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LONG TERM CHANGES IN THE VASCULAR WALL AFTER LASER RECANALIZATION OF AN ARTERY

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Research into an alternative method of treatment of atherosclerosis of the vessels, namely laser recanalization, has been conducted vigorously in recent years [1, 2, 8, 9, 12, 13]. Experiments in vitro and in vivo have led many research groups to use this new method in clinical practice [1, 2, 5, 9, 10, 11]. Nevertheless, laser recanalization of atherosclerotic arteries still requires further intensive experimental study and analysis of the late results of its clinical application [10, 12, 13], with a view to establishing the place and role of the method in the treatment of arterial atherosclerosis.

The method consists essentially of removing the atherosclerotic plaque from the lumen of an artery by the use of laser energy. Laser radiation is transmitted by thin flexible light guides, advanced to the site of the atherosclerotic lesion in the vessel by the use of special laser catheters, and by means of transcutaneous catheterization of the artery. We have undertaken an important study of repair processes in the arterial wall after laser irradiation, for they determine the patency of the recanalized vessel in both the short and the long term.

The aim of this investigation was to determine experimentally possible alternative forms of the course of repair of the arterial wall after laser application and, on that basis, to choose the optimal regime and tactics for laser recanalization of blood vessels.

EXPERIMENTAL METHOD

In chronic experiments on nine mongrel dogs, laser irradiation was applied to the intact vessel wall by means of different systems of laser catheters. Laser irradiation was applied to the wall of the aorta or iliac arteries through a transcutaneous endovascular access (through the femoral or axillary artery). After induction of anesthesia and identification and catheterization of the artery, aortography or angiography of the iliac arteries was carried out. When the angiographic picture had been obtained the site for laser application was identified on the basis of roentgeno-anatomical data. Next, a guided laser catheter or specially modeled angiographic catheter with light guide was introduced into the lumen of the aorta or iliac arteries. Such catheters enabled laser radiation to be applied to the vessel wall. Manipulations of the laser catheter in the lumen of the vessel were carried out under roentgenotelevision control on an angiographic monitor, making

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TABLE 1. Characteristics of Experimental Material

Site of laser irradiation	Total number of sessions of laser irradn.	Type of catheter		Time after irradiation
		light guide	tip	
Descending aorta	8	2	6	16—1 days 2 months
Abdominal aorta	9	9	0	7 days
Subclavian »	10	3	7	1—3 and 7 days
Iliac artery »	7	5	2	3days 2 — 8 months
Femoral artery »	12	7	5	16—28days 28 days 8 months
Total	46	26	20	

Legend. Light guide – a type of laser catheter consisting of an angiographic catheter with laser light guide introduced into its lumen; a tip signifies various tips of spherical shape (quartz, sapphire, metallic).

use of bony reference points. Laser irradiation was applied at five or six points of the arterial wall, separated from one another by intervals of about 1-2 cm. After the end of laser irradiation, a control angiogram was obtained in order to reveal any perforations, dissection of the wall of the vessel, or the development of juxtamural thrombosis or thrombotic occlusion of the laser-irradiated segment of artery. If the femoral or axillary arteries were chosen as the objective of laser irradiation, the operation was performed under visual control. A segment of artery 5-6 cm long was first isolated, clamped with forceps on both sides, and arteriotomy was performed. The inner surface of the vessel wall was irradiated by the laser from the side opposite to the incision at two or three points. The irradiated arterial wall was then examined and integrity of the vessel restored by insertion of two to four U-shaped sutures using atraumatic needles. Having made sure that the central and peripheral segments of the vessel were patent, the operation wound was closed in layers and the sodium salt of benzylpenicillin injected intramuscularly in a dose of 50,000 U/kg body weight. The source of laser radiation in all cases was a laser on copper vapor and an ND:YAG laser (model "LTI-502"). Laser irradiation was carried out by pulsed transmission of energy with a power of 6-10 W and a pulse duration of 2-5 sec. After the end of the experiment in no case were thrombolytic or antiaggregative preparations used. The animals remained under periodic observation and were tested repeatedly at various times after laser irradiation of the artery: 1-3 and 7 days (two dogs), 16 and 28 days (two dogs), and 2-8 months (Table 1).

