RECENT DEVELOPMENTS IN LASER CARDIAC SURGERY

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(Paper JBO-053R received Nov. 6, 1995; accepted for publication Nov. 6, 1995)

Key Words laser cardiac surgery; balloon dilation; atherectomy; laser angioplasty; occlusions.

1 INTRODUCTION

The treatment of coronary heart disease changed drastically in 1977 when Gruentzig in Zurich successfully performed the first percutaneous coronary angioplasty.[1] This treatment became an alternative to either medical or surgical treatment using coronary aortic bypass grafting. The initial success of the procedure made this technique very popular and aroused major interest, worldwide application, and technologic development along with great investment. Such a development was due to the nonsurgical approach, a minimally invasive procedure consisting of femoral arterial puncture. This is a relatively safe procedure that is easy to perform provided adequate training is given to the interventional cardiologist or radiologist.

2 BALLOON DILATION

Briefly, the procedure consists of the introduction into the diseased coronary artery of a small balloon over a metal guidewire which is aimed at crossing the arterial stenosis or occlusion, the penetration of the distal catheter tip of a deflated balloon and its final inflation at a high pressure. This maneuver is aimed at pushing the atheromatous obstructing material aside and compressing it against the arterial wall. However, in the process, the elastic component of the arterial wall may become overstretched and the hard atheromatous material split, fissured, or fractured, resulting in tears within the vessel wall called dissections. The deep damage inflicted to the arterial wall is thought to induce the phenomenon of restenosis which consists of proliferation of smooth muscle cells migrating from the media to the inner layer of the wall (intima), invading the arterial lumen and reducing its diameter or cross-sectional area to a size that drastically decreases the distal coronary flow. The vessel damage also initiates a fibrotic healing process that reduces the diameter of the vessel. Dissections also are prone to cause stenosis or occlusion since the flaps are likely to invade the arterial lumen under pressure of the blood flow in the coronary artery.

3 ATHERECTOMY

These drawbacks, namely, the effects on the arterial wall and the consequent reduction in flow, rapidly led to the concept that ablating the atheromatous material would be superior to pushing it aside and compacting it at the vessel wall. This concept induced research on new ablating tools for the process, which was referred to as atherectomy. Mechanical atherectomy was performed with either a directional device aimed at cutting the obstructing material longitudinal to the arterial great axis or a rotational device that used varying sizes of burrs rotating at a high speed (200,000 rpm) to abrase the hard material, debulk the vessel and increase its pliancy after removal of the fibro-calcific atheroma, when only the elastic component of the coronary arterial wall is left.

4 LASER ANGIOPLASTY

Among the devices able to remove the obstructing material, laser technology seemed to be appealing because of the high capability of laser energy to destroy any kind of tissue. Moreover, laser energy is transmitted without significant loss of energy by optical fibers, which are commercially available at a low cost because of their extensive use in communication. However, due to the high energy involved, the first attempts at delivering high-energy peaks through optical fibers failed because of the breakage of the quartz material. For this reason only continuous-wave lasers were utilized at the early stage of the technique and resulted in deep thermal effects and consequently in a vaporization process. The use of the latter was followed by limited success in peripheral leg arteries but major failures in the coronary arteries. The laser catheters transmitted either visible light with the argon gas source or infrared light with the neodymium/yttrium-aluminum-garnet (YAG) solid-state source through bare fibers or catheters mounted with a metal distal tip for heat dissipation.[2] For this reason it was called the "hot tip" technique.[3] Due to its limited efficacy, it was rapidly replaced by pulsed lasers emitted from either gas (excited dimer: excimer at 308 nm), liquid visible dye or solid midinfrared (Holmium YAG at 2.1 μm) sources.[4] Single-fiber catheters were replaced by multiple-fiber catheters consisting of 20 to 300 optical fibers of 50 to 100 μm, each concentrically or eccentrically arranged around a lumen for the passage of a guidewire.

