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Carbon-Dioxide Laser Surgery Applied to the Intracranial Lesions

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Abstract We have experienced many instances of carbon-dioxide (CO2)-laser surgery during the last five years. The majority of these cases were intracranial tumors. The validity of CO2-laser treatment was evaluated in accordance with following indices. The capacity of CO2-laser in cotrolling the intraoperative hemorrhage and shortening the operating time, the correlation between tumor size/vascularity and intraoperative bleeding/operating time, which were principally evaluated in the case of meningioma group. The degree of tumor removal and postoperative edema with or without CO2-laser, was also investigated in the glioma cases. As a result, the quantity of blood transfused during operations in meningioma groups decreased since the introduction of CO2-laser apparatus into the neurosurgical field as compared with the pre-laser era, although there was no difference in operating time before and after the introduction of CO2-laser surgery. Also noted are no meaningful difference in postoperative brain edema assessed by computed tomographic (CT) scans between the laser-applied glioma group and the non-laser-applied group. Moreover, there seemed no remarkable adverse effects owing to CO2-laser surgery. Some useful operational techniques were also investigated. In conclusion, we thought that the CO2-laser system was useful for intracranial operations.

Key Words : Laser, Carbon dioxide laser, Laser surgery, Neurosurgery, Brain tumors

Introduction

Laser beam is defined as a coherent wave, which have been employed in the many fields of science and now used in all over the world as a tool for many varieties of work. In the medical fields, the laser apparatus for surgical use was firstly built by Maiman in 1960[1)] and also it was said that Rosomoff was the first who introduced it into the neurosurgical operation[2)]. Thereafter it was more widely used in the world including Japan. We have recently operated 61 operations in 56 cases of intracranial lesions by CO2-laser during this 5 years. The purpose of this paper is to evaluate the efficacy of CO2-laser for neuro-

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surgical operation.

Materials and methods

From Dec. 1979 to Nov. 1984, 56 cases (61 times) of intracranial lesions were operated by CO2-laser apparatus at Department of Neurosurgery in Yamaguchi University School of Medicine. The age distribution of the patients were 10 to 75 year-old (mean 49 year-old) and sex difference of those were 22 male and 34 female. All but three cases of cerebral AVMs were intracranial tumors. 17 cases (21 operations) of gliomas, 22 cases of meningiomas, 8 cases (9 operations) of metastatic brain tumors, 2 cases of neurinomas, and one case each of sarcoma, hemangioblastoma, lipoma of corpus callosum, and suprasellar tuberculoma. The laser apparatus used was MEL441 (Mochida). We usually used it intending the effects of coagulation in the case of soft tumors such as gliomas, and also the effects of vaporization for hard tumor such as meningiomas. The power of CO2-laser usually applied was about 30-50 Watts of defocused beam for brain tumors, and the hand-piece was controlled with or without the operating microscope. For investigating the efficacy of CO2-laser system in the neurosurgical field, we evaluated it from several surgical point of view. One was the capacity of CO2-laser in controlling the intraoperative hemorrhage and shortening the operation time. The second was correlation between tumor size and/or vascularity, bleeding, and operation time. Theses two points were principally investigated in the cases of meningiomas. These 22 cases of meningioma group were compared to the 20 consecutive cases of meningiomas, operated before the introduction of CO2-laser apparatus in our department. The third point is the degree of tumor removal and postoperative edema, which was also investigated between seventeen laser-applied glioma cases and ten non-applied glioma group.

Results

a) The correlation between intraoperative blood transfusion, operating time and introduction of CO2-laser system in neurosurgery.

As mentioned previously, it was evaluated in the meningioma group. (Fig. 1) As seen in Fig. 1, it was vivid that intraoperative blood transfusions were decreasing in the

