A Experimental Study on Hemostatic Vascular Management Using an Nd:YAG Laser Bipolar Dissector

Takao Morita¹, Kiyoshi Ishida¹, Katsuhiko Ookubo¹, Katsuyuki Tanaka¹, Hiroaki Nakamura², Norio Daikuzono³

¹²nd Department of Surgery, and ¹¹Laboratory of Electron Microscopy, Saitama Medical School, 38 Moroyama-cho, Iruma-gun, Saitama 350-04, Japan. ³S.L.T. Japan Co., Ltd., 25-6 Yokoyama-cho, Hachioji-shi, Tokyo 192, Japan.

Abstract:

The optical laser setting for successful hemostatic transection of vessels using Laser Bipolar Dissector (LBD) and the important factor in closure and the healing process of the vessel stump were examined in abdominal aortas, mesenteric arteries and femoral arteries of rabbits (n=40). Interluminal bursting pressures (BP) were measured. The cutting edges were harvested at one week (n=4), at 2, 3 and 4 weeks (n=4) and 6 months (n=4), and evaluated by light microscopy. Histopathological examinations were carried out by HE and EVG stainings.

The BP immediately after transection at laser power of 10 (n=5) and 13W (n=5) was above 346 mmHg, and that of 15W (n=5) and 20W (n=5) was 280 mmHg, 208 mmHg respectively. The transected sites of vessels revealed well-apposed tissue welding of vascular wall. The welding of internal elastic lamina without fragmentation is histologically most important for closure of the vessel stump. An increase in the laser power from 10 to 20W resulted in increased severity of histopathological deterioration of tissue connectivity (n=10, p<0.01) and in decreased bursting strength (n=5, p<0.01). Laser power of 10 to 13W was the most suitable for hemostatic dissection of large vessels. In the healing process, cartilaginous foci (n=4) were observed in the vascular cutting edges at 4 weeks after LBD dissection, and osseous foci (n=3) were observed at 6 months.

These observations may suggest that use of the LBD for vascular transection results in excellent tissue welding of vascular stumps in 2 to 3 mm diameter arteries and that the the vascular stump is repaired with the strongest tissue material.

Key Words: bipolar, bursting strength, cartilage and bone formation, contact Nd:YAG laser, healing process, hemostasis, histology, tissue welding, vascular wall
Introduction

One of the greatest concerns of surgeons has been to decide the optimal technique to minimize blood loss and prevent rebleeding in surgical operations. The laser bipolar dissector (LBD, SLT Japan, Co., Ltd.) was developed to improve both the cutting and coagulating properties of the Nd:YAG contact laser [1]. Recently, some investigators have reported that the LBD can perform hemostatic transection of large vessels and might be suitable for dissection of parenchymal organs such as the liver, pancreas, kidney, and lung [2,3]. There has been no report, however, that deals with the safety of the LBD procedure.

The purpose of this study was to determine the suitable optical laser setting for successful hemostatic transection, and to investigate the wound healing process at the cut end of vessels in arteries of rabbits dissected with the LBD.

Materials and Methods

Forty young adult white-eared rabbits were used for the study. Anesthesia was induced by an intramuscular injection of ketamine hydrochloride (30mg/kg) and xylazine (300mg/kg). Under adequate anesthesia, the LBD was applied to the mesenteric artery, the abdominal aorta and femoral artery. Four laser power settings of 10W, 13W, 15W, and 20W were used with the laser set at continuous wave. The vessels could be cut hemostatically by the LBD compression technique. Our studies were carried out in following three different experiments.

In the first experiment, interluminal bursting pressure was investigated in rabbit abdominal aorta. The abdominal aorta was moved 2 cm in length from the cut end using the LBD and connected to an infusion pump, a pressure transducer (A002, Fukuda Densi Co. Ltd., Tokyo) and a multichannel recorder (Polygraph System LB-812, Fukuda Densi Co. Ltd., Tokyo) to measure and record the pressure.