The device that is commonly used nowadays is built according to these principles: (1) multiple fibers for debulking the artery with a large catheter and high flexibility for easy tracking through tortuous arteries; (2) pulsed lasers that deliver high peak energy for effective tissue ablation and low thermal effect; (3) guidance with a conventional angioplasty guidewire aimed at maintaining the catheter coaxial to prevent irradiation of the wall and reduce the risk of perforation. The era of this technique using varying catheter sizes with a preferentially excimer laser because of high protein absorption and low thermal effect started in the late eighties and became popular due to the sophistication of the method, the potential for hard tissue ablation, and the easy-to-use, over-the-wire technique derived from balloon dilation. More than 10,000 patients have been treated in the United States, in Asia and in Europe with a relatively high success rate (85 to 90%) and a reasonably low complication rate (5%).[5,6] However, it rapidly became apparent that laser angioplasty alone could not enlarge the vessel lumen adequately because to obtain this result, the ratio of the vessel to the catheter diameter had to be kept around 1. Doing so markedly increased the risk of wall damage by dissection or perforation. Consequently, to obtain an optimal result, adjunctive balloon dilation was required in 80% of cases. The rate of laser stand-alone procedures was low so the effect of lasers on arterial debulking and vessel wall injury could rarely be evaluated. Vessel walls were damaged not only by the laser-induced shock waves but also by overstretching at high inflation pressures.[7,8]

4.1 Goal of Laser Angioplasty

The actual aim of laser angioplasty was ambiguous even at an early stage of the technique. The original goal for most research groups and clinicians was to create a pilot hole through totally occluded vessels for subsequent angioplasty. This was done with bare optical fibers associated or not with a feedback system that allowed determination of the target tissue. Indeed, it seems risky to create a channel through a total occlusion without determining the precise position of the distal end of the tool aimed at emitting laser irradiation. Fluoroscopy, even if associated with angiography, is not precise enough for the spatial determination of the irradiating tip relative to the vessel lumen and wall. For this reason preliminary attempts have been performed to recanalize totally occluded peripheral arteries using a feedback system consisting of a low-power laser emission at the distal fiber tip to collect a spectroscopic signal.[9] This signal is processed in a computerized system which can discriminate normal from diseased tissue by fluorescence. The laser power is activated only when diseased tissue is recognized at the tip of the fiber. Although more than 300 patients with arterial disease have been treated with this device with an 80% immediate success rate and a low complication rate (10% perforation without clinical sequelae), this method of tissue detection and ablation has not been widely used because of the high degree of sophistication required, the high cost of the machine, and the inability to steer the catheter accurately.

5 Total Occlusions

The concept of recanalization of totally occluded coronary arteries again became popular when guidewires containing 12 optical fibers were manufactured for penetration of occlusions in cases of failure with conventional guidewires.[10] Thus, a niche was found for specific indications consisting of unsuccessful attempts at penetrating total occlusions in patients with viable myocardium, short lesions, and visualization of the distal vessel bed. Recent trials reported a 53% recanalization success rate with 24% perforation and 8% dissection rates. Since the system is blind in terms of tissue determination without any spectroscopic feedback, only short lesions with visible distal vessels can be subjected to this procedure with relative safety. The other goal of laser angioplasty has been to debulk the obstructed vessel by ablating the atheromatous material. This was only partly achieved with multifiber catheters guided by a wire to maintain the distal catheter tip coaxially so that the laser emission is directed toward the lumen at a specific distance from the arterial wall. Damage inflicted by the high energy pulses to the latter structure may be reduced by using a saline flush and/or multiplex delivery to minimize the size of the bubbles, the rapid expansion and collapse of which are thought to induce tears, dissection, or perforation.[11]

6 Laser Transmyocardial Revascularization

Finally, instead of recanalyzing obstructed coronary arteries, an alternative method for revascularization has been recently proposed.[12] The latter consists of creating channels within the myocardium in order to conduct more blood. The channels were created by a CO_2 laser in ischemic myocardium. The results are still controversial since evidence for patent channels after several weeks has not been reported by all the groups involved in the research and only a few groups reported on improvement of the left ventricular function or myocardial contractile reserve.

7 STAGES OF INTERVENTIONAL CARDIOLOGY

Interventional cardiology is now at the third stage of research and development. The initial stage consisted of the early attempts at recanalization using exclusively balloon dilation to relieve stenosis. The second step led to the concept of tissue ablation with either mechanical or laser devices. Since the late eighties we have entered the era of maintaining a vessel's patency through dilation and implantation of stents. [This concept reduced markedly the usefulness of safe debulking.] On the other hand, since wall damage may be obviated by appropriate endoprosthesis placement, techniques aimed at ablating hard material and increasing arterial compliance may be more effective and safe if they are followed by stent wall protection. Finally, the future of laser angioplasty and transmyocardial revascularization depends strongly on the investment in research and development and the reduction in cost so as to make the technique cost/benefit and risk/benefit efficient for patients. Appropriate laser delivery exclusively on the target tissue without wall damage should be evidenced, and myocardial channel long-term patency should be demonstrated before the technique can be widely, ethically applied in patients.

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