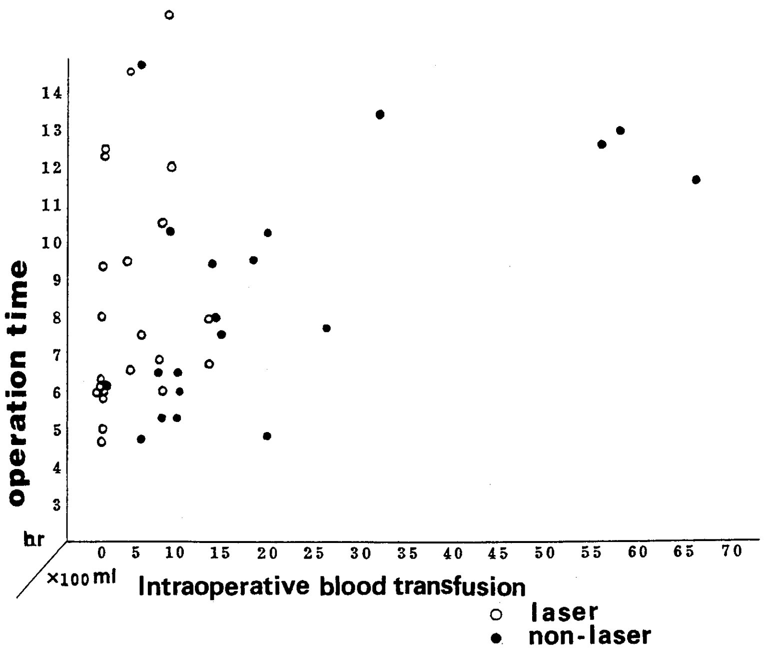

Fig. 1 Comparizon between operating time and intraoperative blood transfusion in laser-applied meningioma group (white circle) and laser-non-applied meningioma group (black circle). It is noted that marked decreasing of intraoperative bood transfusion is vivid in laser-applied group, although there is no difference in operating time in each group.

laser-applied meningioma group than those of laser-nonapplied meningioma group. The mean volume of blood transfusion in the laser applied meningioma group was about 377 ml, and those of non-laser group was about 2056 ml respectively. This result reveals that laser apparatus was clearly effective for controlling the blood loss during operation. However, there was no meaningful differences of the operationg time in these two groups.

b) The correlation between tumor size and/or vasculariy and intraoperative blood transfusion in CO2-laser applied cases of meningiomas.

The size of meningioma was classified as follows. The calibre of tomor under 3 cm on CT or cerebral angiography was samll, 3-6 cm medium, and over 6 cm was large respectively. Also vascularity of tumor was classified mild(+1) (light staining), moderate(+2) (staining of moderate degree), and marked (+3) respectively. (see Fig. 2) This result revealed no correlation between these two items, although some tendency that large tumor and/or vascular tumor necessitating much quantity of blood transfusion intraoperatively were noted.

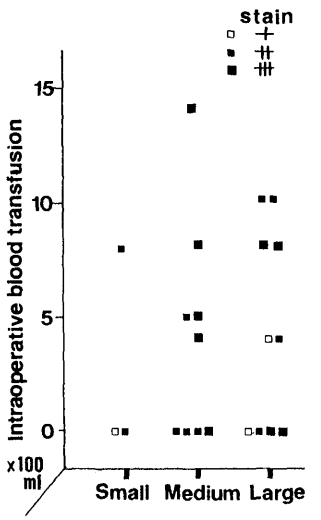

Fig. 2 Relation between tumor size / vascularity and intraoperative blood transfusion in laser-applied meningioma group. White small square shows light staining tumor, and small & large black square reveal staining mass of moderate and marked degree respectively. Tumor size is classified into small (under 3 cm in calibre), medium (3 to 6 cm in calibre), and large (over 6 cm in calibre). There is no meaningful correlation in tumor size / vascularity and intraoperative blood transfusion.

c) Relation between the postoperative edema and CO2-laser surgery in glioma case.

This were evaluated by the following method. To evaluate the postoperative brain edema in laser applied cases, it was compared to those cases of glioma series operated before the introduction of CO2-laser in our hospital. Firstly, we measured the degree of midline shift on CT before and after operation, which was compared to other laser-non-applied glioma group of pre-laser era. (Fig. 3) As to each glioma group, the degree of midline shift was slightly increased on the immediate postoperative state than those of

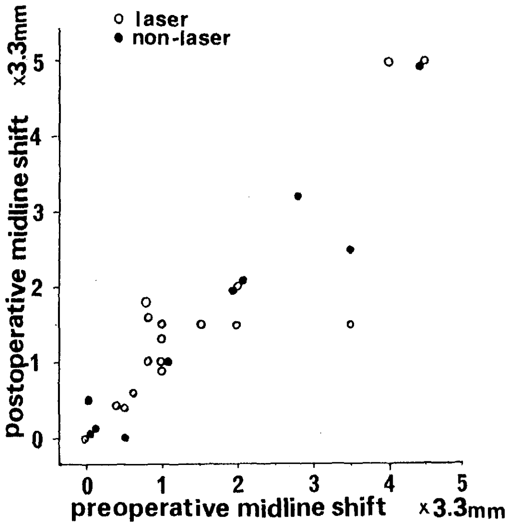

Fig. 3 Relationship between postoperative brain edema (represented by midline shift on CT scan) and application of CO2-laser during operation in glioma cases. White circles show 17 glioma cases treated by CO2-laser surgery, and 10 black circles reveal glioma cases not treated by CO2-laser apparatus. There in no significant difference in the ratio of pre-and postoperative midline shift in laser-applied and non-applied case.

preoperative one, which showed no meaningful difference in both laser-applied and laser-non-applied cases. So it could not be said that postoperative brain edema was more prominent on the glioma cases treated by CO2-laser than those cases of laser non-applied group.

