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Original Article

Nd-YAG Laser Absorption on Standard Color Cards and Test Models of the Esophageal and Gastric Wall

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Abstract: Using fifty-nine standard color cards denoted by the Munsell renotation system and agar test models of the esophageal and the gastric walls, Nd-YAG laser absorption was investigated in relation to differences in surface color of the irradiated target. The black card showed the maximum and the white card the minimum absorption with the Nd-YAG laser irradiation. The statistical analysis from the irradiation experiment with other color cards indicated that there were significant correlations between the absorption of Nd-YAG laser and three attributes of color cards: hue, brightness, and saturation. In irradiation with the Nd-YAG laser to the test models of the esophageal wall, it was observed that the energy of the Nd-YAG laser easily penetrated the translucent first layer and was absorbed mainly by the red-colored second layer. In contrast, laser energy was absorbed only in the first layer during irradiation to the gastric wall model. These results may explain the effects of irradiation observed in Nd-YAG laser irradiation to the esophageal wall.

Key words: Nd-YAG laser, Laser absorption, Laser endoscopy, Esophageal cancer

Although Nd-YAG laser endoscopy was initially introduced to the field of therapeutic endoscopy as a new hemostatic tool, it is now commonly utilized to destroy malignant tumors arising in the gastrointestinal tract[1]. This laser treatment is also appropriate for esophageal tumors, and several clinical trials of Nd-YAG laser endoscopy for treating esophageal lesions have been reported[2,3].

Experimental study of Nd-YAG laser irradiation to the canine stomach and parts of the digestive tract other than the esophagus has revealed that this laser causes thermal coagulation first in the mucosal layer and then in the deeper muscle layer, and the extent of laser thermal damage can be determined from changes occurring in the mucosal layer[4]. On the other hand, experimental irradiation of Nd-YAG laser to the canine esophageal wall showed that an extensive thermal effect was achieved mainly in the deep muscle layer[5]. The reason for this curious difference in the effect on the esophageal wall remains obscure.

The surface of the esophagus is whitish-pink, and the mucosal layer is more translucent than that of other parts of the gastrointestinal tract. Although these color characteristics of the esophageal mucosa are thought to be one of the major causes of the unusual effect on the esophageal wall, the differences in Nd-YAG laser absorption due to difference in surface color of the irradiated target have not been fully investigated.

Therefore, in order to explain the irradiation effect observed in the esophageal wall,

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the differential color absorption characteristics of the Nd-YAG laser was studied by using standard color cards and agar test models of the esophageal and gastric walls.

Materials and Methods

1. Nd-YAG laser source

The Nd-YAG laser system employed in this study was the SL-115 (NEC, Japan). This laser produces a continuous wave output of up to 100 W at a wavelength of 1,060 nm in the infrared region of the spectrum. This beam is focused on a quartz fiber with a 0.3-mm core diameter. The transmission rate of this fiber is 80%, and the laser is emitted through this fiber to the target.

2. Analysis of the Nd-YAG laser absorption on the color cards

a) Standard color cards:

Fifty-nine standard color cards (Nihon Shikisai Kenkyusho, Japan) were used. According to the Munsell renotation system, each color card is denoted by three attributes: hue, brightness, and saturation. The hue includes 10 basic colors, and is expressed as H. The unit of brightness is value (V), which varies from 0 to 10. The unit of saturation is chroma (C), and C varies from 1 to 14. Each color card is expressed using H, V, and C; for example, red:R-4/14 or blue:B-4/10.

The 59 cards were divided into three groups: 1) achromatic (neutral) color, 2) chromatic standards, and 3) other chromatic colors. Group 1 consisted of five cards: N-1 (black), N-3, N-5 (gray), N-7, and N-10 (white). Group 2 consisted of nine cards: red (R-4/14), orange (YR-6/11), yellow (Y-8/12), yellow-green (GY-7/11), green (G-5/10), blue-green (BG-5/9), blue (B-4/10), blue-purple (PB-4/8), and purple (P-3/10). Group 3 consisted of 45 cards with various combinations of H, V, and C.

