A Comparative Study on Application of Nd-YAG Laser Radiation and Electrocautery in Canine Gastric Mucosa—Magnified Observations by Dissecting Microscopy and Scanning Electron Microscopy, and Histological Examinations—

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The mucosal change, the depth of injury and the healing process in the canine gastric wall after Nd-YAG laser (YAG) exposure and electrocautery were studied comparatively by magnified observations. The results were as follows;
1. Mucosal changes caused by the YAG laser beam were more localized within the exposure area than those by electric current.
2. The depth of tissue damage to the canine gastric wall by YAG laser exposure was easy to control when compared that caused by electrocautery.
3. The healing time of the ulcer caused by the YAG laser was shorter than that caused by high frequency current.
4. In the present study on the mucosal changes due to laser exposure and electrocautery using endoscopy, dissecting microscopy and SEM, it was found that these examinations appear to be helpful as experimental procedures to clarify the detailed appearance of the mucosal surface.

It was suggested that endoscopic application of the YAG laser to the gastrointestinal tract was safe and effective when compared with other procedures which have been applied endoscopically for diagnosis and treatment.

(Key Words: Nd-YAG Laser, Electrocautery, Fiberendoscopy, Dissecting Microscopy, SEM)

INTRODUCTION

Since 1970, there have been many experimental and clinical studies on the efficacy and safety of electrocautery (1, 2, 8, 9, 12) and laser application (3, 4, 5, 6, 7, 10) in the gastric wall. Although it was considered in many studies that endoscopic electrocautery and laser radiation were excellent procedures and had many technical advantages for the treatment of gastrointestinal hemorrhages, there are still various unclear points concerning the mechanism of hemostasis in gastrointestinal bleeding caused by laser exposure and electrocautery.

This experimental study was designed, using a canine gastric mucosa, [1] to observe changes in the mucosal surface after Nd-YAG laser exposure, compared with changes after electrocautery by magnified
observations with dissecting microscopy and scanning electron microscopy (SEM). [II] to observe histological changes in the penetration depth into the gastric wall from low power to high power Nd-YAG laser and electrocautery, and [III] to compare healing processes of ulcers caused by Nd-YAG laser beams and electrocautery.

MATERIALS AND METHODS

Seven mongrel dogs, weighing from 10 to 15 kg, were anesthetized with 25 mg/kg of pentobabital sodium. The dogs were divided into three groups. In the first group, the Nd-YAG laser (Medilas; M.B.B.) was applied under laparatomy with the top of the wave guide (triconical delivery fiber) always 2.0 cm from the mucosal surface. The power of the YAG laser was arranged in 10 W steps from 20 W to 70 W and fired every 1.0 second to 4.0 seconds in duration. In the second group, electrocautery was performed endoscopically (PSD: Olympus) using a wire-electrode through the biopsy channel of a gastrofiberscope (GIF-D2; Olympus). The power of electrocautery was selected as low power (level 3 of PSD), moderate power (level 5 of PSD) and high power (level 7 of PSD), and then fulgurated by a cutting wave and a coagulating wave within one second. In the third group, the healing process of ulcers after 50 W YAG laser exposure (moderate power) by endoscopy was studied comparatively with those after electrocautery at moderate power (level 5 of PSD). One hour, 48 hours, 1 week, 2 weeks and 4 weeks after YAG laser radiation and electrocautery, the stomach was removed. Magnified observations of the mucosal surface and reepithelization around the mucosal defect after both YAG laser and high frequency current application were performed by dissecting microscopy and SEM. After over 5 days of fixation in 10% formalin, each lesion was sectioned into 5 mm slices to select the central area of the deepest injury for histological examination. Histological findings were examined by hematoxylin-eosin staining (H&E), azan staining and Elastica-van Gieson staining (E. V. G.).

RESULTS

[1] Magnified observations by dissecting microscopy and SEM

(I) Surface appearance after electrocautery

One hour after fulguration, a dissecting microscopic picture of the coagulated area at low power (level 3 of PSD) for 1.0 second showed a shallow depression with an annular reddish zone (Fig. 1—a). A magnified picture with dissecting microscopy showed a double-annular red zone in the outer cauterized area (Fig. 1—b). Findings of irregular gastric mucosa appeared inside the fulgurated field but a fine reticular pattern of the gastric mucosa was seen outside the red zone.