II-case presentations Case I. This 61-year-old woman admitted to local hospital for fever, headache, and hypertension on Apr 2nd, 1981. During this admission, she had suddenely lost consciousness several times and recovered almost in one hour without neurological deficits. Then she referred to another hospital on May 7th, 1981, and there she pointed out CT abnormality. Therefore she admitted to our clinic on June 4th, 1981. Neurological examination revealed some disorientation, dyscalculia, and recent memory impairment. Also noted were left parietal lobe sign, that is, disturbance of two points discrimination, dysstereognosis, however, there could not be identified any alexia, agraphia, and apraxia. Plain skull film showed vague calcification at the left glomus (15×20 mm in size). CT scan on admission (see Fig. 4) revealed a large calcified mass of high density near the left trigone with marked contract enhancement. Transfemoral cerebral angiography was performed. Left carotid angiography showed square shift of anterior cerebral artery (ACA), some dilatation of anterior choroidal artery (AchA), notably its distal side (plexal portion). Sylvian triangle was also displaced to supero-anteriorly and draping of middle cerebral artery (MCA) temporal branches were noted. In venograms, internal cerebral vein (ICV), basal vein of Rosenthal, and subependymal veins were compressed to contralateral direction. Left vertebral angiography (VAG) also showed displacement of temporal branches of posterior cerebral artery and medial compression of posterior choroidal arteries (PchA). Left temporal osteoplastic craniotomy was undertaken on June 15th, 1981, and large intraventricular meningioma occupying the left trigone was removed. (Fig. 5) Tumor showed firm elastic, partly calcified mass. The calcified part

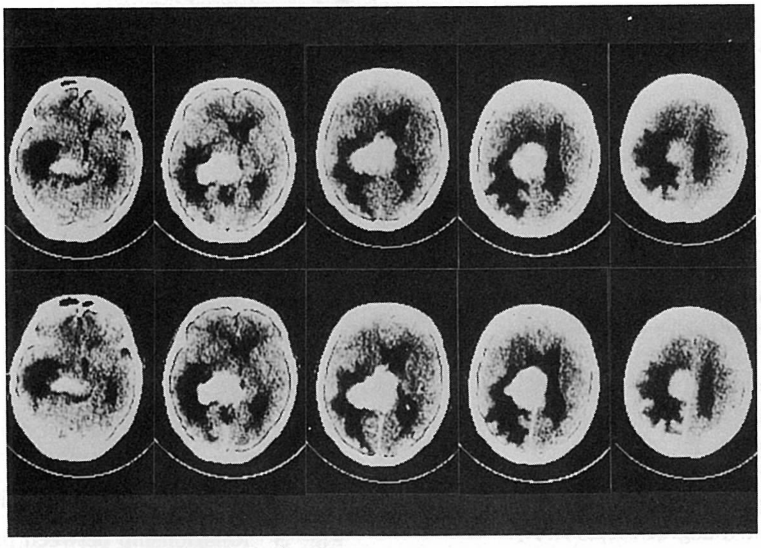

Fig. 4 Plain CT scan on admisson (above) revealed large calcified intraventricular mass lesion occupying left trigone and followed perifocal low density area in left temporo-parietal white matter.

Also noted was some contrast enhancement of this tumor on postinfusion study (below).

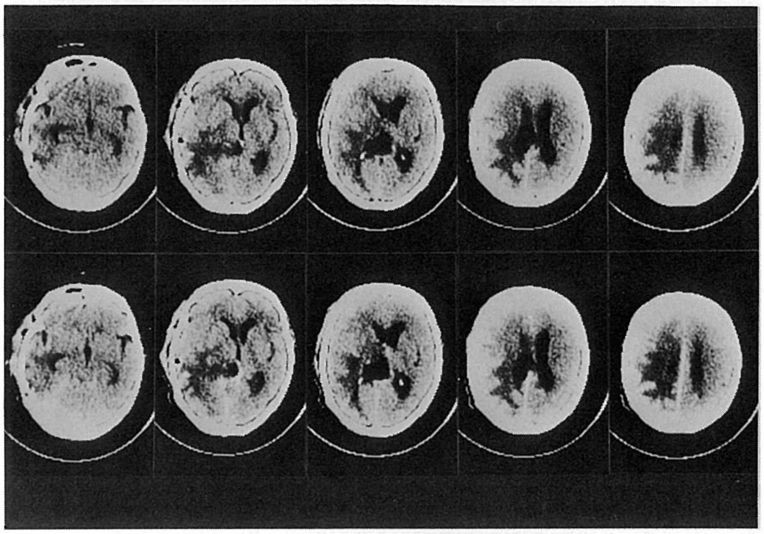

Fig. 5 Immediate postoperative CT scan showed low density area in left trigone after tumor removal on plain study (above) and no definite enhancement (below).

of tumor was difficult to remove by a loop type forceps of monopolar coagulator, however, it was easily vaporized by the application of CO2-Laser. Histological examination revealed meningotheliomatous meningioma. Postoperatively, she showed nominal dysphasia, dysstereognosis, and disorientation of moserate degree.

