performed safely to improve coronary luminal patency, even in totally occluded vessels, in an operative setting. The long-term value of this procedure remains to be elucidated.

Key words: laser angioplasty, coronary artery bypass, atherosclerosis

INTRODUCTION

Excimer laser energy has proved effective in ablating vascular lesions [1,2]. The pulsed-wave design and high-energy wavelength, characteristic of ultraviolet lasers, cause rapid vaporization of target tissue (including calcific plaque) resulting in precise ablation, with minimal thermal buildup and damage to adjacent tissue [3,4]. This precise ablating ability of the excimer laser makes it well suited for small-caliber vessel angioplasty, in which the danger of vessel wall perforation is great. Advancements in fiber optics have resulted in the development of laser delivery systems with external diameters small enough to permit the use of excimer laser energy in coronary arteries. However, there is limited experience with either the intraoperative or percutaneous use of current medical excimer laser systems to perform coronary angioplasty [3–7].

Therefore, the purpose of this study was to determine whether a new coronary angioplasty

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TABLE 1. Clinical Characteristics of 30 Coronary Artery Bypass Patients Undergoing Adjunct Laser Coronary Revascularization*

	Patients			Occlusions				
							Location[b]	
Treatment center	No.	Age[a] (yr)	Sex (M/F)	No. treated (%)	Extent of stenosis[a] (%)	No. totally occluded vessels (%)	Proximal No. (%)	Distal No. (%)
THI	12	54 ± 10	11/1	17 (43)	93 ± 10	10 (56)	13	4
AHI	11	67 ± 10	9/2	13 (33)	94 ± 47	7 (50)	12	1
Uppsala	7	61 ± 4	7/0	10 (24)	65 ± 22	0 (0)	5	5
Total	30	60 ± 10	27/3	40 (100)	87 ± 18	17 (40)	30 (75)	10 (25)

[a]Data are stated as the mean ±S.D.
[b]Location in reference to the bypass graft anastomosis.
*AHI, Arizona Heart Institute; THI, Texas Heart Institute.

excimer laser system could be used safely to perform intraoperative coronary angioplasty as an adjunct to conventional coronary artery bypass grafting. By combining these procedures, we believed that if we were to improve graft "runoff" successfully by increasing the cross-sectional area of the lumens of lesions distal to the graft anastomosis, we could maximize revascularization of all viable myocardium. The first phase of this study was designed to evaluate the immediate safety of intraoperative coronary laser angioplasty.

PATIENTS AND METHODS

From November 1988 through October 1989, the Texas Heart Institute (Houston), the Arizona Heart Institute (Scottsdale), and the Uppsala Academic Hospital (Uppsala, Sweden) conducted first-phase clinical studies of intraoperative laser angioplasty as an adjunct to coronary artery bypass surgery. The protocol conformed to the Food and Drug Administration (FDA) guidelines in regard to the investigational device exemption (IDE) approval for the Spectranetics CVX300 excimer laser system (Spectranetics Inc., Colorado Springs, CO).

Patient Selection

According to the selection criteria specified in the IDE, patients could undergo treatment if they required coronary artery bypass surgery and if they had accessible proximal or distal lesions. Patients could also be included if they had diffuse atherosclerotic disease that might require manual endarterectomy. Written informed consent was obtained from all patients involved in the study.

The combined clinical results of the three investigational centers are based on a total population of 30 patients in whom 40 occlusions were treated with the CVX300 at the time of coronary artery bypass surgery. Table 1 shows the clinical characteristics of the patients treated at each center. Also included are the data pertaining to the occlusions, specifically, the total number in each group of patients and the number treated by laser angioplasty, as well as the extent and angiographically determined length of stenosis and location.

Description of the Excimer Laser System

The Spectranetics CVX300, a portable medical excimer laser system that operates at a wavelength of 308 nm, is specifically designed for coronary laser angioplasty. The CVX300 is operated in a pulsed-wave mode, with the pulse-width factory-preset at 80–100-ns full-width half-maximum. The pulse fluence (energy density per pulse in mJ/mm^2) and pulse frequency can be altered as necessary to achieve optimal ablation. The delivery system for intraoperative laser angioplasty consists of an 800-μm-diameter silica–silica fiber (Polymicro) that is inserted into a 16-gauge (0.066-inch or 1.67-mm) custom-designed, malleable introducer (Fig. 1).

