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In Vitro Tissue Effects of a Combined Ho:YAG/Nd:YAG Laser: Sprinkling of Tissue Fragments by Ho:YAG Laser Light May Be Problematic for Oncological Interventions

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Background and Objective: **Surgery of soft tissue, for example, of the tongue or the liver, requires a cutting and coagulating device. Therefore, a combined Ho:YAG/Nd:YAG laser providing the laser beam of both systems together in one bare fiber seems to be useful.**
Study Design/Materials and Methods: **We studied the effect of such a laser system in vitro on tongues of pigs.**
Results: **Combined application of both lasers results in vitro in a thicker coagulation zone in soft tissue (tongue). Tissue fragments possibly containing vital cells are sprinkled by the pulsed energy of the Ho:YAG laser up to a distance of 20 cm.**
Conclusion: **Using the pulsed Ho:YAG laser for oncologic interventions seems to be problematic. Combined laser effect in vivo may result in better hemostasis.**
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INTRODUCTION

Classic surgical lasers are mainly the cutting CO_2 laser and the coagulating Nd:YAG laser. Surgery of soft tissue, for example, of the tongue, hemangiomas, or the liver, requires a cutting and coagulating device. One approach to this problem was the use of the Nd:YAG laser in the contact-tip method. Conducting partial tongue resections with this technique reduced bleeding compared with electric surgery or CO_2 laser [1], but this method did not become widely accepted [2]. Another approach was the combination of the CO_2 laser and the Nd:YAG laser in one system [3]. This system proved to be effective, for example, for the resection of hemangiomas [4]. The principal problem of this system is that CO_2 lasers and Nd:YAG lasers for optimal performance need different delivery systems. Ho:YAG lasers, like CO_2 lasers, can cut, with minimal damage to adjacent

tissue; however, unlike CO_2 lasers, they also offer fiberoptic delivery. A combined Ho:YAG/Nd:YAG laser providing the laser beam of both systems together in one bare fiber seems to be advantageous.

We tested such a combined Ho:YAG/Nd:YAG laser system in vitro to determine its clinical potentiality.

MATERIALS AND METHODS

Laser Device and Parameters

Studies were performed with a laser system (Ergolas Multifire, Jenoptik Technologie Com-

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pany, Jena, Germany) that emits the combined beam of a flashlamp-pulsed Ho:YAG laser (λ = 2,140 nm, pulse duration = 200–300 μsec) and a continuously pumped Nd:YAG laser (λ = 1,064 nm) through one bare fiber (quartz, diameter = 600 μm).

Tissue was mounted on a motorized slide that moved at a constant speed of 2.5 mm/second to standardize incisions. Distance and pressure when using the free-beam method (distance $\approx$ 1 mm) or the contact-tip method were controlled manually. Pulse energy and rate of the Ho:YAG laser were changed from 0.2 to 2.5 J and from 10 to 25 Hz, respectively, resulting in an average power output of 5–30 W. The Ho:YAG laser was applied alone or in combination with the Nd:YAG laser (20 W) in the free-beam or contact-tip method.

For comparison, incisions were also made with a CO_2 laser (λ = 10,600 nm; Sharplan 1025, Sharplan Laser Industries, Tel Aviv, Israel) in continuous 20-W mode (spot size $\approx$ 260 μm).

Tissue Examined

Fresh tongue (muscle with and without mucosa) was obtained from pigs (Suabian Hall strain). After laser exposure, crater diameter was measured by reflective light microscopy. Tissue was fixed in 10% formalin, embedded in paraffin, sectioned, and stained for histological examination with hematoxylin and eosin (H&E). Using transmission light microscopy, tissue diameters of the incision and thermal effects were quantified.

Sprinkled tissue was collected when applying Ho:YAG (2 J/pulse, 10 Hz) or CO_2 (20 W) laser light for 1 minute stationary to the tissue. Therefore, a microscopic slide (50 mm × 75 mm) was set orthogonal to the tissue, parallel to the laser beam, with a distance of 5 mm to the beam (Fig. 1). Material was fixed with a spray for cytologic use and stained with H&E before transmission light microscopy.