In the repeated experiments an angiographic study was made of the relevant zone of laser irradiation in the vessel wall. For this purpose the left common carotid artery was catheterized and a catheter introduced into the ascending aorta, aortoarteriography was carried out with identification of the zone of concern. The dog was killed after removal of the catheter. Segments of vessels subjected to laser irradiation were excised and, after macroscopic study, were fixed in a 10% solution of neutral formalin. Three to five sections were cut from each segment of the vessel, and paraffin sections were stained with hematoxylin and eosin, orcein and pircofuchsine by Van Gieson's method, and examined under the light microscope.

EXPERIMENTAL RESULTS

As a result of exposure of the vessel wall to laser energy, a definite volume of tissue was removed and a defect of varied depth formed in the arterial wall. In the early period after laser irradiation (2nd-7th day) the defect in the arterial wall resembled a crater of varied depth: from 100 to 200 μ (Fig. 1). Around the edges of the crater (its entire perimeter) a thin zone of thermally carbonized tissue from 20 to 40 μ thick and a zone of coagulation changes up to 200 μ in depth, and varying in their degree of magnitude, especially under the base of the crater, could be observed. These changes are connected with the thermal action of laser radiation on the arterial wall. In the media and, in particular, in the outer membrane of the vessel, small areas of hemorrhage could frequently be seen. The integrity of the inner elastic membrane was disturbed, and disorganization and rupture of elastic fibers could be observed down to a depth of 400 μ.

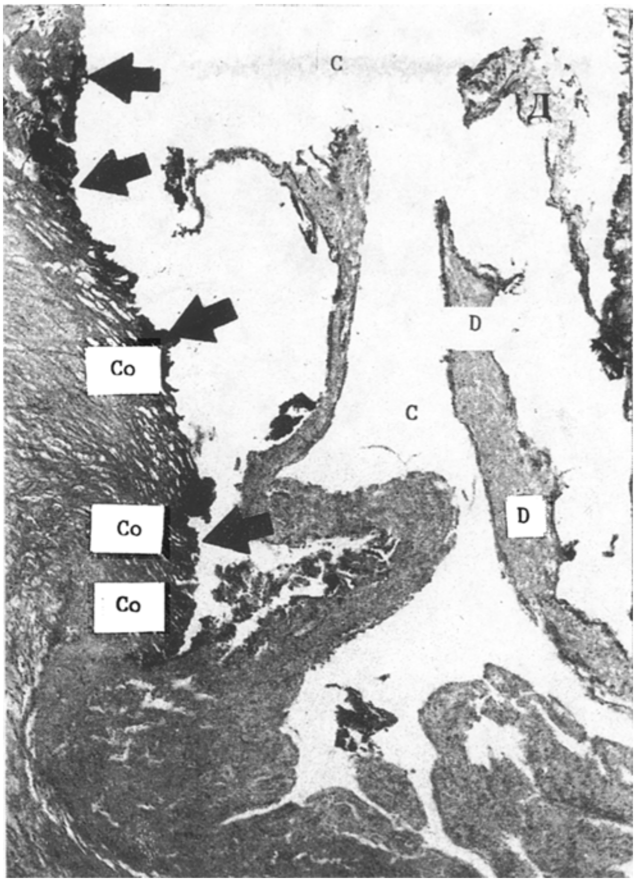

Fig. 1. Vascular wall 7 days after laser irradiation (abdominal aorta). C) Crater; Co) coagulation changes in vascular wall. Small quantity of tissue debris (D) present in cavity of crater. Arrows indicate carbonized zone of tissue around perimeter of crater. Here and in Figs. 2 and 3: stained with hematoxylin and eosin, 60×.

The cavity of the crater 7-16 days after laser irradiation was either free from tissue debris or its floor was covered by a thin layer of a few thrombotic masses. Around the crater fresh granulations were forming. The absence of inflammatory infiltration in the vessel wall must be emphasized. In some cases many newly formed thin-walled vessels with a well-marked intimal layer could be seen in the outer membrane. Endothelization of the surface of the crater was not taking place. It can be tentatively suggested that at this time the crater possesses thrombogenic properties, as was confirmed by the existence of fresh thrombotic masses in its cavity. However, in vessels of large diameter, and in the presence of favorable hemodynamic conditions (for example, the aorta or iliac arteries) the formation of thrombotic occlusion or juxtamural thrombosis of the vessel was not observed macroscopically.