Operative Technique

After median sternotomy, the standard cannulation techniques for instituting cardiopulmonary bypass are performed. Cardiac arrest and myocardial preservation are achieved by injecting hypothermic cardioplegic solution. The coronary artery occlusions are located using a preoperative catheterization diagram and manual palpation. An arteriotomy is performed adjacent to the oc-

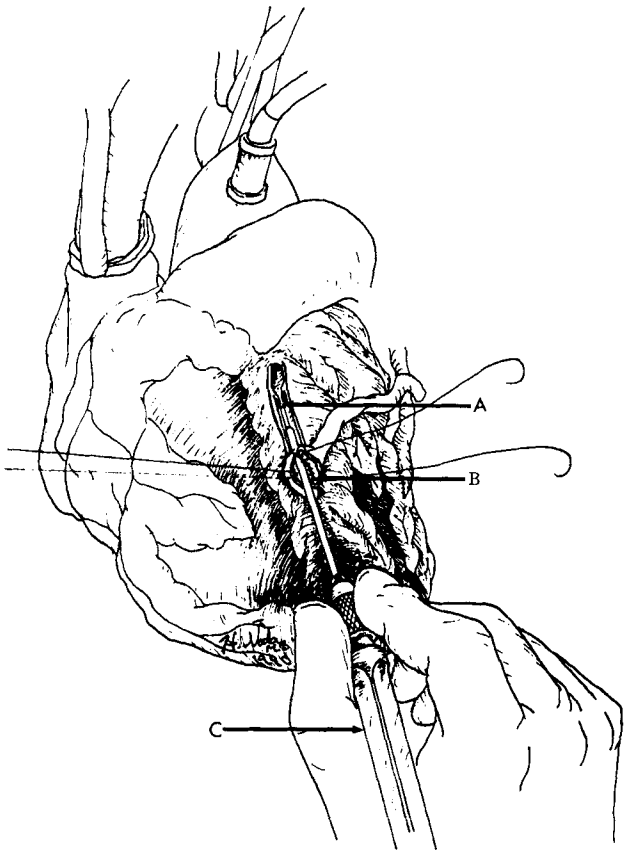


Fig. 1. Technique for adjunct coronary artery angioplasty and coronary artery bypass. **A.** Laser probe/fiber tip in contact with occlusion. **B.** Site for anastomosis of bypass graft after completion of laser angioplasty. **C.** Custom-designed fiber handle/introducer.

clusion to be lased. The degree of vessel obstruction is measured with calibrated coronary probes (1–3 mm, 0.5-mm increments).

The laser delivery system is then inserted through the arteriotomy until the tip touches the occlusion (Fig. 1). The laser is activated at an initial pulse fluence of 30 mJ/mm^2 and a frequency of 5–50 Hz. The laser assembly is advanced across the occlusion as plaque is ablated. Ablation is most effective when the probe is in contact with the plaque. Saline irrigation is used to clear any blood or debris from the vessel under treatment.

After each lasing attempt, calibrated coronary probes are reinserted into the lumen to assess the degree of patency at the lesion site. At the surgeon's discretion, fluence, frequency, or both are increased if the plaque is difficult to penetrate. If vessel patency is restored, a saphenous vein graft or an internal mammary artery is anastomosed to the arteriotomy site. If increasing the fluence and frequency of the laser fails to open the blockage, the laser procedure is abandoned and the conventional distal coronary artery bypass operation resumed.

Variables Studied

Data were collected concerning the type of vessel treated, the location of the stenosis in reference to the bypass anastomosis, and the degree and length of stenosis determined by angiography. Also noted were laser fluence and frequency, the number of pulses fired per occlusion, the duration of lasing, and pre- and postoperative luminal measurements.

RESULTS

The excimer laser was used to perform adjunct coronary angioplasty in 30 patients undergoing coronary artery bypass surgery. A total of 40 vessels were treated with the laser in this series. The degree of occlusion in these vessels ranged from 30% to 100%, and the length of occlusion ranged from 3 mm to 60 mm. Luminal enlargement was achieved in 33 (79%) of the vessels (Table 2), and only four (12%) vessel wall perforations occurred. In the remaining nine (21%) vessels, the lumen was not enlarged, and the vessel was perforated in two (33%) of these cases. The laser dosimetry parameters for each center are shown in Table 2. Surgical repair was required in two (33%) of the vessels that were perforated. No patients died early (within 30 days of operation), and only one patient died late (139 days after operation).