In a low power view with SEM (Fig. 2—a), the surface change of the same coagulated area presented by dissecting microscopy appeared as a shallow depressed area with a sharp borderline with the circumferential area. In the magnified picture by SEM (Fig. 2—b), gastric pits around the depressive area which was clearly divided with a furrow revealed an irregular and distorted pattern. The high power picture showed a rough
Fig. 2  SEM picture of the cauterized field.
1) Low power view reveals a clear depressed area (×20).
2) Magnified view shows irregular and distorted gastric pits close to the cauterized area (×100).
3) High power view reveals rough and uneven microvilli on the epithelial surface of these gastric pits (×10,000).
and uneven surface of the epithelial cells with distorted and reduced microvilli (Fig. 2—c).

(2) Surface appearance after YAG laser radiation
One hour after YAG laser exposure, the surface with dissecting microscopic findings of the exposed area at a YAG laser power of 40 W showed a round flat mucosal elevation with central discoloration and a circular red zone (Fig. 3—a). The magnified picture (Fig. 3—b) revealed a reticular pattern caused by capillary dilatation or intravascular coagulation as in the findings of electrocautery (Fig. 1—b). High power of over 60 W of YAG laser radiation produced mucosal hemorrhage around the annular red zone.

In a low power picture with SEM (Fig. 4—a), a round flat elevation and disappearance of gastric pits in the central area were seen just on the exposed field. In a magnified picture (Fig. 4—b), the borderline of the exposed area was clearly separated from the surrounding normal mucosa. In the ×1,000 picture (Fig. 4—c), almost normal gastric pits were observed near the irritated area. A high power view of the borderline area with YAG laser radiation revealed a normal pattern of epithelial cells with fine, regular microvilli (Fig. 4—d).

[II] Histological findings
(1) Histological changes caused by electrocautery
Two types of wave with cutting and coagulating properties were used in endoscopic electrocautery. Electrocautery at a low power (level 3 on PSD) with both waves produced mucosal coagulation and no submucosal damage (Fig. 5—a). Then fulguration with moderate power (level 5 on PSD) showed deep transmuscular damage, which were more severe with the cutting wave than with the coagulating wave at the same power (Fig. 5—b).

On the other hand, electric cauterity at high power (level 7 on PSD) disclosed small ulcers, and wide cuneiformed degeneration under the submucosal layer, which were more severe with the cutting wave than with the coagulating wave (Fig. 5—c). Within these degenerated areas, there was intravascular coagulation and narrowing of vessels due to compression of degenerated collagen fibers in the submucosal layer. These findings may cause hemostatic effects as in the case of findings of YAG laser exposure. The depth and range of histological damage in the gastric wall by electrocautery may be difficult to control by power and duration.

(2) Histological changes caused by YAG laser radiation
The penetration depth of YAG laser radiation was studied from low power (30 W) to high power (70 W) with pulsed (one second) and continuous (two to four seconds) exposure. At low power of under 50 W and pulsed radiation, histological changes were limited to the mucosal layer, which showed edematous and acidophilic changes within the epithelial layer (Fig. 6—a). These histological findings increased on the mucosal surface and penetrated through the muscularis mucosa to the submucosal layer at the same power and continuous application (four seconds) (Fig. 6—b). Remarkable histological damages, such as epithelial degeneration, thickening of muscularis mucosa and degeneration of collagen fiber, were localized within the exposed field showing a cuneiform area under the
Fig. 4

(a)  Low power view reveals a flat, round elevation (×20).
(b)  In the magnified picture, the margin of the irradiated field is clearly separated (×100).
(c)  Picture of magnified 1,000 times shows regular gastric pits near the exposed field.
(d)  High power view reveals fine microvilli on the epithelial surface of these gastric pits (×6,000).
Histological findings with electric current:

a) Coagulation with low power produces mucosal degeneration (X 8. H.E).
b) Moderate power produces a cutting wave of electroatrocity through the gastric wall (X 7.5. H.E).
c) Electroatrocity with high power cutting wave produces the same submucosal degeneration as the change caused by YAG laser exposure (X 5.5. azan).

Fig. 5
submucosal layer with an exposure power of over 60W (Fig. 6—c).

Degeneration in the submucosal layer was more severe around the vessels, and the cavity of the vessels was narrowed due to the degeneration, which may produce hemostatic effects. No histological damage of the arterial wall was found with E.V.G. staining (Fig. 6—d). High power with continuous YAG laser radiation caused dissociation of the epithelial later and the muscularis mucosa, and it also produced deep degeneration in the submucosal layer (Fig. 6—e).

With YAG laser exposure, it was noted that the depth and degree of histological damage in the canine gastric wall were increased in proportion to the laser power and exposure duration. Therefore, it is suggested that YAG laser exposure is safer and easier to control than electrocautery in the gastrointestinal tract.