Comment : In deep seated large tumors, laser was superior to other methods to make operative fields widely, and another advantage of laser was its capacity of vaporization and non-contactness which could remove the deep seated hard calcified mass more easily with minimal bleeding and brain retraction.
Case II. A 21 year-old young female had noticed a dull headache, right hearing impairment, and gait disturbance on Jan 1976. On May 17th, 1976, she received right suboccipital craniectomy and partial removal of acoustic neurinoma at other hospital, and followed by right deafness and right facial nerve palsy, and exacerbation of gait impairment postoperatively. Thereafter she had undertook a rehabilitation for gait ataxia at several hospitals and also she took several ventriculo-peritoneal shunt operations for progressing hydrocephalus. Then she referred to our hospital for remaining right cerebellopontine angle tumor and hydrocephalus on Feb. 4th, 1981. Neurological findings on admission revealed medial deviation of both eyes, and impairment of vertical and lateral gaze on both sides. Right trigeminal, facial and acoustic nerves were also impaired. Moreover, swallowing impairmenrt, truncal and right limb ataxia, and ataxic gait were also noted. Plain skull film showed right suboccipital bony defect and multiple burr holes for shunt operation. CT scan (Fig. 6) revealed right cerebellopontine angle mixed density mass with inhomogeneous contrast enhancement and moderate ventricular dilatation. Left VAG showed large less vascular mass occupying the right half of posterior fossa, and there was no feeding vessels via external and internal carotid arteries on the right side. On Feb. 23rd, 1981, right suboccipital craniectomy and almost total removal of the acoustic neurinoma was performed. Tumor was light brownish, well-circumscribed, and tense-elastic mass with partial cystic component in it. CO2-laser was also applied and it was found to be effective, however, there occurred transient sinus bradycardia twicely

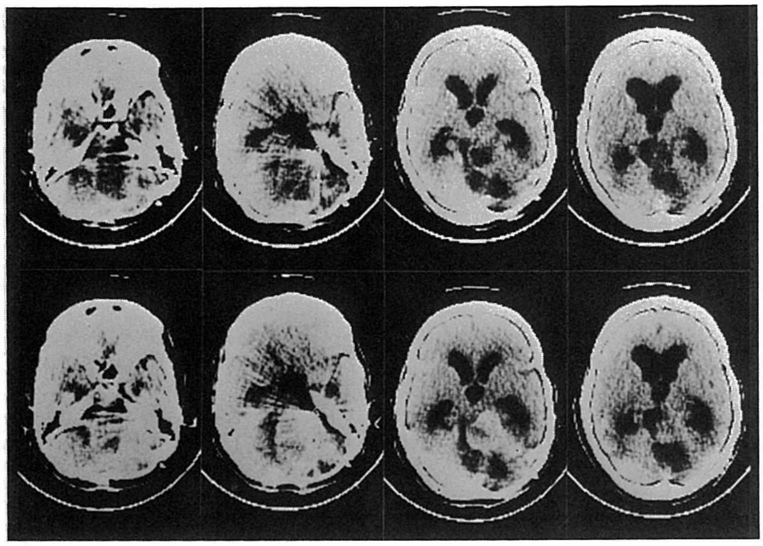

Fig. 6 Preoperative CT study showed mixed deinsity (iso-and low) mass lesion occuying right half of posterior cranial fossa on plain CT (above) and postinfusion study revealed inhomogeneous enhancement of this lesion.