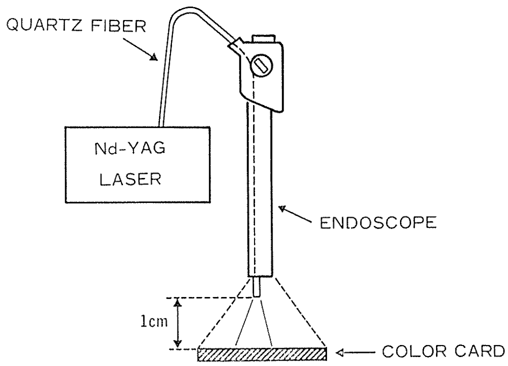

Fig. 1. Measurement of Nd-YAG laser absorption on color cards.
The quartz fiber was inserted into the forceps channel of an endoscope and the tip placed 1 cm above each color card.

b) Measurement of Nd-YAG laser absorption on color cards:

The color cards were irradiated by the laser perpendicularly. The output power of the Nd-YAG laser was set at 20 W, and the distance between the tip of the fiber and a color card maintained at 1 cm. The irradiation spot size on a color card was 1.09 mm^2, and the power density 18.35 W/mm^2. The duration of time causing the perforation of a color card was measured, and the total energy was calculated as the product of the duration and the output power of the Nd-YAG laser. This irradiation to one color card was repeated five times, and the average total energy required to perforate each color card was calculated and expressed as E. The relationships between E and the three qualities denoting each color card according to the Munsell renotation system were determined, and the coefficient of correlation and the regression line between E and H, V, C were calculated (Fig. 1).

3. Nd-YAG laser irradiation to the models of the esophageal and gastric walls

a) The models:

As agar contains water, protein, sugar and some minerals and is reported to show changes similar to the tissues with regard to absorption of and penetration by laser light[6], agar was selected as the most suitable material for the esophageal and gastric wall models. In this agar model, the coagulated zone resulting from the laser irradiation could be recognized as a melted area. Modeled on the difference in color between the inner (mucosal and submucosal) layer and outer (muscle) layer of the esophagus, the first layer of the esophageal wall model was made of non-colored agar and the second layer of red-colored agar. However, since there is little difference in color between the two layers of the gastric wall, this model was composed of two layers of the same red-colored agar. The thickness, length, and width of each agar layer was 5 mm, 3 cm, and 2 cm, respectively.

b) Measurement of the melted area caused by laser irradiation:

The tip of the optic fiber was placed 2 cm above each model, and an Nd-YAG laser beam of 50 w output power was emitted for 5 seconds. The spot size was 4.3 mm^2 and the power density 11.6 W/mm^2.

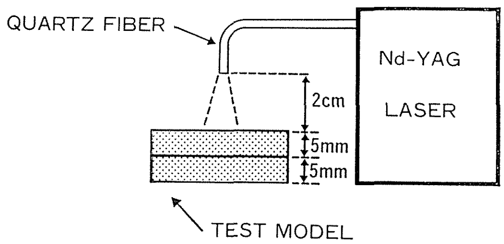

Fig. 2. Nd-YAG laser irradiation to the test models.
The tip of the quartz fiber was placed 2 cm above each model. The agar model of the esophageal wall consisted of an upper non-colored translucent layer and lower red-colored layer, and that of the gastric wall consisted of double red-colored layers.

After the irradiation, each model was cut through the center of the irradiation spot, and the diameter and depth of the melted area observed in each layer of this cross section was measured (Fig. 2).

Results

1. Nd-YAG laser absorption on color cards

a) Achromatic (neutral) color:

The total energy required to perforate the black color card (N-1) was 0.08 joule, and this was the minimum value throughout this study. In contrast, the E on the white card (N-10) showed the maximum value, 180 joules. As the V of the color increased, the E was increased in other achromatic cards.

b) Chromatic standards:

On nine cards, the E required to perforate the cards was higher in the red color group (red, 11 joules; orange, 24 joules; yellow, 21 joules) than in the blue color group (blue-green, 4 joules; blue, 3 joules; green-blue, 3 joules). Thus the Nd-YAG laser was more easily absorbed in the blue color group than in the red color group (Fig. 3).

c) Other chromatic colors:

Table 1 shows the total energy (E) of the Nd-YAG laser irradiation required to perforate each chromatic card. The hue (H) with 49 color cards ranged from red

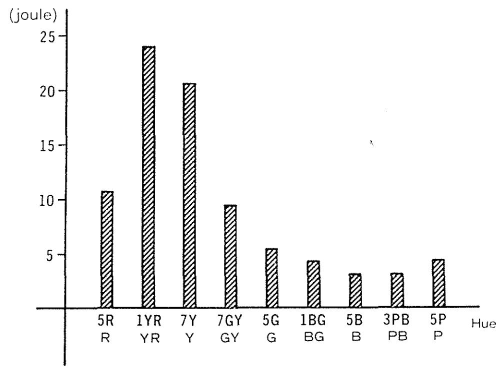

Fig. 3. The E in the chromatic standards.

