Light intensity distribution of a new type of contact laser scalpel

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Received February 20, 2008

The emergent light distribution of a new type of contact laser scalpel is measured in three different states using a light sensor. The relationship between the angle and the light intensity is analyzed. The results show that the strongest light is emitted from two sides and the front of the scalpel. The light from the front mainly plays a role of cutting. The light from two sides contributes to stanch the wound so as to remain a clear visual field during the surgery. It also helps to increase the cutting efficiency.

OCIS codes: 170.0170, 170.1610, 140.3480.
doi: 10.3788/COL20080612.0913.

Since the invention of laser in the early 1960s, laser scalpels have been widely used in surgery for the benign and malignant diseases of the superficial lesions located in the skin, eyes, ear-nose-throat (ENT), alimentary, and urinary-genital openings. The lesions can be reached by the endoscopes non-invasively as through bronchoscope, esophagoscope, gastroscope, etc.[1]. The lasers commonly used in these fields are CO_2 laser[2,3], He-Ne laser, argon ion laser[4], excimer laser[5], ruby laser, Nd:YAG laser[4], Ho:YAG laser, Er:YAG laser, KTP laser, *Q*-switched Nd:YAG laser[6,7], diode laser[2], etc.

The dominant scalpels applied in clinic practice were non-contact laser scalpels. However, the surgery operator could not accurately control the distance between the fiber-tip and the target tissue. The contact laser scalpel was firstly suggested as an alternative of non-contact ones by Joffe *et al.* in 1985, which could solve this problem[8]. Compared with the traditional non-contact laser scalpels, surgery applications of the contact probes boast smaller nose radius, higher cutting speed, larger emitting divergence angle, lower degree of tissue damage, slighter smoke pollution, as well as better hemostatic effectiveness[9]. They also mentioned the first use of a contact laser scalpel to cure tumor in alimentary canal system and declared that the curative effect was inspiring[8]. A typical contact laser scalpel is usually made from artificial sapphire with a round-nose[9], which can get Gaussian light distribution[10,11]. Many researches have been done in the construction and application of such scalpels[12−15].

In this letter, a new type of scalpel, which was made from Al_2O_3, with a wedge-shaped tip was introduced. Its light intensity distribution was measured under different situations. Using Nd:YAG laser as the light source, the emergent light distribution of this scalpel was measured in three different states using a light sensor. The relationship between the angle and the light intensity was analyzed. As expected, the strongest light was emitted from two sides and the front of the scalpel. The light from the front mainly played a role of cutting. The light from two sides contributed to stanch the wound so as to remain a clear visual field during the surgery. It also helped to increase the cutting efficiency.

A typical contact laser scalpel is usually made from artificial sapphire with a round-nose. This kind of scalpel cuts target tissues only through laser-tissue interaction such as ablation. In that case, the focus of the output light should be at the headface according to the working principle of contact laser scalpels.

We designed a new type of contact scalpel (Figs. 1 and 2). The whole length of the scalpel is 8.8 mm. Its columned back is 3.7 mm in length and 1 mm in diameter,

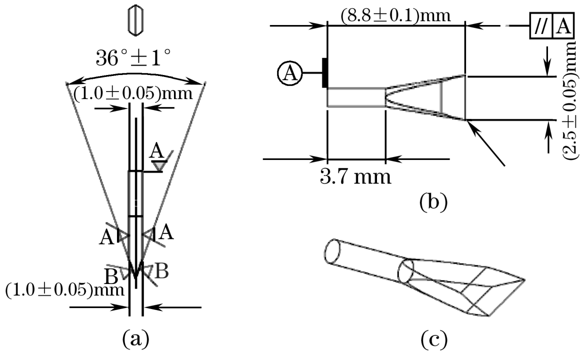

Fig. 1. Design of the scalpel. (a) Columned back of the scalpel; (b) side view of the scalpel; (c) three-dimensional (3D) view of the scalpel.

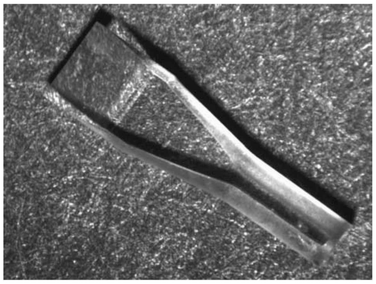

Fig. 2. Picture of the scalpel.

1671-7694/2008/120913-03

which can be coupled with optical fibers. The width of the scalpel edge is 2.5 mm and the angle of the edge is 36°.

