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Original Article

Comparison of Effects of Irradiation with Continuous Wave Nd-YAG and Argon-Ion Laser, and Pulsed Ultraviolet XeCl-Excimer Laser on the Human Aortic Wall

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Abstract: To compare the effects of continuous wave and pulsed laser irradiation on vessel walls, fourty-five human cadaver aortic segments were irradiated with either an Nd-YAG, Argon-ion, or XeCl-excimer laser through a quartz fiber. All segments were immersed in saline solution, exposed to laser radiation with variations in power and duration of irradiation, and examined macroscopically and microscopically. In continuous wave mode lasers, the Nd-YAG laser produced a large, ragged crater surrounded by extensive thermal injury. The crater produced by the Argon-ion laser irradiation was somewhat sharp compared to that produced by the Nd-YAG laser, however, thermal injury around the crater was also observed. In contrast, the pulsed XeCl-excimer laser-irradiated tissue showed small craters with no visible thermal damage. The edge of the crater was smooth, and the microscopic examination revealed minimal thermal injury around the margin of the crater. These results suggest that the pulsed XeCl-excimer laser is more suitable for laser angiopalsty than conventional continuous wave lasers. However, as we were unable to penetrate even the inner layer of the aortic wall, the development of a fibroptic systm capable of transmitting the higher power of excimer laser energy will be needed.

Key words: Argon-ion laser, Excimer laser, Laser angioplasty, Nd-YAG laser, Occlusive arterial disease

As the number of patients who have occlusive peripheral arterial disease grows, the clinical need for non-surgical treatment of this disorder becomes stronger. Although percutaneous transcatheter angioplasty (PTA) using a balloon has been commonly utilized in the clinical field for treating such lesions, the long-term results can be compromised by progressive atherosclerlosis and re-stenosis.

In recent years, it has been reported that laser irradiation has the capability to vaporize and re-canalize the occlusive lesion of a blood vessel[1-3], and may overcome the limitations of conventional non-surgical treatment. Thus, laser angioplasty has attracted considerable attention in many countries, including ours.

For clinical usage of laser angioplasty, however, the question of how to control the precise boundary of the zone of laser injury, and the choice of the optimal laser remain unclear. The present study was undertaken as a basic investigation of laser angioplasty to compare the effects of irradiation with conventional continuous wave mode lasers and a pulsed ultraviolet laser on the human aortic walls, and to

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determine which laser will be more suitable for laser angioplasty.

Materials and Methods

As continuous wave mode lasers, an Nd-YAG laser and an Argon-ion laser (NIIC, Japan), and as a pulsed laser, a xenon chloride (XeCl) excimer laser (Lumonics, Canada) were employed for this study. The Nd-YAG laser emits a line at 1060 nm, and the argon-ion laser operates at 488 and 514 nm. The wavelength of the XeCl-excimer laser is 308 nm. Coupled with the Nd-YAG and Argon-ion lasers was a quartz fiber of 0.6 mm diameter used to deliver the laser energy to the tissues. The output power of the Nd-YAG laser at the fiber tip was set at 50 and 80 watts, and that of the Argon-ion laser, at 2.0 and 3.5 watts. The duration of irradiation was held at 1, 2, 5, and 10 seconds. As for the XeCl-excimer laser, pulse duration and repetition rate were set at 10 nanoseconds, and 40 Hz, respectively. A quartz fiber of 0.4 mm diameter was coupled with the excimer laser apparatus, and delivered 1 mJ per pulse. The duration of irratiation varied from 1 to 5 minutes, or 40 to 200 pulses.

Human aortas were obtained from seven cadavers, and these were dissected into 3 to 5 cm segments. The aortic specimens with atheromatous changes were discarded, and 45 intact segments were selected for this study. The specimens, which were immersed in normal saline solution and positioned perpendicularly to the laser, were irradiated through the quartz fiber, and the depth and width of the laser-induced crater were calculated by ocular manometry. The distance between the fiber tip and specimen was maintained at 3 mm. After the photographs of irradiated segments were taken, these specimens were examined by light microscopy, phase contrast microscopy and scanning electron microscopy.

