Surgical Applications of CO₂ Laser in Otolaryngology

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The surgical CO₂ laser unit and laser bronchoscope were presented which were originally developed under a close co-operation with Asahi Optical Company and our department. The CO₂ laser unit has a maximum power output of 30 Watt and can be used in two ways: in gross surgeries with the use of handpiece and in microsurgeries using the micromanipulator. The laser bronchoscope was designed to applied to the laser irradiation on the disease of tracheo-bronchial system. The clinical applications were discussed among the 118 cases of head and neck tumor operated by laser.

Instruments

Surgical CO₂ Laser Unit

The surgical CO₂ laser unit which we have been using is shown in Fig. 1. The instrument was made under a close co-operation with the Asahi Optical Company and our department. It has a maximum power output of 30 Watt and can be used in two ways: in gross surgeries with the use of a handpiece (Fig. 1-b) and in microsurgeries by connecting it to a surgical microscope (Fig. 1-c, d). The handpiece contains a lens which condenses the laser light into the focal point. Several handpieces having a condensing lens of different focal lengths are available so that selection can be made according to the distance to the target site and the spot size desired. A device to jet nitrogen gas can be connected to the handpiece. This device is used to blow away the smoke produced by laser irradiation and to cool the condensing lens.

When the laser unit is used for microsurgeries, the manipulator of the laser unit is connected to an operation microscope with a specially designed micromanipulator. The micromanipulator contains a condensing lens and a mirror. The mirror directs the laser light toward the lesion to be operated. The angle of the mirror can be adjusted by manipulating a joystick. Since the CO₂ laser light is invisible, a guide light is required to pre-adjust the location to be irradiated. A green light is introduced onto the mirror of the micromanipulator from the side opposite to the laser light, and directed toward the surgeon's eye. Thus, the guide light is superimposed on the image of the surgical field. One can adjust the location of the guide light by manipulating the joystick so that the guide light falls on the place to be irradiated.

Laser Bronchoscope

We made a bronchoscope through which CO₂ laser is irradiated in the trachea and the bronchi. Fig. 2 presents our laser bronchoscope. It basically consists of a ventilation bron-
choscope and an adaptor. The former has a ventilation pipe for oxygen and anesthetic gas, a fiber-optic illumination system, and a suction tube for eliminating the smoke caused by laser irradiation. The latter connects the manipulator of the laser unit to the ventilation bronchoscope, and introduces the laser light into the tracheobronchial system. It has three optical systems: an optical system for introducing the laser light into the bronchus, that for viewing the surgical field, and that for guide light. The adaptor also has a device to adjust the direction of the laser light.

Fig. 1. The surgical CO₂ laser unit

a: An entire view
b: The handpiece
c: A view during endolaryngeal microsurgery
d: The micromanipulator attached to an operation microscope
CO₂ LASER SURGERY (CLINICAL APPLICATION)

Table 1 represents the total cases treated with CO₂ laser in our department.

Gross Surgeries

1. Tumor Surrounded by Bony Structure

The most frequent lesion is carcinoma of the maxillary sinus. Our current therapeutic modality for carcinoma of the maxillary sinus is basically a combined therapy in which radiotherapy, chemotherapy and mechanical or surgical removal of the tumor are adopted in a preplanned combination. The mechanical removal of the carcinoma tissue is done in two ways: transoral resection of the tumor and "necrotomy". We have attempted to utilize the laser for these two purposes. As for transoral resection of the tumor, it takes a quite long time to vaporize the tumor with laser. In order to obtain a laser beam with an identical power, we need a much more powerful laser generator. At this moment, the idea to vaporize easily the most part of the tumor does not seem to be practical.

For the purpose of "necrotomy", laser irradiation is very useful. The term "necrotomy" here means daily procedures to remove necrotic tissue, ill granulation and remaining carcinoma cells during and after the radiotherapy and chemotherapy.

Basically, carcinoma of the other sinuses, the nasal cavity and the epipharynx is treated in a similar way. The laser can be used in the same manner as in the case of the maxillary sinus.

2. Tumor in Soft Tissue

Instead of a cold (traditional) knife, laser can be used for removing a tumor in soft tissue. Such a tumor is located in the oral cavity, the nasopharynx, the thyroid gland or the salivary glands. For benign lesions, a linear vaporiza-
### TABLE 1