Different from the traditional round-nose scalpels, this new scalpel has a wedge-shaped top. The innovative figuration also introduces different light distribution compared with the traditional one. Besides the emitted laser ablation, the wedge-edged tip can mechanically cut the tissue as well, thus higher cutting efficiency will be obtained. The light emitted from two sides can play a role of hemostatic so as to remain a clear visual field during the laser surgery.

The new Al_2O_3 scalpel was strictly geometrical symmetrical in shape to ensure that the emergent light symmetrically distributed into tissue. This study was performed using a diode-pumped solid-state Nd:YAG laser emitting 532-nm light in a pulsed mode. Its highest average output power can reach 60 W. Such a high power can efficiently cut target tissues. Green laser is strongly absorbed by blood filled tissues, so it can also effectively stanch the cut while performing an operation. A perfect control of power, pulse duration, and energy dosage was obtained using this laser system.

The light directly irradiated at a small diaphragm (diameter 2 mm), which was coupled with the scalpel strictly. Adjust the position of the five degrees-of-freedom (DOFs) kinematic holder to allow the light to fully couple into the scalpel. An optic-electric transducer (wavelength range 380 – 780 nm) was used to measure the light intensity at different angles. The sensor was connected with a multimeter. The experimental setup diagram is shown in Fig. 3.

The laser average output power was 10 W, and the distance between the scalpel and the sensor was 150 mm so as to gain an accurate angle resolution. The relative emergent power distribution was measured at three different states. In each situation, the data were measured from −90° to 0° with every 1° as a step. The three states are as follows.

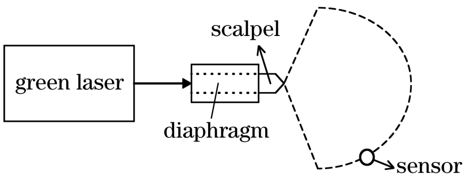

Fig. 3. Diagram of the experiment setup.

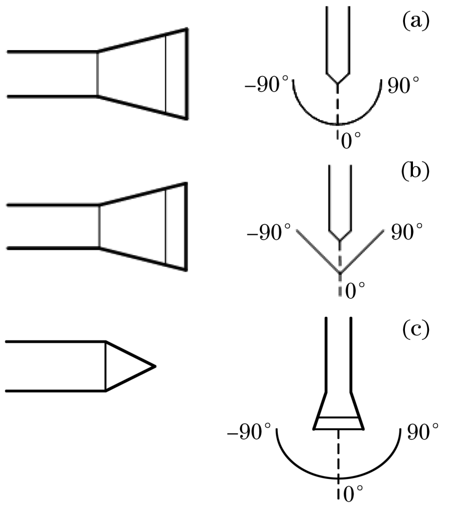

Fig. 4. Three states for measuring the light distribution.

Situation 1: keeping the scalpel upright, measuring the light distribution from −90° to 0° along an arc (Fig. 4(a)).

Situation 2: keeping the scalpel upright, measuring the light distribution from −90° to 90° parallel with the edge of the scalpel (Fig. 4(b)).

Situation 3: keeping the scalpel horizontal, measuring the light distribution from −90° to 90° along an arc (Fig. 4(c)).

Because the scalpel is strictly symmetrical in shape, it is deduced that the light distribution is also symmetrical. The data from 0° to 90° were directly gained from what had been measured.

Then we constructed the relation between different angles and the relative emergent power under each situation. When the scalpel was kept vertical, the incident power was concentrated at the angle ranges from 60° to 70° and from −60° to −70°. The maximum values appear at −65° and 65°. No matter it was measured along the arc or parallel to the edge of the scalpel, the results were almost the same except that in situation 1. There was still weak light between −50° to 50° in situation 1 (Fig. 5(a)), while there was almost no light in that range in situation 2 (Fig. 5(b)).

