Application of Novel CO₂ Laser-Suction Device

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Abstract

Keywords

- laser surgery
- carbon dioxide laser
- neurosurgical procedure
- omniguide
- microsurgery
- laser suction

Background Development of the flexible CO₂ fiber has presented new opportunities for the use of precision laser cutting in cranial procedures. The efficacy of the CO₂ scalpel is further enhanced by combining it with a fluid removal suction capability.

Objectives We report our experience with a novel CO₂ laser-suction device.

Methods The novel laser-suction device was designed in conjunction with OmniGuide Inc. (Cambridge, Massachusetts, USA). We performed a case review of its use in firm tumors that were resistant to resection by bipolar, suction, and ultrasonic aspirator.

Results The laser-suction device was applied in three tumors where resection with ultrasonic aspiration failed. Tumor resection using the laser-suction device was successful in all three cases. There were no complications related to the laser-suction device. There were no instances of intraoperative device malfunction.

Discussion The CO₂ laser combined with suction is a useful instrument for resection of firm tumors that prove to be resistant to ultrasonic aspiration. We also find it to be useful in settings where precise tissue incisions are desired with minimal manipulation. In our experience, the surgical efficiency of the CO₂ laser is improved by the laser-suction device. This device allows the surgeon to utilize a suction device and laser in a single hand and enables concurrent use of bipolar electrocautery without repeated instrument changes.

Introduction

Lasers have a long and varied history of use in neurosurgery. The first laser was developed in 1960 at Howard Hughes Research Laboratories by Maiman using a ruby medium. In the early 1960s various laser media were developed, and in 1964 Patel at Bell Laboratories constructed the first CO₂ laser at 10.6 μm wavelength.¹ Experimental use of lasers in animal brains began in 1965, and the first clinical application was documented in 1966 using a ruby laser. Further development of the continuous-wave CO₂ laser in animal models led to their first use during resection of a glioblastoma multiforme in 1969 by Stellar.¹

Nd:YAG, argon, and CO₂ laser use in neurosurgery proliferated through the 1970s and early 1980s². The CO₂ laser was

applied in various ways, including tumor resection,^{3,4} resection of vascular lesions,⁵ microvascular anastomosis,⁶ nerve repair,^{7–9} thoroscopic sympathectomies,^{10,11} dural closure,¹² prevention of epidural scarring after laminectomy,¹³ and spinal cord untethering.¹⁴ Several limitations, however, tempered enthusiasm for laser use. Notably, the Nd:YAG laser resulted in an unacceptably high amount of heat damage to surrounding tissues.^{15,16} The CO₂ laser surmounted the problem of collateral heat damage. The 10.6 μm wavelength is readily absorbed by water, resulting in maximal effect at the target site and minimal thermal diffusion.^{17,18} Proliferation of its use, however, was significantly hampered by cumbersome design, time-consuming microscope adapters, and the requirement for a direct line-of-sight from the distant laser source (outside of surgical field) to the target (►Fig. 1a).¹ The

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Fig. 1 (A) Early model of CO₂ laser. (B) OmniGuide CO₂ laser (OmniGuide, Cambridge, Massachusetts, USA) design illustrating design of flexible hollow-core photonic bandgap fiber.

hope of overcoming these limitations with the use of fiber-optic cables was frustrated by excessive power loss due to the long wavelength of the CO₂ laser.¹

Clinical utilization of lasers waned in the 1990s to 2000s as standard tools such as bipolar and cavitron ultrasonic surgical aspirator (CUSA) offered more efficient, agile, and familiar means of tissue removal. In 2002, however, Temelkuran published his development of a low-profile and portable CO₂ laser-transmission device utilizing omnidirectional dielectric mirrors lining the inner core of a hollow fiber to confine and guide intense laser radiation (► **Fig. 1b**).^{19–21} The advent of this low-profile, flexible system that could be introduced into the microsurgical field reinvigorated interest in the use of the CO₂ laser. This technology was rapidly adopted by otolaryngologists for treatment of laryngeal pathology, with reports in the medical literature emerging in 2005.^{22,23} Initial case reports in neurosurgery emerged in 2008, and more extensive experience with this new CO₂ laser design was first reported by Killory in 2010.²⁴ The improved design of the CO₂ laser has enhanced its utility and efficiency.^{25–29} Despite the ergonomic improvements of the CO₂ laser, its application is hindered by the generation of smoke, its propensity to cut rather than coagulate small vessels, and its impaired function when the target is covered by fluid—blood, irrigation, or cerebrospinal fluid. Intraoperatively, a two-handed surgeon may utilize a suction device and the CO₂ laser; however, this configuration frequently necessitates time-consuming exchanges between the CO₂ laser with bipolar electrocautery to control bleeding caused by the CO₂ laser. To improve this inefficiency in operative flow, we mounted the CO₂ laser to a suction device, enabling the concurrent use of the suction, CO₂ laser, and bipolar. We describe our experience with this novel laser-suction device and provide two case illustrations.

Methods

Laser Design

The laser-suction device was developed in consultation with the senior author (RWB) by OmniGuide Inc. (Cambridge, Massachusetts, USA). It consists of the CO₂ laser mounted on top of a regulated suction device. The suction is a standard device with the laser fiber secured in a low-profile metal guide. The fiber is superior to the suction tip, and it is recessed slightly behind the tip of the suction. Both are well balanced, allowing the suction to be used at any time whether or not the laser is actively in use (► **Fig. 2**).

