Comparison between the Laser Surgical Unit and the Electrosurgical Unit

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Summary

Thermal effects on the brain, spinal cord and muscles were studied in electrocoagulation and laser photocoagulation. The experiments were performed on cats and rabbits. The monopolar and bipolar electrodes of the electrosurgical unit were applied to the tissues in comparison with the carbon dioxide laser surgical unit.

The experiments were divided into the following two groups: 1) Morphological studies with optical microscope and electron microscope. 2) Temperature measurements with the non-contact infrared thermometer, microthermistor and thermograph.

Minimal lesion was obtained by laser photocoagulation in comparison with electrocoagulation. The size of the lesion increased proportionately to the output power in electrocoagulation, but in laser photocoagulation the width of the brain edema remained within 300 μ. Only tissue defects produced by laser vaporization increased proportionately to the output power and the exposure time.

The temperature at the focus of the laser beam was measured with the non-contact infrared thermometer which indicated 1,500°C. The temperature within the tissue adjacent to the focus was measured with a microthermistor. In laser photocoagulation, the maximum increase was about 10°C at a point 1 mm from the focus. The temperature change occurred within 30 sec when the laser irradiation lasted for 2 sec at 15 W. In bipolar coagulation, the temperature rise was 2.5°C at 3 mm from the electrode and the change lasted for 23 sec. In monopolar coagulation, the maximum rise was about 18°C at 3 mm from the electrode at an output power of 2 W, and the change lasted also for 23 sec.

A conspicuous feature in thermography was the very steep temperature gradient extending from the laser focus to the surrounding tissue. This means that in lasing the thermal effect is highly restricted.

But the most prominent feature of the laser is the so-called "vaporization": The laser can vaporize tissues hemostatically in situ, which is impossible with the electrosurgical unit.

Key words: laser surgical unit, electrosurgical unit, bipolar electrodes, monopolar electrode, vaporization, coagulation

Introduction

Half a century has passed since the electrosurgical unit was successfully introduced into surgery by Cushing and Bovie in 1926.1 In 1940, the superiority of bipolar coagulation in neurosurgery was emphasized by Greenwood, Jr.4,5 in comparison with the usual monopolar coagulation. It is not exaggerating to say that the electrosurgical unit is now being employed by neurosurgeons all over the world to obtain hemostasis during surgery.

On the other hand, a new source of energy was introduced in 1960; namely, the ruby laser developed by Maiman8 and the He–Ne laser by Javan.9 Since then, many kinds of lasers have been introduced. But, among them, the carbon dioxide laser which was developed by Patel91 in 1965 is considered to be one of the most promising instruments as a surgical unit today.

In 1969 we started basic and clinical studies to...
develop a carbon dioxide laser surgical unit for practical use. During the past 8 years we have developed equipment starting with Type 1, and have now reached Type 3 which is a prototype suitable for practical use.

The carbon dioxide laser operates at a wave length of 10.6 μ in the far-infrared. With this wave length it is possible to perform highly hemostatic and precise surgery. The function is essentially due to its thermal effect. As far as function is concerned, the laser surgical unit closely resembles the electrosurgical unit. This paper intends to point out the differences between the two.

**Materials and Methods**

We divided our experiments into two groups:

1) Morphological studies with optical microscope and electron microscope.

2) Temperature measurements with the non-contact infrared thermometer, microthermistor and thermograph.

The following devices were used in the experiments:

**Carbon dioxide laser surgical unit:** The trade name of the device used is Mochida Luketron Medilaser Type 3; Model MEL-442 (Fig. 1). This device was developed by our research team and manufactured by Mochida Pharmaceutical Company, Ltd. It operates at a wave length of 10.6 μ, emitting an invisible beam in the far-infrared, and generates continuous waves. The output power is continuously variable from 0 to 70 W. Using a timer, pulsed waves are available with width varying from 0.1 to 1.0 sec. The He-Ne laser serves as a red pilot lamp which enables the operator of the device to precisely aim the invisible laser beam at the target. The diameter of the focus is 0.5 mm.