Twenty (50%) of the lesions chosen for treatment were located in the left anterior descending (LAD) coronary artery; in 15 (75%) cases, luminal enlargement was achieved (Table 3). The next most common vessels treated were the obtuse marginal arteries (OM 1, 2, or 3) and the right coronary artery, where the success rate was 100%. Laser treatment was also attempted to restore blood flow through two saphenous vein grafts, but luminal enlargement was achieved in only one of these cases. Table 4 outlines the treatment and outcome for each lesion.

Eight patients suffered myocardial injury within the first 48 hours of surgery, as evidenced by electrocardiographic studies showing Q-wave or ST-T wave changes and serial CPK-isoenzyme assays. One of the patients experienced cardiac arrest during transport from surgery to the intensive care unit (ICU) but was successfully revived

TABLE 2. Laser Settings and Results of Laser Treatment at Each Treatment Center

Treatment center	Laser data[a]				CPB time[a] (min)	No. vessels successfully treated[b] (%)
	Pulse fluence (mJ/mm^2)	Frequency (Hz)	No. pulses/ occlusion	Lasing time (sec)		
THI	39 ± 7	15 ± 7	854 ± 847	108 ± 84	129 ± 41	14 (78)
AHI	46 ± 9	26 ± 10	865 ± 950	29 ± 24	93 ± 23	10 (71)
Uppsala	50 ± 7	8 ± 3	415 ± 836	34 ± 50	149 ± 67	9 (90)
Total	44 ± 8	17 ± 11	786 ± 925	54 ± 64	121 ± 48	33 (79)

[a]Results are stated as the mean ±SD.
[b]Success was defined as achievement of luminal enlargement, with or without minor perforation.
*AHI, Arizona Heart Institute; CPB, cardiopulmonary bypass; THI, Texas Heart Institute.

TABLE 3. Results of Adjunct Laser Coronary Revascularization by Type of Vessel (N=40)*

Vessel type	No. treated (%)	No. treated successfully[a] (%)
LAD	20 (50)	15 (75)
OM	7 (18)	7 (100)
RCA	6 (15)	6 (100)
PDA	3 (7)	3 (100)
DX	2 (5)	1 (50)
Vein graft	2 (5)	1 (50)
Total	40 (100)	33 (79)

*DX, diagonal; LAD, left anterior descending artery; OM, obtuse marginal artery; PDA, posterior descending artery; RCA, right coronary artery.
[a]Success was defined as achievement of luminal enlargement, with or without minor perforation. Percentages in this column pertain to vessel type.

through cardiopulmonary resuscitation and drug therapy.

The average hospital stay was 12 days, except for two patients. One patient had pulmonary complications resulting from a concomitant heterotopic heart transplant, single bypass surgery, and an aneurysmectomy. She has returned to the hospital several times since operation. The second patient, who had advanced cardiac disease manifested by a low ejection fraction (20%), had undergone quadruple bypass surgery, aneurysm repair, and endarterectomy.

DISCUSSION

During the past 7 years, the use of lasers as tools for angioplasty has undergone considerable investigation [1–7]. With the advent of small-diameter, flexible laser energy delivery systems, some investigators [3–6] have turned their attention to laser angioplasty for treatment of coronary artery disease. Much of the interest in coronary laser angioplasty has arisen because of the shortcomings associated with conventional angioplasty techniques, such as treating total occlusions and diffuse atherosclerotic segments [8].

Our preliminary clinical studies of laser coronary artery angioplasty as an adjunct to bypass surgery show that it is safe and that it can be used for penetrating totally occlusive lesions. The laser fiber assembly was able to traverse 79% of the 40 vessels treated, including 16 of the 17 (94%) vessels that were totally occluded. The current study, however, does not address patency of vessels after laser recanalization.

Ablation with excimer laser energy occurs only when the silica fiber is in direct contact with the target tissue because there is no converging or diverging lens on the fiber tip. Therefore, the laser beam exiting the essentially flat fiber face diverges rapidly, causing the fluence to diminish as well. This property is advantageous in that the danger of perforating a vessel wall after the laser beam has penetrated an occlusion is lessened. The mean tissue irradiation time at all centers was 54 sec. Therefore, intraoperative laser angioplasty did not significantly extend operation time or cardiopulmonary bypass time (Table 2). Eight patients had evidence of myocardial injury within the first 48 hr of operation; however, no patients died as a result of laser treatment.