Results

1. The Nd-YAG laser and Argon-ion laser

Macroscopic observation (Fig. 1): The

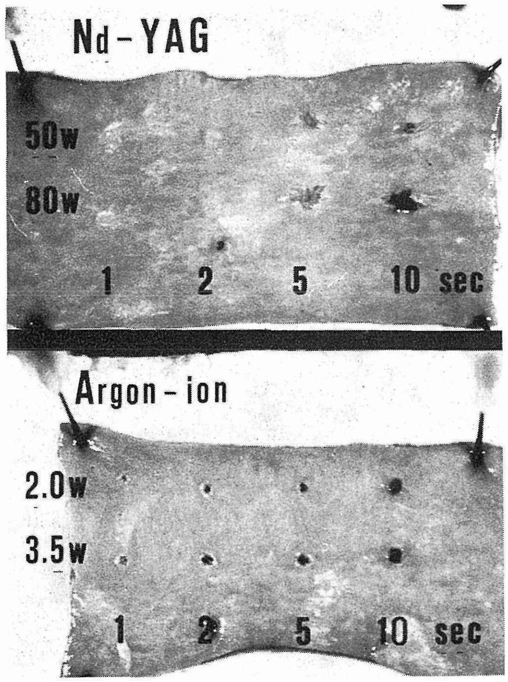

Fig. 1. Aortic specimen irradiated with Nd-YAG laser (upper half) and Argon laser (lower half). Although only whitenings are observed with Nd-YAG laser irradiation of 50 and 80 watts for 1 or 2 second, this laser produces a wide ragged crater with 5 or more second irradiation. With Argon laser irradiation, a crater is formed even at a 1 second duration.

Nd-YAG laser was unable to ablate the aortic walls during 1 or 2 seconds of irradiation, with only whitening of the tissue being observed. With irradiation of 5 seconds or more, this laser produced a wide, ragged crater with extensive blast injury around the crater, scattering the necrotized tissue of various sizes into saline solution. With Argon-ion laser irradiation,

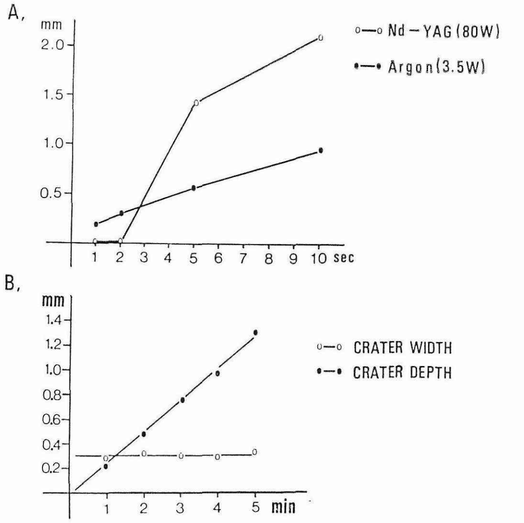

Fig. 2. A: The relationship between crater width and the duration of Nd-YAG and Argon laser irradiation. Although the width of the crater is proportional to the duration of Argon laser irradiation, no linear relationship appeared with Nd-YAG laser irradiation.
B: The relationship between the crater dimensions and the duration of excimer laser irradiation. The depth of the crater increases in a linear fashion with increasing duration of irradiation, while the width remains constant.