Maximum distance of the sprinkled tissue was determined by using a ruler and the naked eye.

RESULTS

Practicability

When using the Ho:YAG laser in the contact-tip method either with or without the Nd:YAG laser, the tip of the bare fiber often became ad-
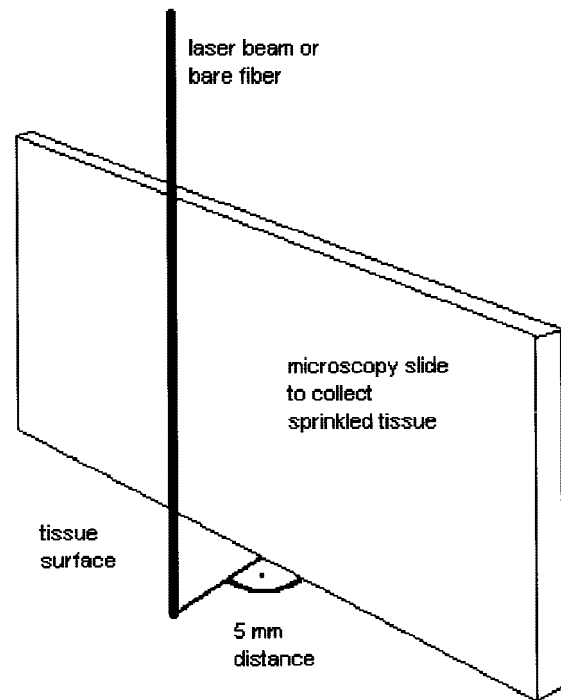

Fig. 1. Arrangement of laser (CO_2 in distance application or Ho:YAG in contact application), tissue, and microscopic slide for collecting sprinkled tissue.

herent to the tissue, resulting in irregular and deep craters. The application of the pulsed Ho:YAG laser light produced explosive effects.

Morphology and Dimensions of the Incisions

The Ho:YAG laser incisions with and without Nd:YAG laser consisted of an irregular row of craters, microscopically showing deep fissures and partly ablated tissue still connected by a small bridge to the main specimen (Fig. 2A,B). Therefore, the diameters of the incisions were highly variable.

Using the same average power output (20 W, free-beam method), the incision of the Ho:YAG laser as opposed to the CO_2 laser appeared to be wider, more shallow, and irregular (Table 1). Incision width produced by applying the Ho:YAG laser in the contact-tip method measured up to 2.4 mm (pulse energy = 2.5 J).