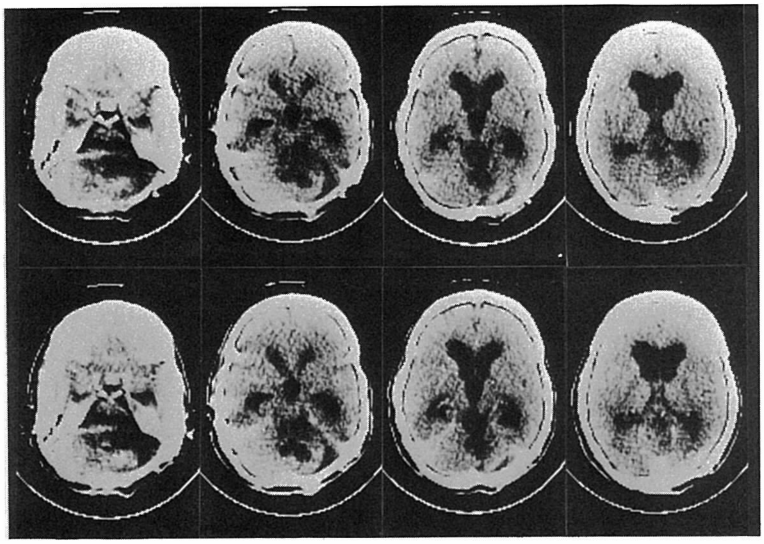

Fig. 7 There was no remaining mass lesion on postoperative CT study in plain (above) and enhancement (below) studies.

possibly owing to thermal effects of CO2-laser to the brainstem at the late stage of tumor extirpation. Postoperatively, right 3rd to 8th cranial nerve palsies on the right were unchanged, moreover, exacerbation of dysphagia was added. So tracheostomy was performed on the second postoperative day. She then took a rehabilitation, however, the improvement of her neurological deficits had been minimal. (Fig. 7) On Nov. 9th, 1981, she referred to other hospital for rehabilitation. Neurological findings on discharge were almost same as those of admission except mild improvement of 3rd, 4th, and 6th cranial nerve paresis on the right.

Comment : It should be in mind that the application of CO2-laser near the vital center necessitates more serious attention as to thermal effects of lasers.

Case III. A 59-year-old man had been complained of decreasing of visual acuity on both eyes since 6 to 7 years before admission to our hospital. He was then pointed out some mental confusion and proptosis on his left eye from his family on Dec. 1980. He then referred to the department of ophthalmology of our hospital, and pointed out retroorbital mass on the left. On Apr 22, he admitted to our clinic. Neurological findings on admission was some mental dullness (dyscalculia etc), left ptosis, bilateral choked discs more prominent on the left, bilateral upward gaze impairment. Plain skull film and laminagram of retroorbital area showed osteolytic lesions in and around the left sphenoid wing. CT scan (Fig. 8) showed a well-defined iso-to high density mass around the left sphenoid ridge, which was partly destructed the major wing of left sphenoid bone and partly invaded to the retroorbital area. Also noted was marked contrast enhancement of this lesions and perifocal edema. Left external carotid angiography showed sunburst-like tumor staining (55×55 mm in size) around the left sphenoid ridge fed by dilated middle meningeal arteries. Also noted was light staining via horizontal segment of left MCA. Left frontotemporal osteoplastic craniotomy and subtotal extirpation of sphenoid ridge-middle fossa meningioma was performed. (Simpson grade 3 operation) Tumor was found to invade the diploic layer of sphenoid bone and partly extended to the retroorbital space. (Fig. 9) Histological diagnosis was fibroblastic meningioma. The postoperative course of this patient was uneventful. He discharged on Jun 20, 1981, with mild upward gaze impairment and proptosis of minor degree on the left. Comment : Laser was more effective to such deeply-seated, firm, and easy-bleeding tumors.

Case IV. Since spring of 1981, this 12-year-old girl showed decreased arm swing on the

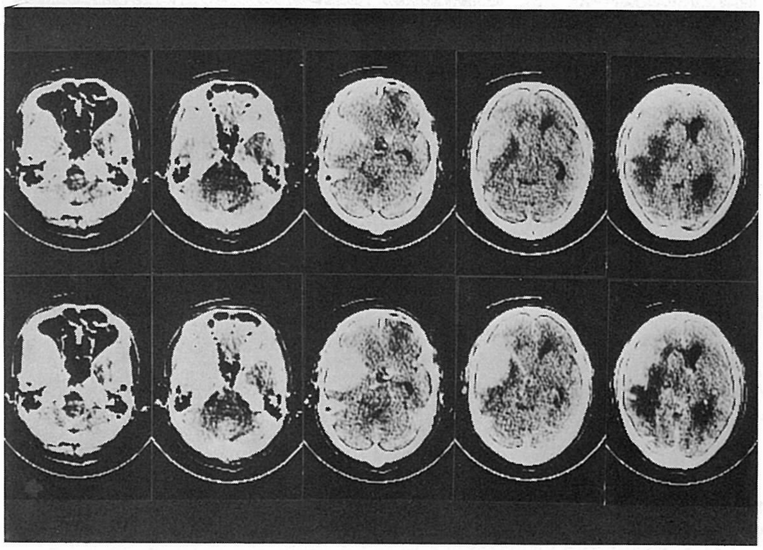

Fig. 8 CT study on admission showed large high density mass lesion in left middle fossa to sphenoid ridge on plain CT (upper row) and marked contrast enhancement (lower row).