[III] Healing process of ulcers produced by electrocautery and YAG laser radiation

The healing processes of the ulcers were studied comparatively. One was produced by snare wire electrocautery at moderate power (level 5 on PSD) for 10 seconds and the other by YAG laser emission at a power of 50W for 5 seconds. Both were examined endoscopically and then examined by microscopy, dissecting microscopy and SEM at the duration of 1 hour, 48 hours, 1 week, 2 weeks, 3 weeks and 4 weeks after production of the lesions.

1) Findings of ulcers caused by electrocautery

After 48 hours, a deep ulcer with marked swelling and slight marginal redness was endoscopically (Fig. 7—a) seen, and it penetrated histologically through the muscular layer (Fig. 8—a). A magnified picture with dissecting microscopy revealed a reticular pattern on the margin of the ulcer, based on remarkable hyperemia of damaged gastric pits (Fig. 9).

A magnified view with SEM showed thermal degeneration on almost the whole margin of the ulcer and partial appearance of regenerating epithelium (Fig. 10—a). The regenerating epithelium consisted histologically of a single layer of indifferent epithelium (Fig. 8—b), in which an irregular arrangement of the cells covered with fine microvilli was noted in the high power picture by SEM (Fig. 10—b). Ulcers caused by electrocautery were healed with central redness lasting for 3 to 4 weeks. The healing time depending on the size of each ulcer (Fig. 7—b).

2) Findings of ulcers caused by YAG laser radiation

Ulcers caused by YAG laser exposure showed endoscopically mild swelling around the normal mucosa and marked redness on the margin after 48 hours (Fig. 11—a), and a degenerative area through the submucosal layer to the muscular layer was observed histologically (Fig. 12—a). There were irregular capillary networks inside the margin of the ulcer and central depression with dissecting microscopy (Fig. 13). On the margin of the ulcer as seen by SEM (Fig. 14—a) and histology (Fig. 12—b), regenerating epithelium with a partially incomplete foveolar pattern appeared and it resembled a cable leading toward the center of the ulcer.

In the magnified picture by SEM, the regenerating epithelium had
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Fig. 6  Histological findings for YAG laser beam.

a) Low power under 50 W and pulse (1 second) exposure produces mucosal damage (× 10, HE).

b) The same power and continuous (4 seconds) exposure causes submucosal degeneration (× 10, HE).

c) YAG laser beam with high power (60 W) produces deep degeneration in the submucosal connective tissue (× 8, HE).

d) High power view of degenerated area shows narrowed vessels and no damage to the arterial wall (× 300, E.V.G.).

e) YAG laser with high power of over 70 W and continuous exposure causes a dissociation of the mucosa and the muscularis mucosa (× 15, HE).
Fig. 8  Histological findings of cauterized ulcer.
a) Ulcer penetrates through the muscular layer (×6.5, HE).
b) Magnified view (×60, HE) shows a single layer of indifferent epithelium on the edge of the ulcer (arrow).
Fig. 10  SEM picture of the cauterized ulcer.
   a) Wide thermal degeneration and partial regeneration (arrow) appears on the margin of the ulcer (×40).
   b) Magnified view reveals round, indifferent cells with fine microvilli (×3,000).
Fig. 12 Histological findings of the exposed ulcer.

a) Low power picture of the ulcer (×8, HE).

b) Magnified view of the edge of the ulcer shows regeneration with an irregular foveolar pattern (×60, HE).
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Fig. 14

(c) SEM picture of the exposed ulcer.
(a) Low power view (×20)
(b) Magnified view inside the ulcer shows regenerating mucosa with an irregular follicular pattern (×1,000)
(c) High power view reveals fine and dense microvilli on the regenerating epithelium (×6,000)
incomplete gastric pits of various shapes and sizes (Fig. 14—b) and each cell was covered with fine and dense microvilli (Fig. 14—c). The ulcers caused by YAG laser radiation were healed with marked converging folds within about 2 to 3 weeks (Fig. 11—b).

**DISCUSSION**

It is generally recognized that fiberendoscopy has both diagnostic and therapeutic uses and is one of the most common procedures in clinical gastroenterology. Recently, several endoscopic modalities for the treatment of gastrointestinal hemorrhage have been established. They include laser radiation, electrocaugulation, hemostatic clips, topical injection of hemostatics, sprays of thrombin and fibrin or some tissue adhesives and cryosurgery (1, 3, 5, 9, 10, 12). As a step in the clarification of the theoretical background, we reported comparative studies of surface changes and histological effects on the canine stomach caused by electrocautery and YAG laser exposure and their healing processes (13, 14).