On the 16th-28th day marked progression of proliferation of the endothelium was recorded. At this time the defect of the arterial wall after laser irradiation still remained shaped like a crater (Fig. 2). From the side of the adventitia, intensive proliferation of granulation tissue was observed (chiefly beneath the floor of the crater). Proliferation of smooth-muscle fibers also was observed and the crater cavity gradually filled with granulation tissue, i.e., cicatrization of the site of laser irradiation was proceeding rapidly. In the media, around the perimeter and close to the crater, and also in the outer membrane, numerous newly formed vessels appeared with a wide lumen and thin walls, around the crater the hemorrhages still persisted, and occasionally islands of carbonized tissue were found. Proliferation of the endothelial layer of the vessel in the form of well defined widened endothelial "cushions" on the edges of the crater, must be particularly mentioned. In this stage of healing the walls of the artery showed signs of inflammation. In the region of the edges of the crater, well defined proliferation of smooth-muscle fibers also was observed.

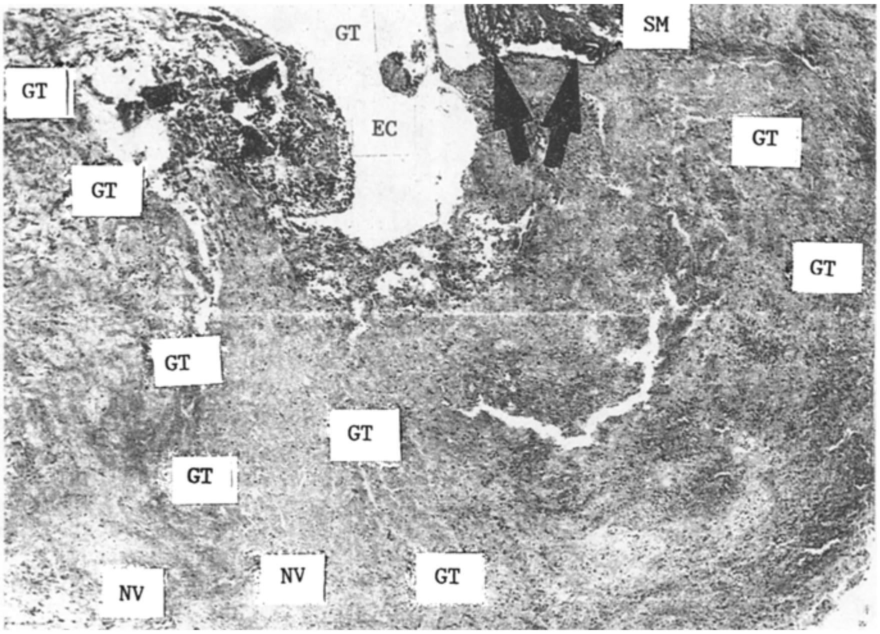

Fig. 2. Vascular wall 16 days after laser irradiation (descending part of aorta). Floor of crater (C), GT – granulation tissue, NV) newly formed vessels in aortic wall, SM) smooth muscle fibers, EC) endothelial "cushions." Arrows indicate persistent single islands of carbonized tissue.