Intraoperative use of laser angioplasty in conjunction with coronary artery bypass surgery may have limitations. Additional investigation should provide information regarding the most effective use of this procedure, such as whether lasing proximal or distal stenoses is appropriate. Performing laser angioplasty on lesions proximal to a bypass graft may not be advantageous. In conventional coronary artery bypass procedures, competition of blood flow ("steal effect") between the native vessel and the graft has been observed [9–12]. Occlusions in distal vessels usually cannot be surgically bypassed because of their small

TABLE 4. Laser Parameters and Lesion Characteristics Before and After Laser Treatment*

Vessel type	Treatment center	Lesion characteristics: Length (mm)	Lesion characteristics: Stenosis (%)	Lesion characteristics: Location[a]	Laser parameters: Fluence (mJ/mm^2)	Laser parameters: Pulses (*n*)	Luminal diameter (mm): Pre-op	Luminal diameter (mm): Post-op
LAD	THI	30	85	Dist	30	2694	<2.0	<2.0
		10	100	Prox	35	826	0	2.0
		40	90	Prox	35	80	0	2.0
		30	100	Prox	40	384	0	2.0
		40	80	Dist	35	568	0	2.0
		40	100	Dist	40–45	2200	<1.0	—[b]
		15	95	Prox	50–60	583	0	2.0
		30	100	Prox	40	113	<1.0	—
	AHI	3	100	Prox	40	160	0	2.0
		4	90	Prox	50	340	1.0	2.0
		5	100	Prox	50	580	1.0	2.0
		40	100	Prox	40	80	0	1.0
		10	95	Prox	40–60	3750	1.0	1.0
		8	80	Prox	40	390	1.5	2.0
		8	90	Dist	40	900	1.0	1.0
	Uppsala	10	60	Prox	50	120	<1.5	>1.5
		4	75	Prox	50	170	1.0	1.5
		6	30	Dist	55	70	1.0	1.5
		10	90	Prox	50	119	1.0	2.0
		3	30	Dist	50	119	1.0	1.5
OM	THI	20	70	Prox	30	207	<2.0	2.0
		20	100	Prox	35	410	0	2.0
		10	100	Prox	30	276	<1.0	1.5
		15	70	Prox	35–40	996	<1.0	2.0
		10	100	Prox	40–50	467	0	2.0
	AHI	5	100	Prox	40	300	—	2.5
		4	85	Prox	40–60	50	1.0	1.5
RCA	THI	60	100	Prox + Dist	30	233	0	2.0
		30	100	Prox	35–60	2231	<1.5	2.0
		15	100	Prox	35–50	2097	0	2.0
	AHI	45	85	Prox	50	670	1.5	2.0
		40	95	Prox	60	2310	1.0	1.5
		50	100	Prox	60	2750	1.0	1.0
PDA	Uppsala	6	60	Dist	55	56	1.0	1.5
		4	75	Dist	50	195	1.0	1.5
		5	60	Prox	35	230	1.5	2.0
DX	Uppsala	6	90	Dist + Prox	60	2640	0.5	Perf
		6	80	Prox	50	70	1.0	1.5
VG	THI	20	90	NA	40	882	—	—
	AHI	40	100	NA	40	675	1.0	2.0

[a]Prox, proximal; Dist, distal location in relationship to anastomosis of graft.
[b]Data not available.
*AHI, Arizona Heart Institute; DX, diagonal; LAD, left anterior descending artery; NA, not applicable; OM, obtuse marginal artery; PDA, posterior descending artery; Perf, perforated; RCA, right coronary artery; THI, Texas Heart Institute; VG, vein graft.

diameter. Restoring blood flow through distal vessels, however, may enhance the runoff of blood from the graft, thus increasing graft patency. For this purpose, adjunct intraoperative coronary laser angioplasty may prove beneficial. In our study, 10 of the 40 occlusions (25%) treated were distal to the graft anastomosis. In many cases, the diameter of the laser assembly was too wide to

permit treatment of distal occlusions, but we hope that new designs in laser delivery systems will overcome this limitation.

In conclusion, we believe that intraoperative excimer laser angioplasty as an adjunct to coronary artery bypass surgery proved a safe technique. The long-term effectiveness of improving myocardial revascularization with intraoperative laser angioplasty remains unknown.

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