There have been no accurate studies of surface changes caused by electrocautery and laser radiation in the gastrointestinal mucosa using magnified observation with dissecting microscopy and SEM. In our study (13, 14), it was noted that the mucosal changes caused by electrocautery were epithelial damage around the cauterized area, and those by YAG laser exposure were localized without epithelial changes in the area near the exposed field.

Histological effects of electrocautery in the canine gastric wall has been reported by Blackwood WD (2), Silvis SE (11), Papp JP (9), Akasak Y (1) and Nakahara A (8). It is evident that the depth of tissue damage through the canine gastric wall is proportional to the energy of the electric current and duration of continuous application. However, in their reports, the histological changes are variable and not proportional to the method of contact with the mucosa by the electrode. Therefore, the degree of contact of the mucosal surface with the tip of the electrode is one of the major problems in endoscopic electrocautery (1, 6, 8, 9, 12, 14).

On the other hand, Goodale RL (4), Dwyer RM (3), Kiefhaber P (5), Silverstein FE (10), Mizushima K (7), Konishi T (6) and Suzuki S (13, 14, 15) reported that the penetration depth of YAG laser beams in the canine gastric wall is proportional to the laser power, the exposure duration and the distance of the mucosa from the top of wave guide, and that the depth of histological damage may depend on the absorptivity or heat conductivity of tissue and be reduced by the cooling effect of the blood flowing in the gastric wall.

The depth of histological damage by electrocautery was variable depending on the power and wave form of the electric current. Since it was possible with a cutting wave at a high level of 7 on PSD to cause the same histological changes as with YAG laser emission which can produce submucosal degeneration of collagen fiber and narrowed vessels, we have recently used coagulation and cutting setting within a moderate level of 5 on PSD (50% of the maximum power on PSD) for not more than 3 seconds clinically. In our studies, the penetration depth of YAG laser exposure to the
gastric mucosa was found to be proportional to its power, time and the
distance of the mucosal surface from the tip of the optical fiber. It was also
discovered that YAG laser emission is more easy controlled than electro-
cauterity, and the former is considered to be more effective and safer in
gastrointestinal endoscopic surgery than the latter.

Although the healing time of experimental gastric ulcers is difficult to
compare for varying grades of ulcers, the size and depth of the ulcers caused
by electrocautery and YAG laser exposure are relatively easy to control and
reproduce. Therefore, they are good experimental models for comparing
the healing process of ulcers produced by high frequency current and YAG
laser beams. Silvis SE (11) reported that the healing process of electro-
cauterized ulcers does not begin until the 3rd day after production of the
ulcers. In our study (16), it was seen by SEM 48 hours after the ulcer was
formed that the regenerating epithelium was more evident and wide spread
inside the margin of ulcers caused by YAG laser than in those caused by
electric current. Although the healing time of ulcers produced by both YAG
laser and electric current was shorter than that of peptic ulcers, depending
on size and depth, ulcer caused by YAG laser healed in a relatively shorter
time than those caused by electrocautery.

It is concluded that the mucosal change and the depth of tissue damage
by the YAG laser beam is more localized, safer and easier to control than
that due to electrocautery in the canine stomach. There was also the
evidence from magnified observations that the healing duration of ulcer
caused by YAG laser was shorter than those caused by electric current. In
addition, it was suggested that clinical application of YAG lasers in the
gastrointestinal tract is useful when compared with other endoscopic
treatment.

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Fig. 1  Dissecting micrograph of the mucosal surface after electrocautery with low power.  
a) Cauterized area in a low power view shows a round zone (× 6).  
b) Magnified view of the margin of the cauterized area (× 16).

Fig. 3  Dissecting micrograph of the area exposed to a 40 W YAG laser.  
a) Low power view shows an annular red zone and central discoloration (× 6).  
b) Magnified view of the margin of the exposed area (× 16).

Fig. 7  Endoscopic findings of a cauterized ulcer.  
a) After 48 hours, a deep ulcer with marked swelling appears.  
b) After 3 to 4 weeks, the ulcer is healed with central redness.
Fig. 9  Dissecting micrograph around the margin of the ulcer shows hyperemia and thermal damage (×6).

(a)  (b)

Fig. 11  Endoscopic findings of the ulcer caused by YAG laser exposure.
   a) After 48 hours, the ulcer appears as a mild swelling with marked redness on the margin of the ulcer.
   b) After 2 to 3 weeks, the ulcer is healed with marked converging folds.

Fig. 13  In a dissecting micrograph, the center of the exposed ulcer is deep, and a depressed red zone is present inside the margin (×6).