Bowel Welding Technique in Dogs and Cats using a Diode Laser: An Experimental Study

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ABSTRACT. A laser bowel welding technique for dogs and cats was developed. The bowel was pinched using a special clamp having an opening on the body developed for this experiment (LW clamp). Using the 2 different types of contact probe (blunt tip: Laser Bipolar Dissector (LBD); sharp tip: Super Scalpel Dissector (SSD)), the laser passed through the hole in the LW clamp to cut the bowels, while at the same time, sealing the cut portion. The results obtained in this study showed that the optimum laser output using LBD was 6–10 W in dog and cat ileum, and 8–10 W in dog and cat colon. Optimum laser output using SSD was 6–8 W in dog ileum, 8–10 W in dog colon, 10 W in cat ileum and 6–8 W in cat colon. No marked differences were observed between ileum and colon when using either LBD or SSD. At the same power, burst pressure tended to be slightly higher with LBD than with SSD, although there were not significant differences between them. Histologically, complete sealing of the welded site was seen. Welding and cutting of bowel in dogs and cats was thus confirmed to be possible using the LW clamp in combination with LBD or SSD probes under a diode laser output of approximately 8 W for 50–80 s (400–640 J/cm). Thus, we can expect that this method is applicable to clinical veterinary medicine.

KEY WORDS: canine, feline, intestine, laser welding, probe.

Lasers cause heating, coagulation and perspiration in biological tissues, and are employed in various medical treatments. In surgery, lasers are primarily used as knives for discission and hemostasis. Moreover, lasers are employed for “welding” biological tissues in clinical medicine, and angiorrhaphy using lasers has recently been applied to clinical practice, as well as to experiments in animals [2, 3, 13]. The mechanism of tissue welding is thought to be the chemical fusion between collagen fibers and fibrin fibers based on collagen alteration and fibrin polymers [16]. There have also been studies into bowel welding using various lasers, including Nd:YAG, CO2, Argon and Helium-Neon [1, 4–6, 9, 10, 12, 14, 15], although they are still in the experimental phase in animals. Laser handling has recently been simplified due to the diffusion of diode lasers and the development of irradiation methods with contact-type laser probes, which come into direct contact with tissues. Thus, the surgical applications of the laser, including abscission of organs, such as the liver and lung, and vessels, have been expanded, and their effectiveness is being reported [7, 8].

Lasers for the biological welding of vessels, the urinary tract and the bowel are expected to be applied to veterinary medicine. To date, however, there have been no reports of such applications, although animal experimental studies have been reported. Enterotanostomosis is a common procedure in veterinary surgery, but the postoperative condition of the sutured area differs depending on the surgeon’s technique. Mechanical anastomosis using a staple, which is the most common method in human medicine to shorten surgery time, sometimes causes mechanical injuries and foreign body reactions. When the bowel is sutured with a laser, however, these disadvantages are not observed. There is good adhesion of the sutured portion, and furthermore, germicidal effects and enhanced wound healing are also observed [12].

In consideration of these facts, a laser bowel welding technique in dogs and cats was developed in this study with the aim of applying the laser bowel welding technique to clinical veterinary medicine. The following points were experimentally investigated: 1) comparison of welding strength between 2 types of contact probe (blunt tip: Laser Bipolar Dissector (LBD); sharp tip: Super Scalpel Dissector (SSD)), as 2 types of contact probe tip are available for tissue welding; and 2) assessment of physical strength at the welded portion of the bowels and the energy required for welding and cutting a 1-cm bowel section.

MATERIALS AND METHODS

Laser generating units and supplementary equipment: The laser generation unit used in this study was an 810-nm Diode Laser PDL-Pulse Diode Laser4, and the contact probes were the LBD and the SSD5. In addition, a laser welding intestinal clamp (hereafter, LW clamp) having a 3 × 40 mm opening on the pinching side of an ordinary intestinal clamp was developed for this study (Fig. 1).