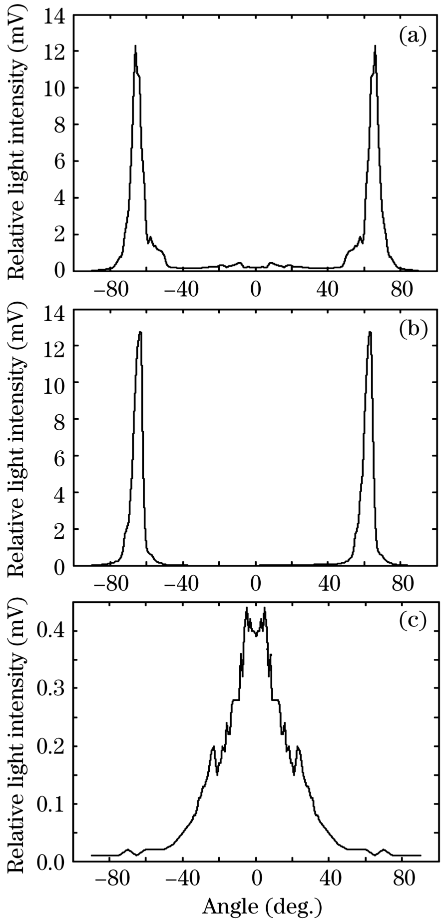

Fig. 5. Emergent power distributions in the three measurement states.

When the scalpel was kept horizontal, the light intensity distribution was different from the former two cases. The incident power was concentrated at the center, from −35° to 35°, while the maximum values occurred at −5° and 5°. Between −5° and 5°, the light intensity reduced by about 11% (from 0.45 to 0.4), as shown in Fig. 5(c).

This new design of laser scalpel could soundly transmit green laser, which is strongly absorbed by blood-filled tissues so as to effectively stanch the cut while performing an operation. The unique geometric shape helps to mechanically cut the target tissue. The light emitted from two sides makes it easier to cut through the laser-tissue interaction.

According to the experiment, it is obvious that when the scalpel is kept vertical, the incident power is concentrated at the angle ranges from 60° to 70° and from −60° to −70°. The high light power emitted from two sides can effectively stanch the wound as well as help to increase the cutting efficiency while the wedge tip plays a role of cutting, as what have been mentioned above.

When the scalpel is kept horizontal, the incident power is concentrated at the center. The concentrated light mainly plays the role of ablating target tissues. It is noticed that there is a slight attenuation from −5° to 5°, which forms a pit in the light distribution curve. The emergent light distribution of the scalpel is highly dependent on its geometrical figure. Idealistically, the energy emitted from the center part of the head face of the scalpel should be strong enough so that it can effectively cut the target tissues. The attenuation in light intensity here may be owing to the limitation of the fabrication process, but it will not significantly affect the cutting efficiency because the attenuation is slight.

In situation 1, there is still weak light between −50° to 50°, while there is almost no light in that range in situation 2. This may result from the increasing distance between the scalpel and the sensor.

Under all the conditions, the emergent power distribution is symmetrical due to the geometrical parameters of the scalpel.

The emergent power distribution of the scalpel can be used to analyze how the scalpel's geometrical parameters affect the light intensity distribution and offer simplified modeling methods to optimize the design.

Furthermore, it is crucial to direct the use of the scalpel when performing an operation so that we can achieve most effective treatment with least hurts to the neighboring healthy tissues.

Due to the small size of the scalpel, we have to keep a relatively long distance between the scalpel and the sensor so as to obtain an accurate angle resolution. This may reduce the light intensity a lot, so we used a laser power as high as 10 W to get a satisfying light distribution resolution. Actually, in a real laser surgery, the distance between the scalpel and the target tissue will be as close as a few millimeters, and the laser output power will be adjusted accurately according to the needs of a certain surgery. The distance between the scalpel and the sensor as well as the output power of the laser will not affect the experiment result, because what we are interested in is the relative light intensity distribution of the scalpel.

During the experiment, the laser output power could be unstable because of the rising temperature and other factors. To overcome this, one method is to reduce the measuring time. We presumed that the light distribution was symmetrical along the center axis because the scalpel was designed and manufactured geometrical symmetrical. Accordingly, only half of the data were measured in our experiment in order to reduce the time. Besides, the output power of the green laser was monitored with a power meter at regular intervals to maintain a stable output.

To further optimize the scalpel, its edge could be made columned in order to focus the laser on the target tissue, which calls on high requirements on the fabrication technique.

Further experiments on *in vitro* tissues and animals will be conducted to study the characteristics of the scalpel such as the cutting speed and injury scope, so that we can better direct the surgery.

This work was supported by the National "973" Program of China (No. 2005CB724302), the National Science Fund for Distinguished Young Scholars from the National Natural Science Foundation of China (No. 60588101), the 111 Project from the Ministry of Education of China (B08020), and the Shanghai Commission of Science and Technology (No. 05DZ22318, 05DZ22325, 04DZ05114, and 064119540). J. Fan's e-mail address is fanfan_i@sjtu.edu.cn or fanfan_i@hotmail.com.

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