When comparing tissue exposed to Ho:YAG laser light alone or with Nd:YAG laser light, distinct differences could be seen. The zone of coagulation beneath the crater enlarged when adding the Nd:YAG laser light. With the contact-tip method (Ho:YAG 10 Hz, 10 W), the zone of coagulation without Nd:YAG laser was 160–400 μm deep; when adding Nd:YAG laser light (20 W), the
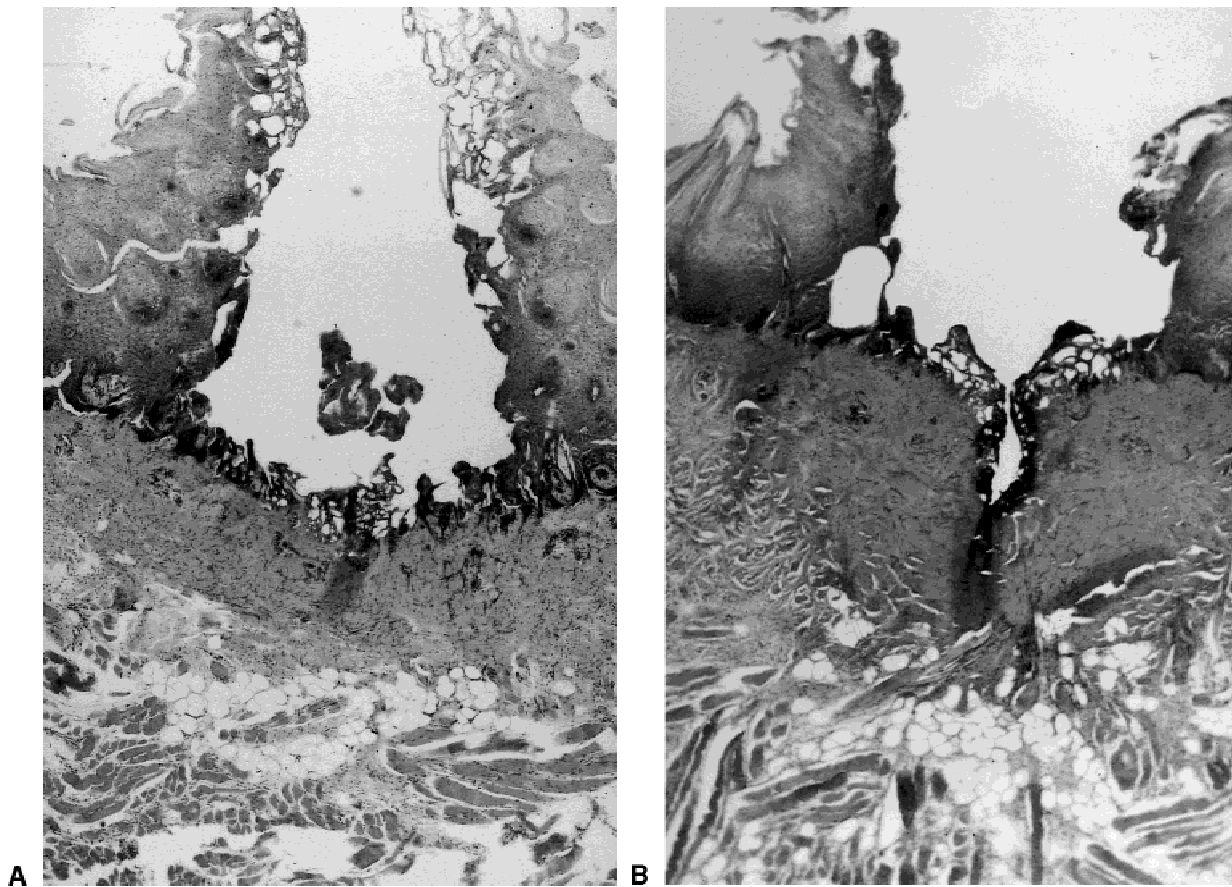
Fig. 2. Incisions on pig tongue done by the Ho:YAG laser (10 Hz, 10 W, contact-tip method) without or with the Nd:YAG laser (20 W) in combination. Hematoxylin and eosin, 50×. **A:** Ho:YAG laser alone. **B:** Combined Ho:YAG/Nd YAG laser.

TABLE 1. Dimensions of Ho:YAG and CO_2 Laser Incisions for the Same Power Settings in the Tongue*

Tissue	Incision depth/mm		Incision width/mm	
	Ho:YAG	CO_2	Ho:YAG	CO_2
Tongue without mucosa	0.28–0.8	3.5–3.7	0.3–1.2	0.26–0.4
Tongue with mucosa	0.6–0.8	3.6–4	0.6–1.2	0.24–0.6

*Speed = 2.5 mm/sec, distance = 1 mm, power = 20 W each, Ho:YAG = 10 Hz, 2J/pulse.

zone was 200–800 µm (Fig. 2A,B). The depths of coagulation for the free-beam method were 0–320 µm and 100–500 µm, respectively.