Bowel: Sixteen dogs and 16 cats, which were either euth-

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anized as unwanted animals or underwent pathologic autopsy after dying from illnesses, were obtained for our study after gaining the appropriate permissions. For experimental preparation, the ileum and colon were harvested from each dog and cat, and were cut into 15-cm lengths, washed in saline, and warmed in an incubator to approximately 38°C.

**Bowel welding and cutting methods:** One of the stumps of a bowel section was pinched with an LW clamp to seal the opening. The laser was directed through the hole in the LW clamp using an LBD or SSD probe, and we were able to successfully cut the bowel while simultaneously sealing with the laser. Welding and cutting were performed at intervals, and it was necessary to allow the probe to cool after irradiation for approximately 5–10 s for both LBD and SSD. The required time differed depending on the combination of LBD, SSD, laser output, dog, cat, ileum and colon, but the time required was 1–4 min. In preliminary experiments, the welded portion sometimes split apart due to the intestinal walls becoming attached to the LW clamp when the clamp was removed. Therefore, when removing the LW clamp, a normal intestinal clamp was used in parallel with the LW clamp in order to protect the welded portion.

**Assessment of physical strength in the welded portion:** An 8 Fr catheter for measuring pressure (cardiac catheter) and a 4 Fr catheter for saline injection were inserted into one side of the bowel and were placed at approximately 2 cm proximal to the laser welded region. The stumps were then closed with a rubber band. The catheter for measuring pressure was connected to a Polygraph ECU-600 via a Disposable Transducer A002c. Bowel-welding strength was evaluated as follows: first, saline was continuously infused with an infusion pump through the 4 Fr catheter for saline injection at a rate of 2.5 ml/min. Intestinal pressure was measured at the time when the welded portion burst (burst pressure, hereinafter BP) (Fig. 2). The stump of the 15-cm bowel section was first welded with an output of 6 W. After BP measurement, the portion welded at 6 W was cut at 15 mm from the end of the stump, and this new stump was welded at 8 W. After BP measurement, the portion welded at 8 W was again cut, and the BP of the welded portion was measured in the same way for 10 and 12 W using same bowel section. BP measurement was performed 8 times for each output (6, 8, 10 and 12 W) for the 8 combinations of animal (dogs or cats), bowel type (ileum or colon) and laser probe type (LBD or SSD) (n=8).

**Energy required for welding and cutting 1-cm bowel section:** At assessment of physical strength at the welded portion, length of the irradiation site and time required for welding and cutting the bowel section was measured. Based on the BP results, the energy (joules) required for welding and cutting 1-cm bowel sections was calculated at an output of 8 W.

**Histological observation:** For histological observation, 4 samples (ileums of dog and cat, and colons of dog and cat) were prepared. Bowel welding and laser cutting were performed at 8 W using LBD probes. Samples were fixed in 10% formalin buffer solution, and embedded in paraffin. HE-stained samples were then prepared by cutting the bowel sections perpendicular to the welded portion, and these were histopathologically investigated using an optical microscope.

**Statistical analysis:** BP values at the 4 tested outputs using LBD (hereinafter the LBD group) or SSD (hereinafter the SSD group) were compared by Sheffe’s test. BP values in the LBD and SSD groups were compared using Student’s t-test. A P value of less than 0.05 was considered to be significant.