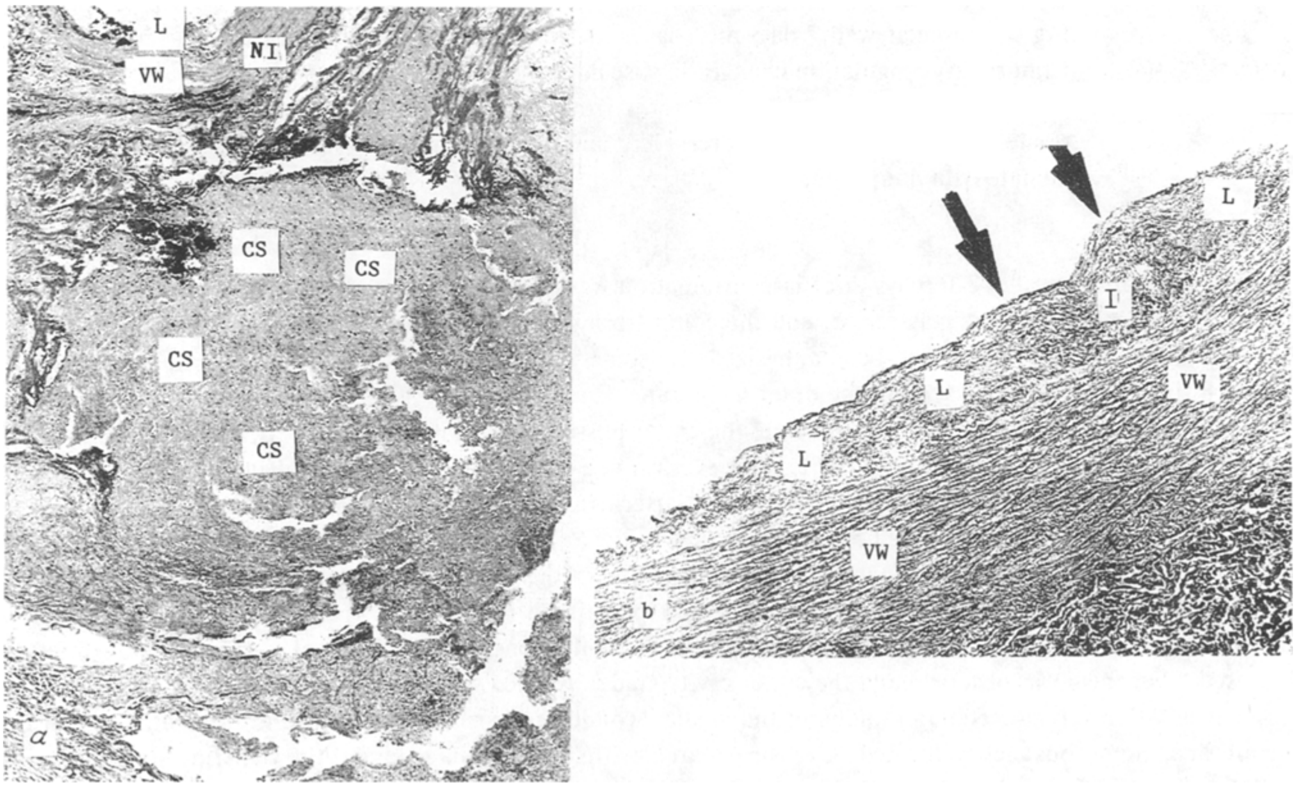

Fig. 3. Wall of dog's abdominal aorta: a) 28 days after laser irradiation. L) Lumen of aorta, CS) connective-tissue scar, NI) newly formed intima; b) 2 months after laser irradiation. VW) Vascular wall, I) intima. Arrows indicate marked hyperplasia of intima at site of laser irradiation.

Finally, by the end of 1 month after laser irradiation, at the site of the tissue defect a scar had formed, the cavity of the crater was completely replaced by ripe granulations (Fig. 3a).

The scar in the vessel wall was covered on the side of the arterial lumen by a continuous thin layer of endothelium. In most preparations thickening of the arterial wall, signs of an inflammatory reaction, and hyperplasia of the endothelial layer of the vessel were absent. Morphological investigations in the late stages (2 months or more) also revealed complete endothelization of the site of laser irradiation, and in some cases areas of marked hyperplasia of the endothelial layer were found (Fig. 3b).

This course of repair processes was observed in the majority of cases. However, there were exceptions, especially when the arterial wall was perforated or in the presence of extensive laser trauma with the formation of a deep crater of large diameter, and when a hematoma was found, penetrating into the adventitia. Hemorrhages were observed in all layers of the vessel wall in such cases, zones of thermal and coagulation trauma were wide, inflammatory infiltration of small-cell type developed, and neutrophilic leukocytes appeared. The inflammatory infiltration also spread to surrounding tissues, and was both focal and diffuse in character.

During the development of this kind of inflammatory infiltration, an occluding thrombus always was formed in the lumen of the vessel. The thrombus developed in arteries of small diameter (axillary and femoral), and also at the site of bifurcation of an artery. The occluding thrombus was organized and partially recanalized.

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