In the second experiment, microscopic examination was performed at the transected site of mesenteric artery. Histologic specimens were fixed in 10% formalin and embedded in paraffin. Longitudinal sections were made and stained with hematoxylin-eosin and with Van Gieson’s elastic stains. Longitudinal microscopic measurements were made at the cut end.

In the third experiment, the healing process was histopathologically investigated in rabbit femoral artery after transection using an LBD with laser power of 13W in continuous wave. The cutting edges were harvested at 1 week (n=4), 2 weeks (n=4), 3 weeks (n=4), 4 weeks (n=4) and 6 months (n=4), and evaluated by light and electron microscopy. Statistical analysis of the
obtained data was performed using Student's t-test.

Results

Our experiments were carried out using rabbit abdominal aortas up to 3 mm in diameter. It is often difficult to compress the vessels wider than 3 mm in diameter, because the distal ends of the bipolar probes are designed to be flat on opposite faces and the size of the flat face is 5.0 × 1.5 mm. The bursting pressure (BP) immediately after transection at laser power of 10 (n=5) and 13W (n=5) was above 346 mmHg, and it was thought from the bursting pressure curve to be within the range from 450 to 500 mmHg. The BP was 282 ± 30.9 mmHg at laser power of 15W (n=5), and 208 ± 22.2 mmHg at 20W (n=5). It was significantly higher at laser output power below 13W than above 15W (n=5, p<0.01) (Table 1)

In a microphotographs of a longitudinal section at the cut end of vessels, the cut ends were divided roughly into 4 areas [4]: a carbonization area, a coagulation area, a conjunction area, and a tapering area (Fig. 1). In the carbonization area, the arterial wall was evaporated and carbonized. Arterial components became homogeneously coagulated in the coagulation area. In the conjunction area, both vessel walls were conjoined and welded, and the internal elastic lamina was tightly adhered to an internal elastic lamina on the opposite side. In the tapering area, the vessel lumen was tapered from the normal area toward the cut end. Although the thermal change involved all layers of the vessel wall, the internal elastic laminas were tightly adhered and welded without fragmentation. Longitudinal microscopic measurements of the cut end of mesenteric artery were made in 10 specimens of each group. The size of the coagulation area at the cut end of the mesenteric arteries was significantly larger at laser power levels under 13 W than above 15W, and that of the conjunction area was significantly larger under 10W than above 13W (Table 2). In addition, the size of the tapering area, which indicates tissue thermal damage, increased as

<table>
<thead>
<tr>
<th>Laser power (W)</th>
<th>n</th>
<th>Bursting pressure (mm Hg)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5</td>
<td>346*</td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>5</td>
<td>346*</td>
<td>—</td>
</tr>
<tr>
<td>15</td>
<td>5</td>
<td>282 ± 30.9</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>208 ± 22.2</td>
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*The upper limit of measurable pressure with our pressure transducer.
laser output power increased. The same observation was found at the cut end of abdominal aorta. With increases of the laser power, the size of the conjunction area was shortened, and the thermal coagulative changes extended over the adventitia from the conjunction area to the tapering area.

During the postoperative period, perforation of the vessel stump and development of aneurysms never occurred in the cutting edges \((n=20)\). The healing process after dissection was accomplished within 2 weeks by organization of the intraluminal thrombus and by the formation of granulation tissue outside the adventitia of vessels.

Characteristic morphological changes after LBD transection were recognized in the tapering, i.e., a proliferation of synthetic type smooth muscle cells at 2 weeks \((n=4)\) (Fig. 2).

After 4 weeks, numerous proliferative cells of chondrocytes, forming clones of isogenic cells amongst common chondroplasts, were recognized in the media of the tapering area \((n=4)\) (Fig. 2).