**RESULTS**

**Laser welding strength (Fig. 3a-h):** i) LBD Group: BP in dog ileum, dog colon and cat ileum tended to remain the same or increase at outputs of 6–10 W, but BP decreased significantly at 12 W (p<0.05) when compared with 8 and 10 W. Maximum BP values in dog ileum, dog colon and cat ileum at 10 W were as follows: 17.00 ± 3.34 mmHg (mean ± S.D.) in dog ileum (Fig. 3-a), 10.63 ± 1.92 mmHg in dog colon (Fig. 3-c) and 24.63 ± 3.16 mmHg in cat ileum (Fig. 3-e). On the other hand, the maximum BP in cat colon was obtained at 8 W (14.13 ± 2.36 mmHg) (Fig. 3-g), and this significantly decreased at 10 and 12 W (p<0.05). The time required to weld and cut bowels using the laser was 1–4 min; the higher the output power, the shorter the time required. ii) SSD Group: BP in dog colon and cat ileum increased at 6–10 W, and decreased at 12 W. The maximum BP values in dog colon and cat ileum were 9.00 ± 1.77 mmHg (Fig. 3-d) and 23.13 ± 2.64 mmHg (Fig. 3-f), respectively, and these were obtained at 10 W. BP in dog ileum and cat colon remained the same or was increased at 6 and 8 W, but decreased significantly (p<0.05) at 10 and 12 W when compared with that at 8 W. The maximum BP value in dog ileum was 16.50 ± 3.96 mmHg (Fig. 3-b) at 6 W. The maximum BP value in cat colon was 13.25 ± 2.96 mmHg (Fig. 3-h) at 8 W. The time required to weld and cut the bowel using a laser was 1–3 min. At the same power output, BP tended to be higher with LBD than with SSD, but there were no significant differences between the LBD and SSD...
Energy required for welding and cutting 1-cm bowel section: The energy (joules: J) required at output of 8 W in the LBD group was 605 ± 31 J in dog ileum, 584 ± 32 J in dog colon, 588 ± 27 J in cat ileum, and 604 ± 26 J in cat colon. The energy required at output of 8 W in the SSD group was 474 ± 42 J in dog ileum, 459 ± 21 J in dog colon, 484 ± 35 J in cat ileum, and 445 ± 32 J in cat colon (Table 1). In the LBD and SSD groups, there were no significant differences among individual intestine samples within each group. When the LBD and SSD groups were compared, SSD required about 80% of the energy required with LBD to weld and cut bowel (p<0.05).

Histological observation: We observed that the welded site was completely sealed. Coagulative necrosis occurred in the laser-irradiated portion itself, and the mucosa of the non-irradiated portions were also tightly adhered (Fig. 4).

DISCUSSION

The results obtained in this study showed that the optimum output using LBD was 6–10 W in dog and cat ileum and 8–10 W in dog and cat colon. The optimum output using SSD was 6–8 W in dog ileum, 8–10 W in dog colon, 10 W in cat ileum, and 6–8 W in cat colon. No marked differences were observed between the ileum and colon when
using either LBD or SSD. Histologically, the welded portions were sealed completely at 8 W. These results suggest that an output of 8 W is the most practical for use with both LBD and SSD in clinical veterinary medicine. At 12 W, BP
decreased in all samples. This is because at higher power output, cutting is dominant and subsequent welding of the irradiated portion is insufficient. BP tended to be slightly higher with LBD than with SSD at the same power output (no significant difference). This was thought to be due to the fact that with LBD, sufficient mechanical pressure was applied to the bowel tissue because the LBD tip is blunt, and thus tissue anastomosis was effectively completed by thermal welding.

There have been numerous reports regarding laser irradiation conditions in various medical fields. Tanaka et al. [12] reported that a BP of 60.8 mmHg is obtained when using Nd:YAG LBD with an output of 10W for 30–60 s (energy: 300–600 J) on a 1-cm injury in rabbit bowel. Sauer et al. [10] reported less tissue injury and a BP of 40.6 mmHg with a non-contact type CO2 laser at an output of 500 mW (30-s continuous wave or 0.5-s pulse wave for 60 s; energy: 107.1 J/cm) for a 0.5-cm enteroanastomosis in rabbits. Mercer et al. [6] reported that irradiation with a 5-s pulse wave at 5 W (energy: 500 J) is preferable with the non-contact type CO2 laser for 0.5-cm enteroanastomosis in rabbits. Vlasak et al. [14] compared 3 types of non-contact lasers, CO2, argon and Nd:YAG, using rabbit bowel, and concluded that irradiation with the Nd:YAG laser at an output of 5 W (energy: 500–600 J/cm) is preferable for suturing in a 1-cm bowel section.

In the present study, laser irradiation at an output of 8 W for 50–80 s (400–640 J) was required to weld and cut 1-cm bowel sections and no marked differences were seen when compared with previously reported irradiation doses [5,6,10,12]. Thus, the diode laser is able to weld and cut bowel when used at power outputs equal to those required for other lasers.

