JOURNAL OF BIOMEDICAL OPTICS 2(4), 347–349 (OCTOBER 1997)

LASERS, THE PHYSICIAN, AND THE VESSELS

Herbert J. Geschwind
Universite Paris XII, DER d'Ethique Médicale, Faculte de Medecine, 8 rue du Général Sarrall, 94010 Créteil, France

(Paper JBO-165P received Jan 14, 1997; accepted for publication July 17, 1997.)
[S1083-3668(97)00704-1]

1 BIRTH OF ANGIOPLASTY

The concept of relieving vascular stenoses by inflating a balloon mounted on the tip of a catheter was a major breakthrough in the treatment of cardiovascular disease when it was initiated in the late 1970s by Gruentzig in Zurich, Switzerland.[1] The latter took advantage of the earlier concept by Dotter in the 1960s, who thought that passing a catheter through a vessel stenosis could enlarge the lumen, thus restablishing an adequate flow distal to the lesion. It took 15 more years to build up a catheter with an inflatable balloon that could push aside the obstructing material and compact it against the vessel wall to restore an adequate lumen.

The first attempt in 1977 on a coronary artery stenosis was successful. This gave a major incentive to physicians to keep going with this technique and to companies to develop new products with more flexibility, thinner catheter diameters and greater "pushability". Born in Europe, the new method of treating coronary heart and peripheral vessel disease became an alternative to the previously utilized techniques, namely, medical treatment or bypass surgery. Its uses rapidly overwhelmed health care institutions, which led to the development of more and more sophisticated X-ray equipment and improved imaging quality for more precise diagnosis of lesion severity.

A new field of specialty developed after Gruntzig was attracted by U.S. medicine, namely, the Emory University Hospital in Atlanta, where he created the Interventional Cardiology Catheterization Laboratory in 1979. Courses were rapidly developed to teach cardiologists and radiologists the technique of percutaneous approach via the femoral artery, positioning of the guiding catheter into the coronary ostia, and pushing the balloon catheter through the lesion under fluroscopic and angiographic control.

The first generation of catheters was replaced by the "over the wire" technique which consisted of distally advancing a metallic guidewire through the stenosis and then pushing the balloon catheter over the wire and positioning it in the lesion, where the balloon was inflated. However, it was rapidly realized, based on histologic data from both animal experiments and clinical procedures, that this method split the atheroma but did not ablate it and the arterial wall was overstretched, with major damage consisting of fractures, fissures, and tears extending from the intima to the media and even sometimes to the adventitia. Moreover, both angiography and histology showed that the results obtained by dilatation were far from being optimal. In other words, since no obstructing material was ablated, tissue remnants were left behind in the lumen, thus leaving a residual stenosis. The latter could not consistently be seen with angiography since this method of evaluation is not precise enough to detect for tissue remnants. The latter could be recognized only when new diagnostic tools such as angioscopy and intravascular ultrasound devices showed flaps and inadequate lumen associated with major damage inflicted to the arterial wall following dilatation.[2,3]

2 BIRTH OF ATHERECTOMY

It was thought that these results could be improved by the use of devices that would be able to ablate tissue rather than pushing it aside. This technique was called atherectomy.[4,5] Mechanical atherectomy consisted of rotational abrasion of hard tissue whereas directional atherectomy was aimed at cutting tissue longitudinally to restore an adequate lumen. Both of these devices had the drawback of being too large for the coronary vessels if one wanted to restore a normal lumen, too stiff, and finally too difficult to steer in small tortuous vessels.

3 LASERS

On the other hand, laser technology appeared to be the ideal tool since it had been shown to deliver a high energy level for ablation of any kind of tissue, including hard metals or calcium. Moreover, the energy could be delivered through flexible, thin optical fibers without any significant loss of energy from the laser cavity to the obstructing target located in the tortuosities of small, distal coronary arteries.[6] Since the technology of thin optical fibers was well established in the field of communication, it was thought that it would be easy to build a laser catheter similar to the one commonly used for bal-