Fig. 9 Postoperatice CT revealed left temporal low density area without contrast enhancement (below).

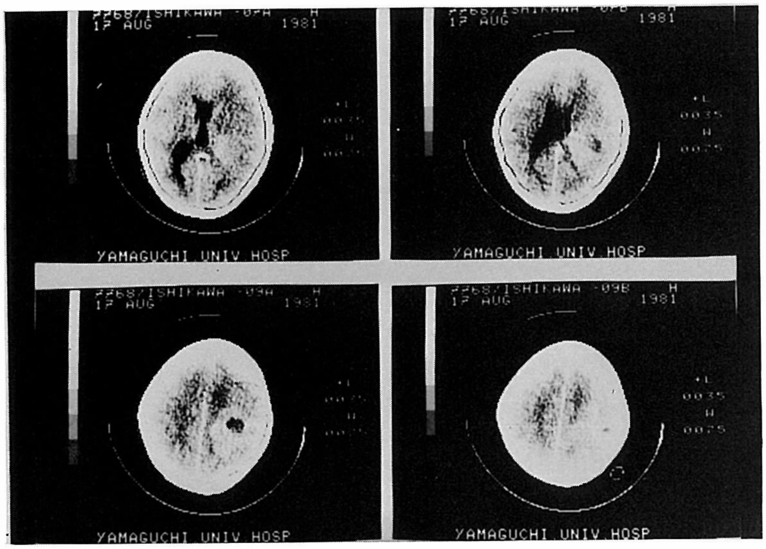

Fig. 10 Preoperative CT showed right parietal mixed density lesion with mass effects.

left on walking. She had complained of fever and headache, followed by nausea and vomiting since July, 1981. Then weakness of her left hand had progressed, and she noticed gait disturbance on Aug 17th, 1981. She then referred to our department from the pediatric department of our hospital. Neurological findings on admission was mild dyscalculia, bilateral blurred disc margins, left mild ptosis, left hemihypesthesia (5/10), and left hemiparesis including face (−1). Plain skull showed some widening of coronal suture. CT scan (Fig. 10) revealed right parietal ill-defined high density mass

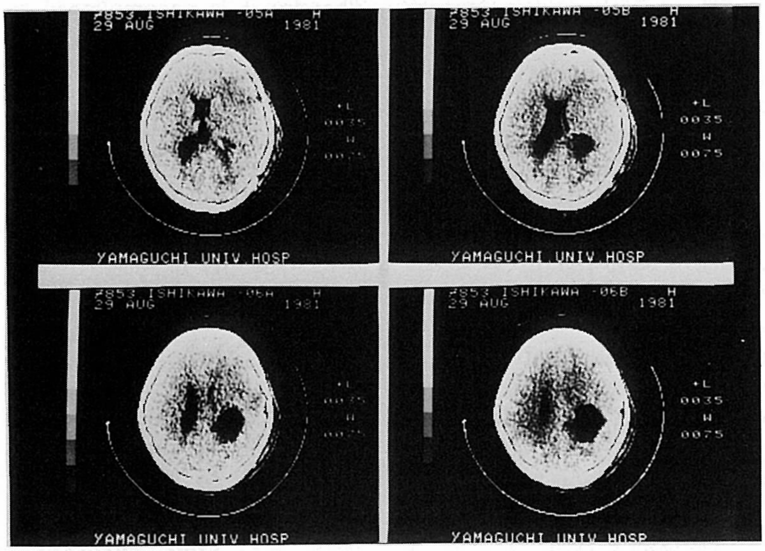

Fig. 11 Postoperative CT study revealed right parietal low density area consisting with tumor removal.

with marked mass effects and moderate contrast enhancement. Also noted were low density area in it showing the presence of cystic component or tumor necrosis. Right parietal osteoplastic craniotomy and tumor removal was performed on Aug 27, 1981. Tumor showed ill-defined, yellowish mass with easy bleeding, which was fairly controlled by application of small water-soaked ball of cotton-pledget and defocused beam of CO2-laser. As tumor border being ill-circumscribed, it was justified by the macroscopical appearance of those of normal white matter and its histological findings suggesting to be borderzone area. (Fig. 11) Postoperatively, deterioration of right hemiparesis and hemihypesthesia was noted, however, it was slightly remitted by rehabilitation to the level of preoperative state. Postoperative radiation and chemotherapy was undertaken. (Total dosis of radiation was 5050 rad) On Dec 2nd, she discharged with left hemiparesis and hemihypesthesia.
Comment : In the case of ill-defined tumor such as glioblastoma, it was fairly difficult to determine the border of tumor. Tumor removal by continuous suctioning and minimal bleeding with defocused beam of laser made the exposure of normal white matter more easily.