Mizuho Type GT-S4U-A, spark gap, monopolar; Mizuho Micro 1 C, bipolar; manufactured by Mizuho Ikakogyo Co., Ltd., Tokyo, Japan.

**Non-contact infrared thermometer** (Fig. 2): Mikron-57 Infrared Thermometer, ranging from 750°C to 1750°C;

Mikron-25 Infrared Thermometer, ranging from +40°C; manufactured by Mikron Instrument Co., Inc., Ridgewood, N. J., U.S.A.

**Microthermistor** (Fig. 3): Model MGA-3, Type 215, manufactured by Shibaura Electronics Co., Ltd., Tokyo, Japan.

**Thermograph** (Fig. 4): Canon CT-4A, manufactured by Canon Inc., Tokyo, Japan.

**Polygraph:** Multipurpose Polygraph RM-150; Medical Corder PMP-3002; manufactured by Nihon Koden Co., Ltd., Tokyo, Japan.

**Powermeter for CO₂ laser:** Laser Powermeter Model 201 and Model 2055, manufactured by Coherent Radiation Inc., Palo-Alto, Calif., U.S.A.
Powermeter for electrosurgical unit: Electrosurgical Analyzer EMS Model 1200, manufactured by Electro Medical Systems Inc., Denver, Colorado, U.S.A.

1) **Morphological studies**

The cortex of the brain and the spinal cord of the cat were coagulated both with the laser surgical unit and the electrosurgical unit. The chosen output power of the laser was between 0.3 W and 2 W, with which small vessels on the surface of the cortex and the spinal cord can be coagulated.

Immediately after coagulation, the specimens were fixed with glutaraldehyde and osmic acid for study with the electron microscope and, after sacrificing the animal, they were fixed with 10% formalin and stained with hematoxylin and eosine for study with the optical microscope.

Vaporization of experimental brain tumors and human brain tumors was performed at outputs between 15 W and 60 W.

2) **Temperature measurements**

The temperature at the focus of the laser beam was measured with the non-contact infrared thermometer which was connected to the polygraph for recording (Fig. 2).

The temperature gradient of the tissue surface surrounding the focus was measured with the thermograph (Fig. 4), recorded in analog pattern (Fig. 5A, 5B) and printed out in digital form (Fig. 6A, 6B).

The temperature within the tissue adjacent to the focus was measured with the microthermistor (Fig. 7) and recorded on the polygram.
above experiments were recorded in stills and 16 mm movie film.

**Results**

The extent of the lesions produced on the brain surface of the cat by the methods mentioned above is shown in Table 1.

1) **Morphological Studies**

The lesions produced by the laser on the surface of the brain or spinal cord consist of three layers namely, starting from the surface: a charred layer, 10–20 µ thick; a honeycomb structure layer produced by the bursting of the tissue fluid or by acute dehydration and about 20–30 µ wide; a layer of edema, 250–300 µ thick (Figs. 8, 9). Whether the honeycomb structure is

| Table 1 The extent of the lesions produced on the brain surface of the cat. |
|-----------------|-----------------|-----------------|
| Laser at 2W     | 0.7mm           | 25µ             | 70–100µ         |
| Laser at 15W    | 0.7mm           | 50µ             | 250–300µ        |
| Laser at 25W    | 0.7mm           | 50µ             | 300µ            |
| Bipolar at 2W   | 1.5mm           | 80µ             | 300µ            |
| Monopolar at 2W | 4.5mm           | 500µ            | 500µ            |
observed or not depends upon the output power. When the tissue is coagulated with an output power as low as 5 W or less, no honeycomb structures is observed (Fig. 10).

It should be pointed out that the extent of the lesions is surprisingly small, considering the fact that the site of the focus was vaporized at a temperature of as high as 1,500°C. Observation by optical and electron microscopes revealed that the tissue remained intact at a point 1 mm from the focus (Figs. 8, 9, 11, 12A, 12B).