Table 2 Laser thermal effect at the cut end of rabbit mesenteric arteries in relation to laser power

<table>
<thead>
<tr>
<th>Laser power ((W))</th>
<th>(n)</th>
<th>Diameter of vessel ((mm))</th>
<th>Size of areas ((mm)) (\text{mean} \pm \text{SD})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tapering area</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>0.56±0.11</td>
<td>0.09±0.02</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>0.55±0.12</td>
<td>0.26±0.02</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>0.53±0.15</td>
<td>0.29±0.03</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>0.53±0.10</td>
<td>0.15±0.01</td>
</tr>
</tbody>
</table>

\(*p<0.01\)
3). After 6 months, the organized tissue in the lumen and the granulation tissue surrounding the outside of the vessel wall at the cut end degenerated and was replaced with adipose tissue. Osseous foci were recognized in the newly formed vascular wall in the lumen of the tapering area (n=3) (Fig. 4).

Discussion

Lasers are used in surgery to coagulate, cut or vaporize tissue. Fanta et al. [5] reported that the major advantage of the Nd:YAG laser beam in lung surgery was its rapid sealing effect on small airways and blood vessels up to 3 mm in diameter. Joffe [6] reported a technique for coagulating vessels 1 to 3 mm in size using a contact Nd:YAG monopolar probe. The LBD was developed to improve both the cutting and coagulating properties of the Nd:YAG contact laser. Nishiwaki et al. [1] reported that the LBD hemostatically cut through arteries up to 2 mm in
Fig. 3 Light micrographs of a rabbit femoral artery 4 weeks after LBD dissection (HE stain, x40). Cartilaginous foci formation occurred in the media of the tapering area.

Fig. 4 Longitudinal sections of a rabbit femoral artery 6 months after LBD dissection (HE stain, x40). Osseous foci were recognized in the newly formed vascular wall in the lumen of the tapering area.
diameter. LBD is ideally suited for tissue welding because the high power from the center of the sapphire probe achieves tissue coagulation and vaporization in the vessel wall, and the low power from the peripheral area of the tip achieves good laser fusion.

Although settings for the laser power and the total energy for successful laser hemostasis depend on the size of the vessels and the type of laser. High power energy causes tissue coagulation or vaporization in the vessel wall at the cut end, and low-power provide good laser fusion. In our experiment, no rupture at the site of hemostatic transection occurred at a BP test immediately after transection, even when pressure as high as 346 mmHg was applied. Also, BP decreased significantly at laser powers above 15W. The notable finding in this study was a decrease in bursting strength with increasing laser power.

The mechanism of tissue welding via laser is not yet fully understood. In our study, the bond of the coagulation area is microscopically a fusion of the vessel wall by severe thermal coagulation, and that of the conjunction area is a welding of the vessel wall by good laser fusion. The strength of the cut end was histologically found to be in direct proportion to the sizes of both the conjunction and coagulation areas, and these areas were much smaller with high laser power than with low laser power. Increases in laser power resulted in an increased severity of histopathological weak bonding. Based on this study, we employed 10 to 13 W of laser power in LBD procedure.

There are several reports on pseudoaneurysm formation after laser assisted vascular anastomoses [8, 9, 10]. Hartz et al. [11] have reported that aneurysm formation is related to the damage of the internal elastic lamina adjacent to the laser vascular anastomoses. Our experiment in vascular transection using LBD showed that tight welding of the internal elastic laminas without fragmentation plays an important role in closure of the vessel stump.

The healing process of the cut end of vessels using LBD was accomplished within one week by endothelialization of the vascular lumen and within 2 weeks by organization of the intraluminal thrombus and by the formation of granulation tissue outside the adventitia of vessels. The fundamental healing process in LBD dissection is similar to that of high frequency electrocoagulation and laser-assisted vascular anastomoses. However, in this study, cartilaginous foci were observed in the vascular cutting edges at 4 weeks after LBD dissection and osseous foci were observed at 6 months. Cartilage and bone have high tensile and compressive strength while at the same time having some elastisty. The construction of the vascular cutting edges with cartilaginous and osseous foci formation ensures the greatest strength. On the basis of the results of this study, we conclude that use of the LBD for vascular transection results in excellent tissue
welding of vascular stumps in 2 to 3 mm diameter arteries, and that the vascular stump dissected with LBD is repaired with the strongest tissue material. This technique may be useful in laparoscopic surgery.

References