Discussion

a, Historical overview : Schawlow and Townes were the first who developed the theory of optical maser in 1958[3]. Maiman also firstly built and introduced the operational laser apparatus, and thereby he named it as laser[1]. The word "laser" means an abbreviation of Light Amplification by Stimulated Emission of Radiation. In 1965, CO2-laser was firstly developed by Patel in the United States[4], and it was introduced to the clinical use. By the way, Takizawa et al.[5-8], and Kamikawa et al.[9,10] were the pioneer of laser apparatus and/or operations in the neurosurgical field in Japan. They introduced, and advanced the technique of laser surgery. Takizawa had also developed the CO2-laser apparatus for neurosurgical use with collaboration to the Mochida pharmaceutical company[5-7]. We introduced the laser apparatus (Medilaser S Model MEL 441) to the neurosurgical operation since Dec. 1979 and 56 cases of intracranial lesions were operated at our department during this last five years. Through these experiences, laser surgery was thought to be essential for removing the intracranial tumors, notably on firm tumors such as meningiomas. Now many types of laser beam are available. These may be solid, as in ruby laser, gasseous as in the carbon-dioxide laser, or fluid. The physical effects of the beam depends on the wave length emitted. Short wave radiation, for example, passes through fluids with minimal absorption of energy and hence is suitable for retinal surgery. Long wave radiation, as emitted from a carbon-dioxide source, is absorbed by fluids to the extent of 99.9% of as energy, and was chosen for this reason for the present purpose[11].

2, Nature of CO2-laser system CO2-laser beam belonged to far-infrared spectrum having wave length of 10.6u, and its main biological effects depends on its thermal effects. The beam of the CO2-laser is completely absorbed by the water[6,7]. Because of the specific property of the CO2-laser beam (10.6u) of being absorbed by water and the fact that biological tissue consists of 75% -90% water, it has been clearly demonstrated that the laser acts by vaporizing tissue at its focal point while leaving adjacent tissue practically unaffected thus enabling a fine hemostatic incision to be performed without precluding primary repair of the resultant wound[12].

3, Pathological changes in CO2-laser surgery. In experimental study, the temperature of the focal point on the cortex of a rabbit was 1500℃ when vaporized by the laser beam with the focal diameter of 0.5 mm and with the output power of 25 watts. However, the extent of thermocoagulation layer around this spot was only 50 u, moreover, the layer of cerebral edema out of thermocoagulation layer was about 210 u. So it was concluded that there was no thermal effects as the point 0.3 mm far from the spot in experimental study of acute stage[7].

4, Clinical merit It is said that operative laser has some useful merit, which can coagulate or vaporize the tissue without contact. Thereby it is accomplished by introducing CO2-laser appararus into the neurosurgical field that operative blood loss was decreased and also operating time was shortened[10]. Strait et al. experienced 20 cases of meningiomas operated by CO2-laser system and concluded that the use of CO2-laser in combination with the operating microscope represents a significant advancement in the ability to remove meningiomas that might prove difficult to extirpate by conventional means[13]. Other author pointed out the clinical advantage of CO2-laser as a means of working at the bottom of a deep hole, minimal disruption of nonmalignant tissue, and ability to maintain orientation while working deep within the brain using preoperative CT scan and roentgenographic monitoring[14]. It is also said that the vaporization effect consists in transforming into smoke and vapour pathological tissue to be removed without any mechanical trauma to surrounding tissues[15]. From our experience, the CO2-laser appararus for surgical operation was effective for controlling intraoperative bleeding by changing power of the laser apparatus and size of the beam, thereby enable the radical removal of the tumor more easily. Also it should be stressed that the CO2-laser is safer and minimal thermal effects on adjacent cerebral tissues, thereby make the intraoperative procedures safely.

5, Indication of CO2-laser surgery It is particularly helpful in surgery of brain tumors because of its highly hemostatic quality. Operators can minimize blood loss and operating time by utilizing the laser[5]. Kaplan et al. concluded that application of laser surgery was as follows ; 1) all operations where the anticipated blood loss is significant, 2) operations performed on or through infected tissue, 3) extirpation of malignant tumors, 4) cavitational surgery involving the use of an endoscope or microscope[12]. Takizawa pointed out that the indication of CO2-laser for brain tumor have two. It was the hemorrhagic, and fibrous tumors which are difficult to extirpate by ordinal method using electro-coagulator and suction tube[7].