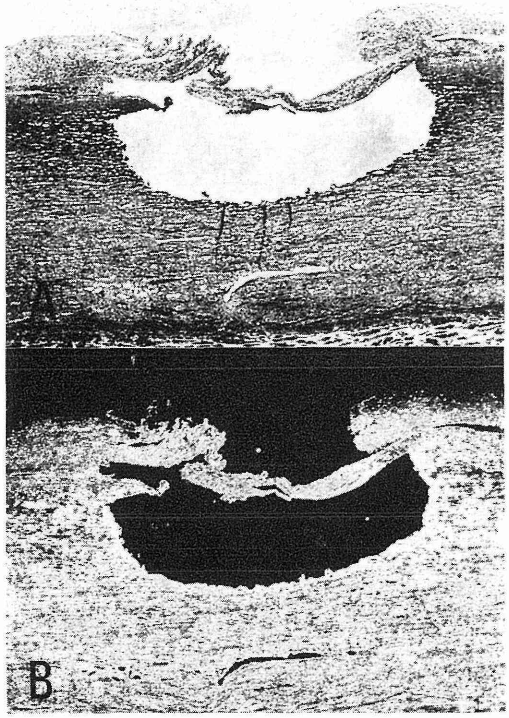

Fig. 3. Aortic segment irradiated with Nd-YAG laser of 50 watts for 10 seconds. A large irregular crater with extensive thermal injury is seen in both light microscopic (A) and phase contrast microscopic (B) views.

crater formation was seen even at a 1 second radiation. The small particles of tissue debris were also generated during lasing. Although the margin of the crater was smoother compared to that induced by the Nd-YAG laser irradition, thermal damage around the crater, such as carbonization, was apparent. A proportional relation between the width of the crater and the duration of irradition was recognized in irradition with the Argon-ion laser, but not with the Nd-YAG laser (Fig. 2A).

Microscopic observation: Figure 3 shows the typical histologic appearance of a human aortic wall after irradiation with the Nd-YAG laser using 50 watts for 10 seconds. The aortic wall was ablated and a large irregular crater was observed. Surrounding the crater, carbonization and vacuolization of the tissue was evident throughout the length of the aortic wall. This thermal injury spread 4 mm laterally from the margin of the laser crater. The crater produced by Argon-ion laser irradiation of 2.0 watts for 10 seconds was somewhat sharp compared to that produced by the Nd-YAG laser. In observation with phase contrast microscopy, however, the zone of thermal injury caused by Argon-ion laser irradition extended 0.9 mm circumferentially around the margin of the crater, indicating lateral diffusion of this laser energy (Fig. 4).

2. The XeCl-Excimer laser

Macroscopic observation (Fig. 5): On the

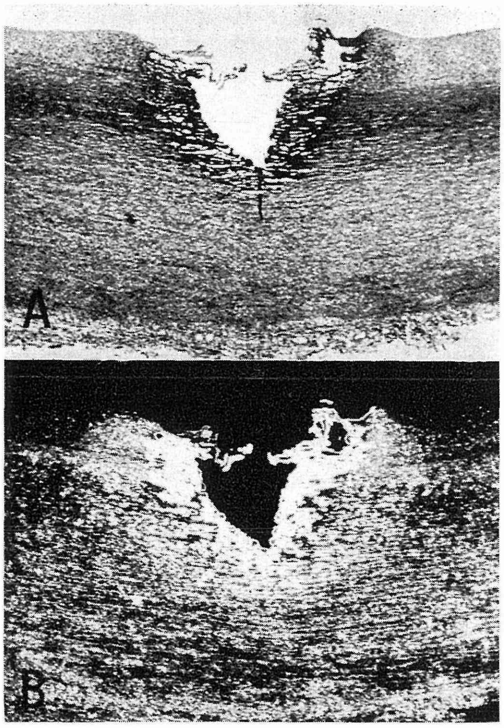

Fig. 4. Aortic segment irradiated with Argon laser of 2.0 watts for 10 seconds. Crater margin is not as irregular as that of the Nd-YAG laser. Thermal injury seems to be restricted within a narrow area on adjacent tissue in the light microscopic view (A), however, the phase contrast microscope reveals that the thermal damage extends widely around the margin of the crater (B).