Fig. 9 Light micrograph of the cortex of a cat vaporized by the CO₂ laser with an output of 25 μ and an exposure time of 0.1 sec. The minimal scale graduation is 25 μ. The width of the necrosis is 50 μ and the width of brain edema is 250 μ. The influence of the heat was confined within a width of 0.3 mm. The small arrows show the necrosis while the large arrows show the edema. Hematoxylin-Eosine staining.

Fig. 10 Light micrograph of laser photocoagulation of the cortex of a cat with an output power of 2 W. Thin necrosis, 25 μ thick, without honeycomb structure. The width of edema is about 70 μ. The small arrows show the necrosis and the large arrows show the edema.

Fig. 11 Electron micrograph of the necrotic layer produced on the cortex of a rabbit by CO₂ laser irradiation with an output power of 15 W. Destruction of myelin sheaths and of the fine structure of axons is observed. Dissociation of myelin sheaths is prominent. Glutaraldehyde and osmic acid fixation.

Fig. 12A Electron micrograph of the cortex of rabbit at a point 1 mm from the laser focus. The tissue remained intact. Glutaraldehyde and osmic acid fixation.

Fig. 12B Electron micrograph of the cortex of a rabbit at a point 1 mm from the laser focus. Both myelin sheaths and other fine structures remained intact. Glutaraldehyde and osmic acid fixation.
Vaporization of tissue is a unique feature of the laser. In contrast to the ordinary definition of vaporization; i.e. the conversion of a solid or liquid into a vapor without chemical change, the term is used in laser surgery to include chemical change because the tissue is completely burnt up, producing a certain amount of smoke. Tissues are rapidly and hemostatically vaporized with a power output of more than 5 W (Figs. 9, 13, 14A, 14B). The operator can precisely vaporize tissues to the desired degree by adjusting the output power and exposure time. Switching between vaporization and coagulation can easily be accomplished by selecting between focused and defocused beams, respectively. The diameter of the lesions corresponds to that of the laser beam focused on the tissue.

On the other hand, the lesion produced by monopolar electrocoagulation is considerably larger than by laser photocoagulation. As shown in Table 1, the diameter on the cortical surface measures as much as 4.5 mm which is larger than the tip of the coagulation forceps. The width of the necrosis and the edema layer is twice as large as that produced by laser photocoagulation (Fig. 15).

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Fig. 13 Vaporization of the glioblastoma induced by methylcholanthrene and transplanted in the subcutaneous tissue of a C-57 black mouse. V-shaped defect with a sharp margin was produced hemostatically by laser irradiation.

Fig. 14A Light micrograph of the experimental tumor shown in Fig. 13. The tumor (upper part) infiltrated into striated muscle (bottom). Hematoxylin-Eosine staining.

Fig. 14B The tumor shown in Fig. 14-A. was completely vaporized with the CO₂ laser. Charred layer and network necrosis of a honeycomb type were observed. This honeycomb structure is thought to be produced by acute dehydration or bursting of cellular and intercellular fluid. It should be pointed out that there is no bleeding and no cellular infiltration under the necrotic layer. The width of the necrosis is 30 to 40 μ. Hematoxylin-Eosine staining.

Fig. 15 Light micrograph of the cortex of a cat coagulated with the monopolar electrode at output of 2 W. Duration of the current was 2 sec. The minimal scale graduation is 25 μ. Wide necrotic layer accompanied by a wide layer of edema is observed. The lesion was so large that only one third could be covered with this magnification. The small arrows show the necrosis and the large arrows show the edema. Hematoxylin-Eosine staining.
In comparison with monopolar coagulation, the lesion produced by bipolar coagulation is much smaller than expected. The diameter is confined to the distance between the two legs of the bipolar electrodes (Fig. 16A). But, within the scope of our experiments, the depth of the necrosis is proportionate to the output power and the duration of the current (Fig. 16B).