The BP obtained under optimal conditions in this study was lower than previously reported [6, 10, 12]. One of the reasons for this was that the stay suture was used in other studies, but was not used in this study. The normal pressure at the terminus of human ileum is 6.2–7.7 mmHg, and the pressure does not normally increase above 15.4 mmHg, even when peristalsis is elevated [11]. There have been no reports on the pressures in the small bowels of dogs and cats, but there are probably no substantial differences between humans and these animals with regard to function and structure of the small bowel. We have already applied this technique to many enteroanastomosis cases in dogs and cats. In all cases, there have been no complications, including disruptions or perforations at the welding site (data not shown). Thus, we believe that a diode laser is applicable to clinical veterinary medicine when used in conjunction with the stay suture, which protects the welded portion against higher pressures at the time of welding.

Table 1. Energy required for welding 1-cm of bowel

<table>
<thead>
<tr>
<th>Method</th>
<th>Dog</th>
<th></th>
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<th>Cat</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Ileum</td>
<td>Colon</td>
<td>Ileum</td>
<td>Colon</td>
<td></td>
</tr>
<tr>
<td>LBD</td>
<td>605 +/- 31a</td>
<td>584 +/- 32a</td>
<td>588 +/- 27a</td>
<td>604 +/- 26a</td>
<td></td>
</tr>
<tr>
<td>SSD</td>
<td>474 +/- 42</td>
<td>459 +/- 21</td>
<td>484 +/- 35</td>
<td>445 +/- 32</td>
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Data are shown as mean +/- S.D. (n=8).
Unit: joule.
a) The significant differences are shown against the individual value of SSD (p<0.05).

Fig. 4. Histological findings immediately after welding the cat ileum (HE stained) using LBD with performance output of 8 W power. Adhesion of mucosa was observed. The welded portion of bowel was pressured by a laser welding intestinal clamp (low magnification: a). Coagulative necrosis occurred in the laser irradiated portion itself, and the mucosa of the non-irradiated portions was also tightly adhered each other (middle magnification: b). Black bar shows laser irradiated site.
SSD required about 80% of the energy required for LBD to weld and cut bowel. The laser-irradiation tip of the SSD is structurally sharp and its focal point is located at the end of the tip. Therefore, the laser may be condensed at a certain point and the dose of irradiation to certain tissues may increase. This factor is thought to be the reason for the strong cutting power of SSD. Because the laser-irradiation portion of LBD is obtuse and the laser is weakly condensed, the cutting power of LBD is weak. However, it has the advantage of strong welding power, as it coagulates the tissues while applying mechanical pressure [7]. Based on these characteristics, it is preferable for clinical veterinary medicine to use LBD at the beginning of welding, when the welded regions are easily disrupted, and to subsequently use SSD to weld and cut bowels.

The energy required to weld and cut bowels in dogs was almost the same as that in cats. In addition, it was also almost equal to that reported in rabbits. Thus, the energy required to weld and cut bowels using the laser is not apparently influenced by the thickness of the bowel wall.

For this study, a clamp having an opening (LW clamp) was prepared. The bowel was pinched with the LW clamp and the laser was applied through this opening to cut the bowel while simultaneously sealing the stump. The welding mechanism in laser suturing is thought to be the chemical fusion between collagen fibers and fibrin fibers based on collagen alteration and fibrin polymers [16]. Therefore, uniform laser irradiation to induce tissue fusion is important. In this study, appropriate mechanical pressure was applied to the fused portion using contact-type probes in addition to the LW clamp. In preliminary studies, we used 2 unmodified intestinal clamps. However, complete sealing was not possible, as uniform mechanical pressure was not obtained around the irradiation site.

These results demonstrate that the welding of ileum and colon in dogs and cats is possible with the LW clamp in combination with the LBD or SSD probe under a diode laser output of approximately 8 W, 50–80 s (400–640 J/cm), and we believe that this method can be widely applied to living organisms.

REFERENCES