The total cases treated with CO₂ laser in our department

<table>
<thead>
<tr>
<th>Gross surgeries</th>
<th>Bone tissue</th>
<th>Soft tissue</th>
<th>Miscellaneous</th>
<th>Others</th>
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<tr>
<td>(118)</td>
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<tr>
<td>Malignant lesions</td>
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<td>oral cavity</td>
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<td>carcinoma</td>
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<td></td>
<td>33</td>
<td>2</td>
<td></td>
<td>22</td>
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<tr>
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<td>tongue</td>
<td>oropharynx</td>
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<tr>
<td></td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
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<tr>
<td></td>
<td>nasal cavity</td>
<td>thyroid gland</td>
<td>thyroid gland</td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>1</td>
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<td>Others</td>
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<td>papilloma of the inferior lip</td>
<td>papilloma of the inferior lip</td>
<td>epithelial hyperplasia</td>
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<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>of the vocal fold</td>
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<td>Benign lesions</td>
<td></td>
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<td></td>
<td></td>
<td>cyst</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
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<td>1</td>
<td></td>
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<tr>
<td></td>
<td>external auditory canal</td>
<td></td>
<td>nasi</td>
<td>1</td>
</tr>
</tbody>
</table>

**tion is done over the capsule. For malignant lesions, a linear vaporization is made with a safety margin attached to the pathology. Small mass lesion can be simply vaporized with laser.**

**3. Use of Laser for Debulking Procedures**

In some selected conditions, debulking of a mass by laser makes it feasible to remove the mass completely with minimum damages to the neighboring unaffected structures. This is often favorable to better functional results.

**Case: 1** The patient was a 14-year-old boy who had developed ameloblastoma in the right molar lesion of the mandible. The tumor was measured to be 4 cm×3 cm×1 cm in size and presented a cauliflower-like appearance. Marginal mandibullectomy was indicated, because X-ray examinations revealed that the outer margin of the mandible was intact. The portion of the tumor which protruded in the oral cavity was vaporized with laser. This gave a better orientation of the margin of the lesion and the remaining portion of the tumor was removed with a minimum surgical intervention into the unaffected structures (Fig. 4, 5). The amount of bleeding during the laser vaporization was only 10 ml.
CO₂ LASER SURGERY (CLINICAL APPLICATION)

Fig. 4. Case 1. Ameloblastoma of the oral cavity

a: Tumor in the right molar region of the mandible (before treatment)
b: After debulking with laser vaporization
c: Tumor was extirpated with marginal mandibulectomy.
d: After operation

4. Other Applications

a. Laser debridement with a defocused beam is extremely useful to remove infected granulation of a raw wound. This makes the wound dry and aseptic and gives a bed favorable to a skin flap.

b. Laser can be used for skin incisions and for elevation of a skin flap. A linear vaporization is made for these purposes.

c. For superficial lesions of the oral mucosa, including leucoplakia and ulcer, laser vaporization with a defocused beam is useful.

Microsurgeries

The use of laser for endolaryngeal microsurgeries has been becoming more and more popular. Some points will be made on this aspect.

1. Differences in Postsurgical State between a Cold Knife and Laser.

In order to determine the differences in postsurgical state between a cold knife and laser, we conducted an experimental investigation with dogs. In each dog, an endolaryngeal microsurgery was performed with a cold knife on one vocal fold and with laser on the other. Along the entire length of the membranous portion, the epithelium and the superficial portion of the lamina propria were removed. The post-operative healing processes were
Fig. 5. Case 1. Ameloblastoma of the oral cavity

a: Debulking with laser vaporization
b: Marginal mandibulectomy
A: Tumor  B: Cortical bone preserved  C: Periostium
c: Preoperative orthopantomogram
d: Postoperative orthopantomogram

TABLE 2
Differences in postsurgical state between a cold knife and laser

<table>
<thead>
<tr>
<th></th>
<th>Laser</th>
<th>Cold knife</th>
</tr>
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<tbody>
<tr>
<td>1 Coagulation necrosis</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>2 Inflammatory reaction</td>
<td>Not marked</td>
<td>Frequently marked</td>
</tr>
<tr>
<td>3 Epithelization</td>
<td>3W</td>
<td>2W</td>
</tr>
<tr>
<td>4 Excessive granulation</td>
<td>None</td>
<td>Frequent</td>
</tr>
<tr>
<td>5 Scar formation</td>
<td>Minimum</td>
<td>Occasionally marked</td>
</tr>
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</table>
investigated with gross and microscopic observations. The results are summarized in Table 2.

It should be emphasized that no excessive granulation was developed after laser vaporization and, hence, minimum scar formation. This is advantageous from a viewpoint of phonatory function. The difference in development of excessive granulation can be attributed to the differences in the state of wound immediately after the surgery. The wound made with a cold knife is often rough on the surface and the angle between the wound surface and the remaining epithelium is often acute. The wound is not covered with anything, presenting a greater opportunity for infection. On the other hand, the wound made with laser is smooth on the surface and the angle between the wound surface and the remaining epithelium is obtuse. The wound is covered with a layer of coagulated tissue which protects the wound like a bandage. All these conditions seem to assure a favorable manner of regeneration of the epithelium and lamina propria. Fig. 6 presents several pictures related to this investigation.