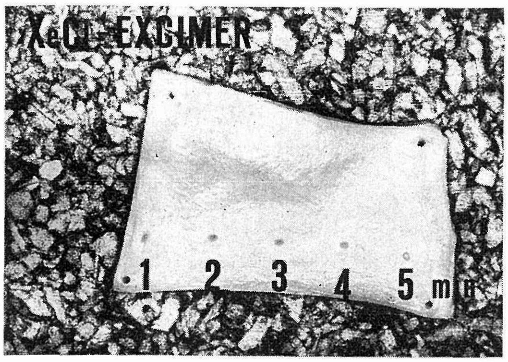

Fig. 5. Aortic specimen irradiated with XeCl excimer laser of 1 mJ/pulse for 1 to 5 minutes (repetition rate is 40 Hz). Small craters with no visible thermal injury are observed.

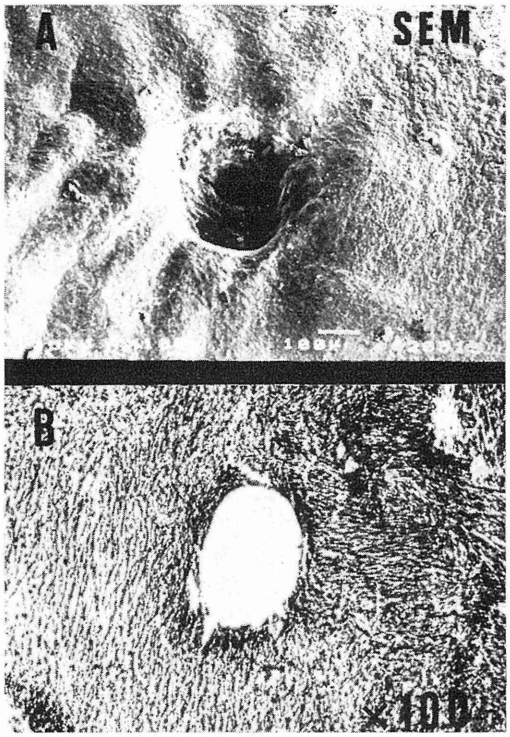

Fig. 6. Scanning electron microscopic view (A) and histologic view of cross-section (B) of the aortic wall irradiated with excimer laser of 1 mJ for 3 minutes. Both demonstrate clean incision with minimal thermal damage around the margin of the crater.

aortic segments irradiated with XeCl-excimer laser of 1 mJ, small craters were observed with no visible evidence of discoloration or carbonization in adjacent tissue. During lasing, the tissue debris was not noted. Measuring the crater width and depth with micrometry, the relationship between the crater width and depth and duration of irradiation was examined. It was apparent that the depth of the crater increased in a linear fashion with increasing duration of irradiation, while the width remained constant, about 0.3 mm, at every duration (Fig. 2B).

Microscopic observation: Figure 6A shows a scanning electron microscopic view of the aortic wall irradiated with the excimer

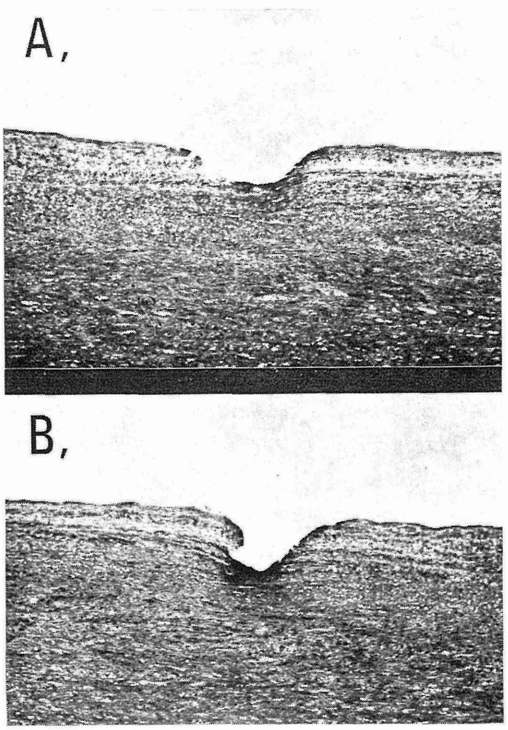

Fig. 7. Longitudinal histologic specimen of the aortic segment irradiated with excimer laser of 1 mJ/pulse for 3 minutes (A) and 4 minutes (B). The margin of the crater is sharp with minimal thermal injury to adjacent tissue, however, laser is unable to penetrate the inner layer of the aortic wall.