Table 1. The total energy (E) calculated for irradiation with Nd-YAG laser to each chromatic color card.
H, hue; V, brightness; C, saturation. The unit of E is the joule.

H	V	C	E	H	V	C	E
R	2.5	4	1.5	G	6.5	11	12.0
	4	11	11.0		7	6	10.0
	5.5	4	4.0		7	10	15.0
	6.5	1	2.0		8	4	10.0
	6.5	11	20.0	BG	3	4	1.5
	7	6	30.0		4.5	9	4.0
	8	4	24.0		5.5	6	4.0
YR	3	4	1.5		6.5	8	10.0
	5.5	12	24.0		7	4	5.0
	5.5	4	4.0		7	6	8.0
	6.5	1	2.0	B	3.5	4	1.5
	6.5	4	3.0		4	9	3.0
	6.5	11	18.0		5.5	6	4.0
	7	10	13.0		6.5	1	3.0
	7	11	17.0		6.5	8	10.0
Y	3.5	4	1.5	PB	2.5	4	1.5
	6.5	1	2.5		3	11	3.0
	6.5	6	2.0		3.5	11	3.0
	8	12	21.0		5.5	6	5.0
GY	6.5	4	1.5		5.5	10	15.0
	6.5	6	3.0		6.5	1	3.0
	7	8	9.0	P	2.5	4	1.5
	7	10	12.0		3	11	2.5
G	3	4	1.5		5.5	8	20.0
	4.5	10	6.0		6.5	1	2.5
	5.5	4	4.0		7	4	6.0
	6.5	1	2.5				

to purple, and the value (V) and the chroma (C) with color cards ranged from 2 to 8 and 1 to 14, respectively. The relationship between E and H, E and V, and E and C are presented in Figures 4, 5, and 6. The regression lines and the coefficients of correlation (r) between E vs H, E vs V, and E vs C were $E=0.92H+2.91$ ($\gamma=0.33$); $E=2.26V-4.85$ ($\gamma=0.52$); and $E=1.02C+1.31$ ($\gamma=0.51$), respectively. These three coefficients were found to be statistically significant ($p<0.01$).

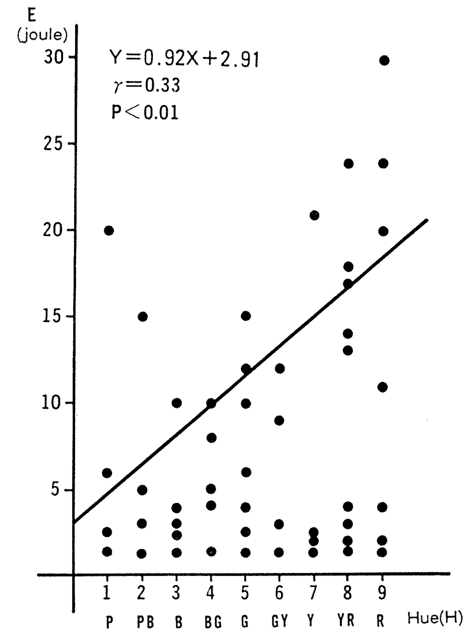

Fig. 4. The relationship between E and H.

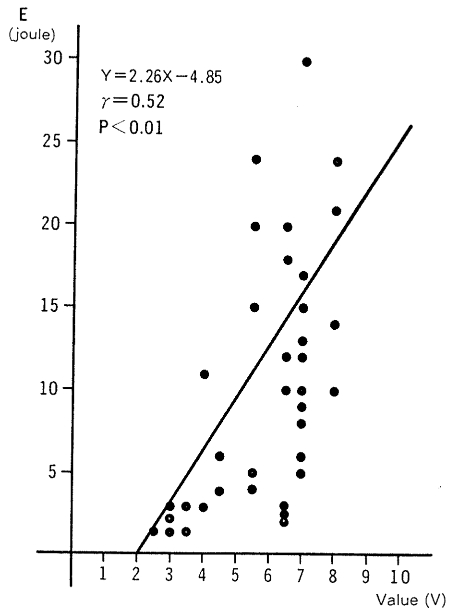

Fig. 5. The relationship between E and V.