2. Precise Determination of Extent of Removal

The human vocal fold has a layer structure. Hirano (1975), one of the present authors, emphasized the importance of the layer structure in physiological and pathological aspects. As shown in Fig. 7, the vocal fold consists of two major layers: The mucosa and the muscle. The mucosa, in turn, consists of the epithelium and the lamina propria. The lamina propria can be divided into three layers according to the distribution of collagenous and elastic fibers: the superficial, intermediate and deep layers. The latter two, as a whole, are called the vocal ligament. Almost all diseases of the vocal fold originate from a given layer, and do not extend beyond a certain layer except for neoplastic lesions. A selective removal of the layer(s) affected is demanded for a favorable postsurgical phonatory function. This can be best achieved with the use of laser. Fig. 8 shows some examples of selective removal of the layers of the vocal fold.

3. Benign Neoplasms

Papilloma and other benign neoplasms of the larynx can be effectively treated with laser.

Case 2: A 64-year-old male developed a hoarseness and dyspnea. Examinations revealed a neurofibroma of the left vocal fold. The tumor occupied most part of the membranous portion, attaching to the ventricular fold superiorly and extending into the "lower lip" inferiorly. The tumor was vaporized with laser under endolaryngeal microsurgery. A laser beam of 10 Watt and 0.1 sec. was irradiated repeatedly until the entire tumor was eliminated and the intact vocal ligament was exposed. After the surgery, the wound healed well and the voice recovered (Fig. 9). Aerodynamic examinations presented normal test values and mucosal wave was observed on a stroboscopic observation.

4. Whitish Thickening of the Epithelium of the Vocal Fold

Whitish thickening of the epithelium can be divided histologically into three major groups: epithelial hyperplasia, epithelial dysplasia and carcinoma. Each can be further divided into two pathologies (Fig. 10). The extent of laser vaporization for each group is shown in Fig. 11. For hyperplasia, the vaporization should involve the superficial layer of the lamina propria partly or entirely as well as the epithelium.
Fig. 6.

a : Finding immediate after the excision
   right side : cold knife
   left side : laser vaporization
b : One week after the operation
c : Frontal section
   Excessive granulation is observed on the right side (cold knife)
   No recognizable excessive granulation is observed on the left side (laser)
d : Schema of differences between laser and cold knife
e : A marked growth of connective tissue after cold knife surgery.
**Fig. 7.** Schematic presentation of the structure of the human vocal fold

**Fig. 8.** Selective vaporization of the vocal fold
Fig. 9. Case 2: Neurofibroma of the vocal fold

a: before surgery
b: after laser irradiation
c: 2 months after the surgery
Fig. 10 Histological classification of the whitish thickening of the epithelium

I a, b Hyperplasia
II a, b Dysplasia
III a, b Carcinoma
   a : carcinoma in situ
   b : invasive carcinoma
Fig. 11. Indication of the selective vaporizations the vocal fold for different histological patterns

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
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<td>Hyperplasia</td>
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<td>○</td>
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<tr>
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<tr>
<td>Dysplasia</td>
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<tr>
<td>atypia (++)</td>
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<tr>
<td>Carcinoma</td>
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<td></td>
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</tr>
<tr>
<td>a) CIS</td>
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<td></td>
<td>○</td>
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<tr>
<td>b) invasive</td>
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<td>(TI)</td>
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<td></td>
<td>or</td>
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</table>

linear vaporization    spot vaporization    superficial vaporization

A focused beam is removed along the incision line
A focused beam is radiated to the tissue to be removed
A defocused beam is radiated to superficial lesion, yielding also a hemostatic effect

Fig. 12. Fundamental technique of CO₂ laser surgery
For dysplasia, the superficial layer of the lamina propria should be removed entirely. It is safe to remove the vocal ligament partly or entirely in treating carcinoma in situ.

For invasive carcinoma of T1 lesion, radiotherapy has been of choice as an initial treatment. So far, we have used laser chiefly for cases of radiation failure. In these cases, a part of the vocalis muscle is also removed. Postsurgical phonatory function seems to be unexpectedly good. Comparisons of radiotherapy and laser surgery for T1 lesion are remained for further investigations. For more extensive lesions, such as T2, T3 and T4, treatments with laser alone do not seem to be promising. Some supplemental use of laser, for example, that as a debulking procedure, might be helpful in lessening radiation dosis, the necessity of surgical intervention, or the extent of surgical intervention. At present, we are not very positive in this respect.

CONCLUSION

There are three basic techniques of clinical applications of laser as shown in Fig. 12.

For linear vaporization, a small focused beam produced with single mode is required. The power of laser depends on the nature of the tissue to be cut.

For spot vaporization, the size of the focused beam, the laser power and the energy density distribution depend on the size and physical properties of the tissue to be removed.

For superficial vaporization, a defocused beam of a weak power is demanded.

The size of the beam, the power, and the energy density distribution at the target site are determined by the output power, exposure time, beam width, beam divergence, beam mode and focal distance of the condensing lens. The pertinent use of CO₂ laser in the head and neck regions is extremely helpful in treating varied pathologies, if it is applied with an adequate technique.

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