2) Temperature measurements

In the experiment on the brain tissue of the rabbit, the temperature at the focus of the laser beam with an output power of 15 W showed 1,500°C (Fig. 2). The temperature at the focus depends upon the material lased. For example, when a slate is lased, the temperature rises up to 2,500°C and for bone, the temperature is intermediate between that of the slate and with soft tissue.

The temperature within the tissues was measured with a microthermistor specially made for this purpose (Fig. 7). The temperature at a point 1 mm from the focus of the laser beam in the brain of a rabbit showed a maximum rise of 10°C with an output power of 15 W and a lasing time of 2 sec. The temperature rose immediately, reaching peak value in 2 sec, but it took about 30 sec to drop down to the previous level (Fig. 17).

In muscle tissue, the temperature rise was between 6 and 8°C with an exposure time of 1 sec (Fig. 18).

On the other hand, it proved to be rather difficult to evaluate the results of temperature measurements with the electrosurgical unit. The extent of the lesion varied according to the power output and the duration of the current. Thus, the distance from the margin of the lesion to the sensitive probe of the thermistor varied according to each condition. As a result, the temperature often scaled out on the polygraph if the lesion expanded to surround the probes (Figs. 19, 20, 21). On the contrary, if the distance was too great, the temperature remained unchanged. Considering the results mentioned
above, we placed the tips of the coagulating forceps at a point 3 mm from the probes of the thermistor. The power output was calibrated to be 2 W, high enough to coagulate the cortical arteries and veins.

In monopolar coagulation, the polygrams were superimposed with the electrical noise. The rise and fall of temperature occurred rapidly. The temperature curve was triphasic, i.e. if the current was applied for 2 sec, the temperature immediately rose to its initial high peak, then started to drop rapidly immediately after switching off the current, reaching its lowest point below the previous level within 1 sec. But the overshooting was restored to the previous level within 1 sec and the temperature rose again to the second peak 1 sec later. Then the curve dropped very slowly to the previous level. The curve extended over 23 sec (Figs. 19, 20). The maximum rise of temperature was indicated directly on the thermometer scale (Fig. 3) which showed 18°C in the brain tissue of the rabbit (Fig. 20).

In bipolar coagulation, the temperature curve was monophasic. The rise and fall occurred rapidly within 3 sec followed by a very slow decrease to the previous level, taking 23 sec in all (Fig. 21). The maximum increase in temperature was 2.5°C with an output of 2 W.

The temperature gradient from the focus to the surrounding tissue on the surface of the cortex of the rabbit was recorded with a thermograph (Fig. 4). As shown in Figs. 5A, 5B, 6A and 6B, the temperature gradient is very steep with lasing, but gently sloping with monopolar
coagulation. These results show that laser action is highly restricted in comparison with electrocoagulation from the viewpoint of thermal effect. These results also agree with the morphological studies.

Discussion

With respect to the nomenclature for surgical devices, there is some confusion among authors. Some prefer such terms as laser knife, light knife or laser scalpel. On the other hand, there are many words for the electrosurgical unit, e.g. electroknife, electroscalpel, radioknife, Bovie, electrocautery, surgical diathermy, etc. Strictly speaking, the term “knife” or “scalpel” indicates a tool used only for cutting, and the term “coagulator” or “cautery” indicates a tool employed only for thermal coagulation. In 1928, Cushing and Bovie used the term “electrosurgical unit” in their paper. As a matter of fact, this device is used in three ways: cutting, coagulation and blending (simultaneous cutting and coagulation). Therefore, the term “electrosurgical unit” seems to be the most appropriate word for this device. Thus, “laser surgical unit” is considered to be a better term than “laser knife” and “laser scalpel.”

There are various kinds of lasers available today, the wave lengths of which cover spectra from ultraviolet to infrared. Physical and biomedical qualities differ widely depending upon the wave length. Among them, the carbon dioxide laser is the most promising device as a surgical unit.

The laser beam with a wave length of 10.6 μ is completely absorbed by water. Since all tissues contain a certain amount of water, this laser beam can be absorbed by any tissue without staining it. This is one of the most important reasons why the carbon dioxide laser is used as a surgical knife and a coagulator.