---

Address all correspondence to Herbert Geschwind. Phone and Fax: 331 4981 3665; E-mail: geschwind@univ-paris12.fr

loon angioplasty, with a single fiber or fiber bundles aimed at delivering the ablation capability of the laser to the obstructing target tissue. However, at that time, only one fiber was coupled into a continuous wave argon or Nd YAG laser for delivery of heat, resulting in coagulation, carbonization, and necrosis. The thermal effect was enhanced by the use of the so-called ''hot-tip'' consisting of a balloon-shaped metal ball mounted at the tip of the laser catheter for even heat distribution and an atraumatic catheter tip. Indeed, this generation of catheters was extensively used in the peripheral arteries and to a lesser degree in the coronaries because it was rapidly realized that focusing high energy toward the arterial wall could create perforations, with subsequent blood extravasation. Therefore the goal of laser angioplasty gradually became not to utilize focal energy with the risk of perforation and actually not to take advantage of the true characteristics of laser power, but to turn it into heat, mild or moderate, in order to melt parts of the obstructing tissue. Doing so, it was not necessary to focus the laser beam toward the obstacle but just to let heat dissipation act. Thus, there was no need for a laser but for heat, which could be obtained as well from any source of energy that was less expensive and less dangerous. The risk of perforation was due to the inability of bidimensional fluoroscopy and angioscopy to determine the precise position of the catheter tip relative to the wall. It appeared that a complementary feedback would be required which could consist of additional imaging techniques such as angioscopy or intravascular ultrasound and fluorescence spectroscopic detection of atheromatous tissue.

4 HEATING MACHINES

Recanalization of occluded peripheral arteries was obtained with the ''hot tip'', but some groups argued that the same results could have been obtained with the metal tip not heated.[7] Thus, it was thought that the mechanical so-called ''dottering effect'' played a major role. However, heating was followed by complications in rare attempts to recanalize occluded coronary arteries. Although some authors showed that the thermal effect induced less platelet aggregation than pulsed lasers, a majority of specialists in the field selected pulsed laser technology for vessel recanalization. This change of mind was due to the new availability of pulsed excimer or holmium YAG lasers since the high energy per pulse could be coupled into thin optical fibers without breaking them down. This major breakthrough was obtained by lengthening the pulse duration, thus allowing high peak energy to be reduced. The attraction of pulsed excimer lasers stemmed also from the histological demonstration that this type of emission provides clear cuts with smooth edges, without any thermal effect.

4.1 UNEXPECTED LASER EFFECTS

The problem of such an experimental finding was that the interesting results were obtained in air. The results in blood or saline were different. It took several years for researchers to show that pulsed irradiation on vessel walls results in major damage, with tears and dissection of the intima that extended to the media and even to the adventitia. At first these effects were thought to be due to acoustic shock waves generated by the high pressure developed at the pulse peak.[8] It was secondarily shown that irradiation in vessels resulted in flattening of internal elastic lamina, deep tears within the media located not only at the site of laser delivery but also at a distance distal to it. Also, high-speed photography showed that each pulse of delivery induced vessel dilatation followed by constriction due to fast-expanding gas bubbles, followed by their collapse. Moreover, scanning electron microscopy showed that after pulse irradiation of vessel wall tissue, a crater with a diameter similar to that of the multifiber catheter could be created but that the results were far from being optimal. There were tissue remnants left by dead space between the fibers and side effects consisting of tissue elevation and dissection around the crater edges. The experimental results were consistent with those observed after laser angioplasty: incomplete recanalization due to tissue remnants, almost 50% angiographically detectable dissections, some reocclusions, perforations, aneurysmal formations, and more important, a high restenosis rate, at least similar to that observed after balloon dilatation.

5 NEW DEVICES

Thus, what could interventional cardiologists do with lasers in diseased vessels? Keep going with those expensive machines and catheters that gave poor results, give up, or try to do something else? Actually, since the multifiber catheter was wire guided, it could not treat total occlusions, which was a major limitation of the technique. Consequently, a new device came out consisting of a conventional angioplasty guidewire with 12 optical fibers which was aimed at creating a pilot channel for subsequent multifiber laser angioplasty or dilatation.[9]

6 TRANSMYOCARDIAL LASER REVASCULARIZATION

More recently an old concept has been revived for clinical application. Its goal is to improve blood supply to the myocardium by creating channels to increase blood flow from the left ventricle throughout the channels.[10] The channels were created by using a surgical approach with a CO_2 laser or by an intraventricular approach with excimer or holmium YAG lasers. Few experimental data are available that could demonstrate an increase in myocardial blood flow, reduced ischemia, or a significant improvement in left ventricular systolic function. Despite this lack of evidence, clinical trials are under way that show a drastic decrease of symptoms in patients with intractable angina. These results are thought to be related to a neurogenic effect, induction of angiogenesis, or a direct increase of blood supply through the channels.

Do these facts mean that laser angioplasty has totally failed? The answer is not clear. On the one hand, a majority of interventional cardiologists are deeply disappointed after a more than 10-year period during which no superiority of laser angioplasty over conventional techniques could be demonstrated. This in turn did not stimulate companies to develop products that are expensive, thus limiting the number of institutions willing to purchase laser equipment. On the other hand, some difficulties of using the device may be at least partly solved. For example, the strong side effects could be reduced by saline flushing during laser emission, multiplex energy delivery at the distal catheter tip, or homogeneous distribution of light through a window mounted on the tip.

