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Editorial Comment

Laser Arterial Recanalization: A Current Perspective*

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Laser irradiation has certain properties that make it applicable for arterial recanalization. These include its ability to vaporize tissue as well as to be selectively absorbed by different tissues. Like ordinary light, a laser beam can be conducted through flexible optical fibers. It is this ability that allows the laser to be adapted to standard catheterization techniques for arterial recanalization.

Potential role of the laser in treating coronary artery obstructions. Despite the success and wide acceptance of coronary balloon angioplasty and bypass surgery, revascularization cannot be accomplished in many patients with these techniques. Furthermore, patients with reoccluded bypass grafts and restenosis after balloon angioplasty comprise a constantly growing population group. It is in this type of patient that laser recanalization may provide the alternative therapy for revascularization. Unlike balloon angioplasty, which redistributes the plaque, and bypass surgery, which bypasses the plaque, the laser beam ablates plaque material into its elementary components, namely water vapor, carbon dioxide and other combustion by-products (1). By reducing the bulk of obstructing plaque and leaving behind a smooth vascular surface, the laser beam has the potential of reducing the restenosis rate seen with balloon angioplasty. Also, as a percutaneous procedure, it may be repeated on several occasions, thus postponing the need for major surgical procedures.

Experimental studies. Preliminary work using laser irradiation (2–4) was conducted to evaluate the effect of various wavelengths, pulse duration and energy fluences (joules/cm^2) on plaque vaporization. These studies demonstrated that the majority of laser wavelengths in the visible and infrared region of the electromagnetic spectrum was absorbed by plaque and converted into heat, which subsequently vaporized the plaque. In the ultraviolet region of the spectrum, excimer laser wavelengths appear to have a photochemical type of effect resulting in plaque ablation with minimal thermal damage. Pulsed laser systems at a low hertz value also resulted in ablation with minimal thermal damage to the surrounding artery. Such systems were more efficient in the ablation of calcific plaque (3).

Experiments conducted in atherosclerotic animal models confirmed the feasibility of laser recanalization in the presence of circulating blood without embolization (5). Chronic follow-up of arterial sites irradiated with an argon or carbon dioxide laser did not show acceleration of atherosclerosis despite persistent elevation of serum cholesterol (6,7). Unfortunately, bare fiber-optic delivery systems resulted in frequent arterial perforation. Perforation in the peripheral circulation did not lead to hemodynamic compromise; however, in the coronary circulation of dogs (8), perforation consistently led to cardiac tamponade and death.

Laser catheter systems to prevent perforation. Because of the high perforation rate with the bare optical fiber, several modifications of the fibers were introduced. The first modification was the placement of a metal ring around the tip of the optical fiber. Use of the ring helped to visualize the fiber tip during fluoroscopy but it did not prevent beam scatter from the end of the optical fiber, and a high perforation rate also resulted. Another modification was introduced that encapsulated the entire optical fiber tip with a metal cap resulting in a pure thermal probe called the "hot-tip" (9). With this device, perforations were markedly reduced because of the blunt shape of the fiber tip as well as the absence of beam scatter, but the device could only create a channel equal to its own size. Further modification of this device led to a "hybrid" probe (10) that allowed 20% of the laser beam to exit from the end of the metal cap through a small window. Behind the window a sapphire lens focused the exiting beam, thus limiting the beam scatter. Another system utilized only a sapphire-tipped catheter (11). In another effort to prevent perforation, a window was placed at the end of the catheter to allow the laser radiation to exit through the transparent window to ablate plaque (12). This device also allowed for information on the detection of fluorescence from the impact on the arterial wall to be fed back to a computer, which then analyzed the fluorescence and differentiated plaque from the normal wall. This information was then used to inhibit laser activation if normal wall was encountered. Ultimately, this "intelligent" catheter system could be utilized to ablate plaque safely.

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Clinical studies. Clinical studies were initiated using various fiber modifications. Preliminary studies (13) were done in the peripheral circulation using a bare fiber through a balloon catheter to maintain a coaxial position within the vascular lumen. This created a small vascular lumen and also resulted in frequent arterial perforation. Other studies (14) were conducted using the "hot-tip" probe. Balloon angioplasty was required to enlarge the channel in peripheral arteries. The advantage afforded by these "hot-tip," "hybrid" and sapphire-tipped fibers was that totally occluded arteries could now be recanalized and subsequently dilated with balloon angioplasty, thus avoiding bypass surgery. The perforation rate was reduced to <20%. In the superficial femoral artery, perforations did not result in the need for transfusion or emergency bypass surgery. Debris materials collected weighed <1 mg (10).

Similar devices have been tested in the coronary circulation in patients and have revealed that arterial recanalization was feasible (15,16). However, success in the coronary circulation has been limited by the lack of adequate mechanical engagement of the plaque, resulting in difficulty in crossing the obstruction. This has also led to excessive thermal damage to the arterial wall resulting in thrombosis.

The current study. Quantitative spectroscopy as a diagnostic technique described in the study by Leon et al. (17) in this issue of the Journal provides an alternative approach to laser arterial recanalization without perforation. Specifically, this system provides a feedback mechanism to stop lasing by recognition of the fluorescence signal of normal arterial wall. The highest fluorescense intensity signal was obtained by using a broad blue light excitation or with a helium-cadmium laser at 325 nm. The normal arterial wall signal was differentiated from the plaque signal by enhancement of these signals using a computerized video method. This study was done in vitro and the effectiveness of this system will need to be confirmed in vivo. If the fiber system is in direct contact with the plaque, however, the interspaced blood would be mostly displaced; thus, it may not alter the effectiveness of the system. In stenosis, however, it may be more difficult to achieve a clear field. Thus, interruption of blood flow or displacement with saline solution may be required. Another possible limitation of this system is the small diameter of the channel made, which may require balloon angioplasty as follow-up therapy. Also, a thin arterial media with a deeply localized plaque in the vascular wall could potentially result in loss of adequate structural integrity. Finally, similar nonenhanced detection methods may be adequate for a safe recanalization approach (18).

The use of a steerable guidewire system has allowed for considerable reduction in the perforation as noted with other devices. A "monorail" wire guidance for the heat-delivering fiber systems has reduced the perforation in animal and clinical studies. Thus, the need for an expensive and sophisticated feedback mechanism may not be necessary, especially in stenoses.

Two other imaging techniques are currently available that could potentially be used to guide arterial interventions. Endovascular two-dimensional echography at the tip of a catheter can provide detailed cross-sectional images of the arterial lumen including thickness and composition of plaque (19). Miniaturized angioscopes (0.5 mm diameter) can also provide detailed images of intra-arterial pathologic lesion and dimension analysis (20).

Conclusions. The study of Leon et al. (17) can be perceived as another advance in the field of laser technology and photobiology. The feedback mechanism using plaque identification to control plaque ablation may improve the safety of the laser recanalization process, especially in small arteries. Ultimately, several devices including mechanical systems may prove to be effective to recanalize obstructed arteries. Which technique will turn out to be most effective for a specific type of pathologic lesion (clot, calcific plaque or fibrotic plaque) will need to be further defined.

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