2. The effect of irradiation to the esophageal and gastric wall models

After the Nd-YAG laser irradiation to the esophageal model, a semicircular melted

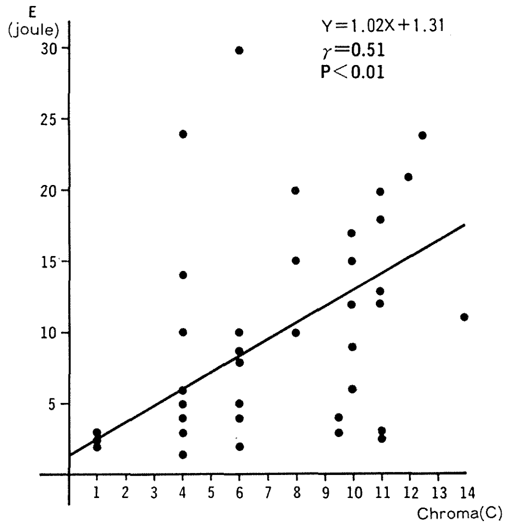

Fig. 6. The relationship between E and C.

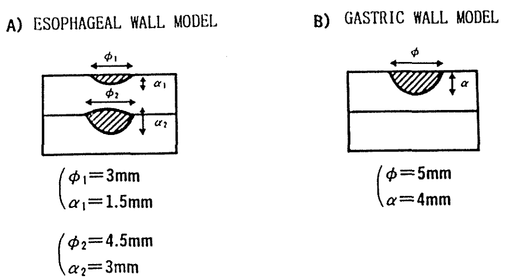

Fig. 7. The diameter and depth of the melted area observed in each test model.

area was observed on the surface of the translucent first layer. The rest of the first layer was unaffected, and a melted area was again generated in the red-colored second layer which was more extensive than that observed on the surface of the first layer. However, the melted area in the gastric wall model was seen only on the surface of the first layer (Fig. 7).

Discussion

In the medical application of laser light, it is very important to understand the action of laser radiation on biological tissues. The main absorption in biological molecules such as amino acids and nucleic acids occurs within the range of wavelengths shorter than 280 nm, that is, the ultraviolet region[6]. On the other hand, since living tissue has a high water content, absorption of the laser light by the water plays an important role in the efficacy of irradiation to the tissue. Thus, absorption of the laser light by the biological tissue can be expected because of the absorbability of water and some pigments such as melanin and hemoglobin. Previous studies have revealed that the high water content of most tissues leads to very strong absorption of infrared radiation[7], and the absorption coefficient of hemoglobin is particularly high in the green region of the spectrum[8]. By applying these phenomena, the carbon dioxide laser with a wavelength of 10,600 nm has been used as a surgical knife, and the argon-ion laser with a wavelength of 488 and 515 nm has been applied to photocoagulation, especially in ophthalmology. Thus, to use laser light effectively, it is necessary to determine the spectroscopic character of the target tissues.

However, the processes of thermal interaction between laser light and biological tissues are complex, and this makes it difficult to select the most suitable laser source for each clinical case. Therefore, it is necessary to understand the action of laser lights now being used, and to predict the thermal effect on the target tissue from the surface color of the irradiated tissue.

Because of the near-infrared emission of the Nd-YAG laser light, its absorption by tissues is low, and scattering is strongly manifested. However, as demonstrated by Goldmann[9], a good correlation between the thermal effect and the color, brightness, and saturation of the target tissue was also demonstrated in this study, suggesting that the absorption of the Nd-YAG laser is affected by the surface color of the tissue. Moreover, the results of the second experiment in this study showed that the thermal energy of the Nd-YAG laser light can easily penetrate non-colored tissue. It was apparent that the thermal energy of the Nd-YAG laser was absorbed mainly by the red-colored second layer of the esophageal test model, and this effect could explain the different results observed in the irradiation experiment with the canine esophagus. In contrast, the change seen in the gastric wall model was similar to that observed in the canine stomach and other parts of the gastrointestinal tract.

In conclusion, the thermal effect on the esophageal wall caused by Nd-YAG laser irradiation cannot be easily judged from the change occurring in the mucosal layer, and in the case of Nd-YAG laser therapy for an esophageal lesion, the type of laser irradiation should be different from that used for irradiation of a gastric lesion. Further study is needed to establish the optimal conditions for the endoscopical use of the Nd-YAG laser in the esophagus.

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