He also stated that deep seated tumor such as pinealoma of tiny calibre is a good indication of laser surgery[6]. CO2-laser was also applying to osteoma[11]. However, it is currently under study whether skin or scalp should be incised by laser or not. Ordinarily laser surgery had been directed principally to the brain tumors. However, Kamikawa et al have been applied this to the case of large intracerebral AVMs and obtained a good results[10]. Therefore application of CO-laser surgery to intracranial vascular lesions is thought to be promissing hereafter.

6, Technique of laser surgery. We have usually used the CO2-laser system by controlling the hand piece of Medi-Laser S macroscopically, or occasionally under the operating microscope. Because of the limitation of operative field and the decreased light which occurred in combined use of operating microscope and CO2-laser system via the adapter set, we usually did not attach it to the operating microscope. Under these circumstances, we had found several available technique in laser surgery.

a) On hollowing the tumor mass, some misunderstanding about the depth of tumor could be occurred during the voporization or coagulation of the tumor. As vaporizing the tumor tissue by laser, the tumor itself is gradually pushed out by the pulsation of the underlying brain tissue. So operators should be in mind that it is necessary to notice the true thickness of remained tumor tissue by palpating it with suction tube or fingers during tumor resection by CO2-laser.

b) In the case of brain tumors showing easy bleeding during operation, it is fairly difficult to control the bleeding because there is a layer of coagulated blood over the tumor bed when applying the laser beam. In such cases, it is beneficial to compress the tumor bed by water-soaked cotton-ball, which are handled by the suction tube on the left hand. On the other hand, defocused beam of CO2-laser should be directed to the dry field of tumor bed which was made by rolling the cotton-ball by a suction tube.

In the literature, it is said and advocated to use the CO2-laser by the method of defocused beam[7]. Another method of how to use the laser system is those of combining it to cryosurgery[6], or ultrasonic apparatus. These aspect should be investigated more aggressively.

References

1) Maiman, T. H.: Optical and microwave-optical experiments in rudy. *Physiol. Rev. Lett.*, **4**: 564, 1960.
2) Rosomoff, H. L. and Carroll, F.: Reaction of neoplasm and brain to laser. *Arch. Neurol.*, **14**: 143-148, 1966.
3) Schawlow, A. L. and Townes, C. H.: Infrared and optical masers. *Physiol. Rev.*, **112**: 1940, 1958.
4) Patel, C. K. N.: High power carbon dioxide lasers. *Sci. Am.*, **219**(2): 22-33, 1968.
5) Takizawa, T.: Comparison between the laser surgical unit and the electrosurgical unit. *Neurol. Med. Chir. (Tokyo)*, **17**(1): 95-105, 1977.
6) Takizawa, T.: Laser surgery of brain tumors (in Japanese). *Adv. Neurol. Sci. (Tokyo)*, **22**: 101-110, 1978.
7) Takizawa, T.: Laser surgery of brain tumors. *Neurol. Surg. (Tokyo)*, **6**: 743-745, 1978.
8) Takizawa, T., Yamazaki, T., Miura, N., Matsumoto, M., Tanaka, Y., Takeuchi, K., Nakata, Y., Togashi, O., Nagai, M., Ariga, T., Mizutani, H. and Sano, K.: Laser surgery of basal, orbital and ventricular meningiomas which are difficult to extirpate by conventional methods. *Neurol. Med. Chir. (Tokyo)*, **20**: 729-737, 1980.
9) Kamikawa, K., Ikeda, T., Hayakawa, T. and Ohnishi, T.: Application of laser scalpel in neurosurgery (in Japanese). *Surg. Therapy (Osaka)*, **35**: 626-636, 1976.
10) Kamikawa, K., Hayakawa, T., Ohnishi, T. and Yoshimine, T.: Laser neurosurgery (in Japanese). *Clin. Surg. Today (Tokyo)*, **17**: 45-75, 1980.
11) Kosary, I. Z., Shacked, I. and Farine, I.: Use of surgical laser in the removal of an osteoma of the skull. *Surg. Neurol.*, **8**: 151-153, 1977.
12) Kaplan, I. and Sharon, U.: Current laser surgery. *Ann. NY Acad. Sci.*, 267: 247-253, 1976.
13) Strait, T. A., Robertson, J. H. and Clark, W. C.: Use of the carbon dioxide laser in the operative management of intracranial meningiomas; a report of twenty cases. *Neurosur-*

gery., **10** : 464-467, 1982.
14) Kelly, P. J. : Brain tumor vaporized by carbon dioxide laser. *JAMA*. **243** : 1791, 1980.
15) Perria, C., Francaviglia, N., Borzone, M., Chinnici, A., Piano, E. and Pacini, P. : The value and limitations of the CO2 laser in neurosurgery. *Neurochirurgia*, **26** : 6-11, 1983.