laser using 1 mJ for 3 minutes. This revealed a smooth-walled crater with no recognizable evidence of thermal blast injury on adjacent tissue. A histological specimen of a cross-section (Fig. 6B) of the aortic segment, irradiated with the excimer laser at 1 mJ for 3 minutes, that is 120 pulses, demonstrated clean incision with minimal thermal injury which was restricted within very narrow limits. Similar change was also observed in the longitudinal-section. Figure 7A shows a histological specimen irradiated with the XeCl-excimer laser at 1 mJ for 3 minutes, and figure 7B shows irradiation for 4 minutes, demonstrating sharp edges of the laser crater with minimal thermal injuries. However, the capability of this system to ablate the aortic wall was limited, and it was unable to penetrate the inner layer of the aortic wall, even after 5 minutes of irradiation.

Discussion

The Nd-YAG, Argon-ion, and carbon dioxide (CO_2) laser have a continuous wave mode, and are now most commonly used as a new surgical tool in the medical field. In this basic study, the authors selected the Nd-YAG and Argon-ion laser, and excluded the CO_2 laser because of the lack of flexible fiberoptics capable of transmitting laser energy. Another laser source employed in this study was the XeCl-excimer laser which emits ultraviolet light of 308 nm wavelength. It has been reported that this excimer laser light can be readly absorbed by the protein and lipids in atherosclerotic tissue. and it is possible to precisely ablate the occluded lesions in a vessel with minimal thermal injury[4].

With regard to continuous wave mode lasers, the Argon-ion laser in this study was considered to be more suitable for angioplasty than the Nd-YAG laser. But even with the Argon-ion laser, the irradiated tissue exhibited a ragged and irregular central crater associated with a concentric thermal injured zone, which was probably due to the lateral diffusion of laser energy. From these results, it is obvious that light from the continuous wave mode laser penetrates deeply into the tissue, and tends to produce tissue necrosis and coagulation before significant ablation. Thus, because of the photothermal effect caused by these lasers, it will be difficult to control the depth of ablation on the irradiated tissue. Actually, in several reports using the Nd-YAG laser with a bare fiberoptic fiber, perforation of the vessel wall occurred frequently[5,6], and this problem has led to the development of laser probes, such as the metal cap[7,8].

In contrast, the ablation of tissue caused by the excimer laser radiation was substantially different from that which occurred with continuous wave mode lasers. From the light microscopic and even the scanning electron microscopic view, craters produced by this pulsed ultraviolet laser showed precise edges, and the thermal injury around the crater was negligible. The depth of the crater produced by irradiation with the XeCl-excimer laser was proportional to the duration of irradiation, namely to the number of pulses. These effects observed in irradiation with the excimer laser were similar to those reported by Grundfest et al[9], and are considered to derive from the photochemical action of ultraviolet photons which are absorbed by organic molecules and cause localized electronic excitation of molecular bonds, and the extremely short nature of the excimer pulses[10]. From these results, it is suggested that by using the excimer laser it will be possible to control the range of tissue ablation with minimal damage to adjacent tissues, and this laser is expected to become one of the most suitable laser sources for laser angioplasty.

In our experiment, however, this excimer laser and a quartz fiber of 0.4 mm diameter could only deliver 1 mJ/pulse energy to the targetted tissue, and this is not enough power to vapolize and ablate long and hard occlusive lesions in the peripheral artery. For laser angioplasty, several tens of millijoules per pulse of laser irradiation at the tip of the fiberoptic wave guide will be needed. Therefore, before the excimer laser angioplasty is clinically adopted, effort should be made to develop a special fiber capable of transmitting the high peak powers of excimer laser energy.

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