Sprinkled Tissue

When using the Ho:YAG laser (2 J/pulse), tissue fragments were macroscopically sprinkled and dispersed up to a distance of 20 cm. Transmission light microscopy of the glass slide set next to the laser beam showed separated, apparently intact, cells and larger, nontransparent tissue fragments (Fig. 3A,B).

No cells or larger tissue fragments could be detected on the microscopic slide set next to the CO_2 laser beam. Only material resulting in homogeneous, hardly stained, highly translucent areas adhered to the glass surface (not shown).

DISCUSSION

The Ho:YAG laser emits energy at approximately 2,100 nm and is still a relatively new laser to medicine. It has been used in laser surgery for the past 10 years. Like the CO_2 laser when it was first used clinically, the Ho:YAG laser is poised for rapid and widespread use. Ho:YAG lasers, like
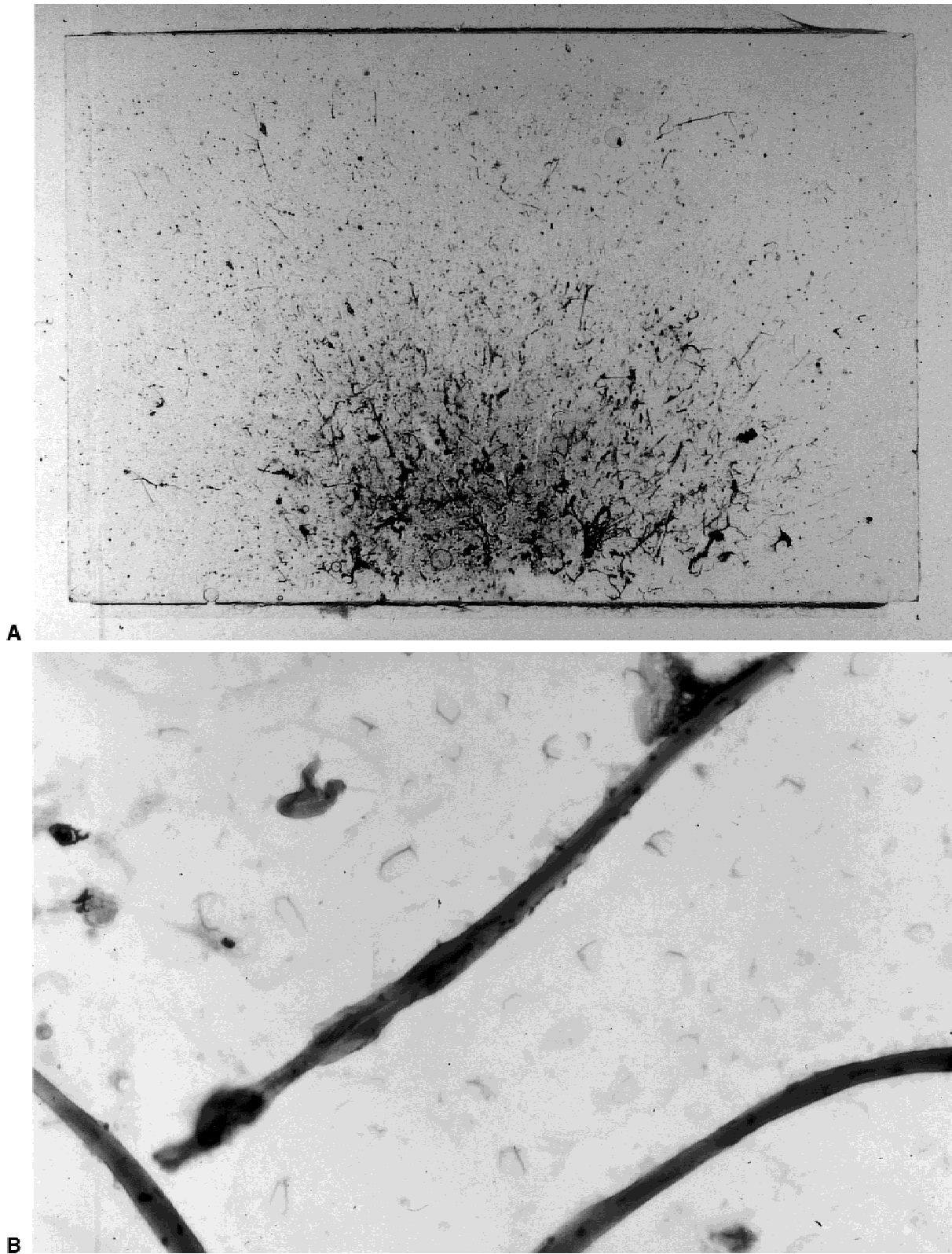
Fig. 3. Dispersed tissue on a microscopic slide set next to the Ho:YAG laser incision (Fig. 1; contact-tip method, 15 Hz, 30 W, duration ≈ 60 seconds, hematoxylin and eosin). **A:** Complete glass slide (original size: 75 mm × 50 mm). **B:** Enlarged section from A (320×). The structure diagonally crossing the figure consists of muscle cells. Membranes and nuclei have a partly intact morphologic appearance. Especially larger fragments, as seen in A, could include vital cells.