In neurosurgery, an output power ranging from 0 W to as high as 70 W is needed. Selection of this output power should be precisely controllable. Considering these conditions, the carbon dioxide laser can be characterized as well qualified as a neurosurgical instrument.

Stellar has studied the biomedical qualities of the carbon dioxide laser and described its action as “gentle.” This seems to appropriately express the main feature of the carbon dioxide laser, because “gentleness” is a prerequisite for neurosurgery. Precise surgery can be gently performed under an operating microscope especially developed for laser surgery (Fig. 22).

The highly hemostatic quality of the carbon dioxide laser is particularly useful to control bleeding from parenchymatous organs and highly vascularized tumors such as meningioma. Gonzalez, et al. reported that the blood loss encountered during electrocoagulation of the free edge of the liver of dogs was five times more than that during laser radiation. He also reported that the average time required to control bleeding in the subcapsular lesion by electrocoagulation was 14 times longer than that for complete hemostasis by laser radiation.

On the other hand, Filder, et al. reported that the CO2 laser had significantly superior hemostatic qualities while cutting the liver of dogs when compared to the Bovie (p<0.025) and conventional knife methods (p<0.001), but there was no significant difference in the time taken to achieve hemostasis in the laser and Bovie groups.

Hall stated in his paper on animal experiments that when the hepatic vessels were clamped during incision, the total hemorrhage from the liver was reduced 40% by diathermy and 85% by laser compared with the scalpel control.

In our experiment on glioblastoma induced by methylcholanthrene and transplanted into the subcutaneous tissue of C-57 black mouse, we encountered no bleeding from the tumor during vaporization (Figs. 13, 14A, 14B).

In our clinical experience with some brain tumors such as meningioma, ependymoma and

Fig. 22 Operating microscope specially developed for laser surgery.
neurinoma, tumors were removed rapidly without bleeding when the CO₂ laser was used in combination with the suction tube. This technique of laser surgery is much superior to the conventional method with the ball point electrode and the loop electrode which have been used for over half a century since Cushing.

When the operator removes a brain tumor piece by piece with the loop electrode, charred debris attached to the electrode often decreases efficiency. Conversely, laser vaporization is performed without contact with the tissue. For pinealoma, however, simple vaporization under the laser microscope is recommended, protecting such vital veins as the great cerebral vein of Galen and internal cerebral veins with wet pledgets.

The problem whether skin or scalp should be incised by the laser is currently under study. In our experience, the healing process after scalp incision by laser, though highly hemostatic, took several days more than incision by conventional surgical scalpel, i.e. a cold knife. We have no clinical experience with skin incisions by the electrosurgical unit, but the healing process is now under observation on the skin of rabbits, comparing the effects of laser, electrosurgical unit and cold knife. We believe that the time delay and the width of the scar can be reduced by improving the device through sufficient increase of the output power and minimizing the focal diameter.

Some authors insist that coagulation of vessels larger than 1.5 mm in diameter should be performed with the electrosurgical unit. At present, it is safer to use the bipolar coagulator for coagulation of the vessels if the operator finds it difficult to protect the vital structures behind them.

As shown in Figs. 19 and 20, the temperature curve for monopolar coagulation was triphasic. The reasons why the temperature dropped to the minimum point below the previous level and overshot again are unknown. But we speculate that these phenomena might have been caused by temporary vasospasm due to the current, and by vasodilation in rebound, respectively.

**Conclusion**

The carbon dioxide laser is a very useful device, especially as a neurosurgical instrument. It is particularly helpful in the surgery of brain tumors because of its highly hemostatic quality. Operators can minimize blood loss and operating time by utilizing the laser. Moreover, they are assured of highly precise surgery under the operating microscope specially developed for the laser.

However, unless devices presently in use are satisfactorily improved, the laser surgical unit cannot completely replace the electrosurgical unit.

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