7 EXPECTATIONS

Great expectations could be anticipated if the enormous potential of laser technology were realized. It seems paradoxical to learn that the U.S. Air Force plans to develop a laser system able to destroy a high-speed missile at a 300-km distance and to realize that a laser beam in contact with an almost stationary target within a vessel is unable to ablate it properly. Such a discrepancy could well be the consequence of insufficient investment in research and development of laser technology in medicine and especially in that of angioplasty. Obviously, insufficient notice has been taken of the unique potential for laser beams to be specifically focused on an atheromatous target through ultrathin optical fibers. This is especially true at a time when stents are being used extensively following suboptimal angioplasty results to prevent early recoil and arterial wall remodeling, and to treat dissections or tissue remnants.

The combination of effective atheroma ablation without damage to the arterial wall and stent implantation to obtain a long-term optimal result without significant restenosis could well be the ideal method of treatment for stenotic vessel lesions, at least during the next 5 or 10 years. Then prevention of atherosclerosis through diet, no smoking, and administration of specific drugs could possibly avoid interventions or surgery. Moreover, it may be possible to use soft laser irradiation on the arterial wall during or following angioplasty to reduce the smooth muscle cell proliferation process, the third component of restenosis, which is induced by wall damage due to overstretching by balloon or pulsed laser shock waves.

It is really a gamble to predict the future of laser treatment for vessel disease at present, because the credibility for new recanalizing devices is low whereas the expectations for arterial remodeling with stents and grafts is high. It is the task of physicians, companies, engineers, physicists, and investors to promote research and development in laser technology for the best interest of patients with arterial disease.

REFERENCES

1. A. Gruentzig, A. Senning, and W. E. Siegenthaler, ''Nonoperative dilatation of coronary artery stenosis: percutaneous transluminal coronary angioplasty,'' *N. Engl. J. Med.* **301**, 61–68 (1979).
2. F. S. Larrazet, P. J. Dupouy, J. L. Dubois-Rande, A. Hoirosaka, J. Kvasnicka, and H. J. Geschwind, ''Angioscopy after laser and balloon coronary angioplasty,'' *Am. Heart J.* **23**, 1321–1326 (1994).
3. R. A. Nishimura, W. D. Edwards, C. A. Warnes et al.: ''Intravascular ultrasound imaging: *in vitro* validation and pathological correlation,'' *J. Am. Coll. Cardiol.* **16**, 145–154 (1990).
4. S. H. Stertzer, J. Rosenblum, R. E. Shaw et al., ''Coronary rotational ablation: initial experience in 302 procedures,'' *J. Am. Coll. Cardiol.* **21**, 287–295 (1993).
5. E. Topol, F. Leya, C. Pinkerton, P. L. Whitlow, B. Hofling, C. A. Simonton, R. R. Masden, P. W. Serruys, M. B. Leon, D. O. Williams, S. B. King, D. B. Mark, J. M. Isner, D. R. Holmes, S. G. Ellis, K. L. Lee, G. P. Keeler, L. G. Berdan, T. Hinohara, and R. M. Califf, ''For the CAVEAT study group. A comparison of directional atherectomy with coronary angioplasty in patients with coronary artery disease,'' *N. Engl. J. Med.* **329**, 221–227 (1993).
6. H. J. Geschwind, G. Boussignac, B. Teisseire, and C. Vieilledent, ''Percutaneous transluminal laser angioplasty in man,'' *Lancet* **2**, 844 (1984).
7. D. C. Cumberland, D. I. Taylor, C. L. Welsh et al., ''Percutaneous laser thermal angioplasty: initial clinical results with a laser probe in total peripheral artery occlusions,'' *Lancet* **1**, 1457–1459 (1986).
8. T. G. Van Leeuwen, J. H. Meertens, E. Velema, M. J. Post, and C. Borst, ''Intraluminal vapor bubble induced by excimer laser pulse causes microsecond arterial dilatation and invagination leading to extensive wall damage in the rabbit,'' *Circulation* **87**, 1258–1263 (1993).
9. J. N. Hamburger and P. J. de Feyter, ''Recanalization of chronic total occlusions using a laser guidewire: the first 100 patients in a single-center experience,'' *Circulation* **I-94**, 618 (1996).
10. M. Clayton, Y. Wang, M. J.-Herold, C. Klassen, M. Unress, K. Ugurbil, C. Sampson, S. L. Wann, M. Mirhosheini, ''Ventricular function and volumes in acute ischemia after transmyocardial laser revascularization: quantification by cine magnetic resonance imaging,'' *Circulation* **I-94**, 295 (1996).