CO_2 lasers, can cut, with minimal damage to adjacent tissue; however, unlike CO_2 lasers, they also offer fiberoptic delivery (which is ideal for endoscopic surgery) and the ability to treat tissue in a liquid-filled enviroment (e.g., saline, blood) [5]. Much clinical and experimental research has focused on cutting and ablation of tissue in cavities difficult to access. Ablation of cartilage in joints [6], bone in endoscopic sinus surgery [7], and soft tissue in coronary angioplasty [8] are examples showing the bandwidth of possible indications. A combination of this device with the mainly coagulating Nd:YAG laser is a promising tool, especially for the surgery of soft tissue. In good vasculated tissues, the combined laser effect in vivo could lead to a better hemostasis because of the finding of an enlarged zone of coagulation in vitro. A side effect in vivo of the deeper tissue damage may be delayed wound healing, as observed when using a combined CO_2/Nd:YAG laser [3]. In vivo studies in an animal model or clinical applications will have to show whether these findings are transferable to vivid tissue.

Normally, the Nd:YAG laser alone in contact mode produces accurate cutting and coagulation effects with much less surrounding tissue damage than the noncontact beam [9]. Our results paradoxically indicate the opposite result for the combined use of the Ho:YAG and Nd:YAG laser. A hypothetical explanation for this fact is that the explosive Ho:YAG laser light effect prevents a real contact-tip application by repeatedly interrupting the contact time. Thus, the "contact application" has to be considered as a interrupted free-beam technique with an extremely short distance, which may explain the deeper tissue coagulation.

Use of the contact-tip application is limited because the explosive effects and the adherence of the fiber made controlled and precise cutting difficult.

The incisions done by the Ho:YAG laser are more irregular than those by the CO_2 laser because the Ho:YAG laser is not pumped continuously. Fissures resulting from the explosive forces could dangerously dissect the tissue [8]. It seems to us of special importance that cellular material is sprinkled by disrupting forces. Some dispersed cells have a microscopically normal aspect. Especially the larger fragments of tissue may contain vital cells. A spread of tumor cells by this mechanism seems to be possible.

Incisions by the Ho:YAG laser are wider and more shallow than by the CO_2 laser, which is explained at least in part by the different application forms (600-μm bare fiber vs. 260-μm spot size). It can be expected that the use of a thinner fiber and a higher pulse rate will improve these cutting properties. For cutting soft tissue the CO_2 laser is normally still preferable.

In summary, the combined Ho:YAG/Nd:YAG laser is an interesting new tool providing coagulating and cutting properties through one flexible bare fiber. Our first in vitro findings suggest that its use is limited to the treatment of benign lesions because the explosive effect of the pulsed Ho:YAG laser light may sprinkle vital cellular material.

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