Laser Use and Safety

The laser-suction device and CO₂ laser fiber are opened onto the sterile field. The proximal end of the fiber is passed off the field and connected to the CO₂ laser and helium cooling source. All personnel in the operating room, except the surgeon and first assistant whose eyes are protected by the

Fig. 2 Laser-suction device featuring low-profile CO₂ laser mounted on top of graduated suction. Note that the CO₂ laser tip is recessed slightly behind the tip of the suction in this design.

surgical microscope, are required to wear protective glasses with 10,600 nm filters. The laser is operated in the power range of 1 to 20 W.

Case Reviews

Clinical imaging, case histories, operative reports, and intraoperative video were collected retrospectively. All procedures were performed at Rush University Medical Center.

Results

Case 1

A 38-year-old woman had an incidentally discovered and asymptomatic 1-cm calcified posterior fossa mass discovered 5 years prior to presentation following a motor vehicle collision. This lesion was managed nonoperatively, as she remained without referable symptoms. She began to develop occasional diplopia and headaches over the past year and was found to have new papilledema on an annual eye examination. A follow-up magnetic resonance imaging (MRI) revealed enlarged ventricles and interval growth in the posterior fossa mass. She underwent an endoscopic third ventriculostomy at an outside hospital. Her neurological exam was normal. Preoperative imaging (►Fig. 3a) revealed an enhancing lesion in the posterior fossa arising from the right inferior tentorial surface compressing the quadrigeminal plate. A suboccipital infratentorial-supracerebellar craniotomy approach was uti-

Video 1

(A) Video demonstrating attempted resection of firm meningioma with cavitron ultrasonic surgical aspirator (CUSA). (B) Video demonstrating efficacy of laser-suction device in the same tumor where the CUSA had proven ineffectual.

Online content including video sequences viewable at: www.thieme-connect.com/ejournals/html/10.1055/s-0033-1347373

lized. Intraoperative findings revealed an extremely firm tumor that was difficult to resect using typical debulking methods, including CUSA. The laser-suction device was used to debulk the tumor in a piecemeal fashion. The tumor was disconnected from its attachments to the inferior tentorial edge using the laser-suction device and bipolar electrocautery (►Videos 1A, B, supplemental videos demonstrating tumor dissection with CUSA and laser-suction device). Final pathology revealed a WHO grade I meningioma with psammoma bodies. Postoperatively, the patient was neurologically normal and was discharged on postoperative day 2. Follow-up MRI at 1 year revealed gross-total resection of the tentorial meningioma (►Fig. 3b).

Fig. 3 (A) Preoperative T1-weighted magnetic resonance imaging (MRI) with contrast. (B) Postoperative T1-weighted MRI with contrast.

Fig. 4 (A) Preoperative T1-weighted magnetic resonance imaging (MRI) with contrast. (B) Postoperative T1-weighted MRI with contrast.

Case 2

A 71-year-old woman presented with a 1-month history of right leg weakness, imbalance, and progressive extraocular muscle paresis. Imaging (►Fig. 4a) revealed a cystic mass arising from the floor of the fourth ventricle with an enhancing nodular component and hydrocephalus. A suboccipital craniotomy was performed and a right-sided telovelar approach was used to access the fourth ventricle. The cyst was decompressed and biopsies were sent of the tumor. Intraoperative findings revealed an extremely firm tumor embedded within the floor of the fourth ventricle and resistant to attempted debulking with CUSA. Given that the mass effect on the brainstem had been relieved by the cyst decompression and that further resection of tumor required significant manipulations of the floor of the fourth ventricle, further resection of the tumor was not attempted. She required ventriculoperitoneal shunt placement prior to discharge. Final pathology initially revealed a subependymoma WHO grade I. Postoperatively, she awoke with improved right leg weakness and unchanged extraocular paresis. She represented on postoperative day 12 with altered mental status and was found to have recurrence of the fourth ventricular cyst. The tumor was resected in a piecemeal fashion down to the floor of the fourth ventricle using the laser-suction device (►Video 2, supplemental video demonstrating tumor dissection with laser-suction device). Imaging revealed near-complete resection of the tumor, with a thin residual margin left embedded within the brainstem (►Fig. 4b). She awoke with no new neurological deficits. She was discharged on postoperative day 5 with

improved mental status and significant improvement in her extraocular muscle paresis. She returned to the hospital, unfortunately, on postoperative day 21 having suffered a pulmonary embolism, which ultimately proved to be fatal.

Case 3

The third case is a 52-year-old woman with progressive neck pain for 2 years. Her symptoms continued to worsen and she began to develop tongue numbness. Imaging revealed a homogeneously enhancing ventral lesion at the level of the foramen magnum with significant compression of the medulla and upper cervical cord (►Fig. 5a). A far lateral approach with C1–2 laminectomy was used to access the tumor. The tumor was partially resected with use of CUSA, but given the tough nature of the tissue it proved easier to remove with the CO₂ laser. The neural elements were successfully decompressed and the bulk of the tumor resected; however, a

Video 2

Supplemental video demonstrating the use of the laser-suction device during the resection of a firm fourth ventricular subependymoma that was adherent to the brainstem.

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Fig. 5 (A) Preoperative T1-weighted magnetic resonance imaging (MRI) with contrast. (B) Postoperative T1-weighted MRI with contrast.

residual capsule firmly attached to the vertebral artery was left behind (► **Fig. 5b**). Postoperatively, the patient did well and was without swallowing or airway difficulties. She experienced trace weakness on her left side and left tongue, all of which resolved by her 6-month follow-up. Final pathology revealed a WHO grade I meningioma.

Discussion

Analyses of line-of-sight CO₂ laser use prior to OmniGuide technology found a limited role for its use. Retrospective studies comparing the CO₂ laser to other techniques demonstrated an increased operative time, increased number of reoperations, and no change in outcomes (except in the case of meningiomas located in functional regions).^{30,31} The advent of the flexible OmniGuide fiber has enhanced the utility of the CO₂ laser, overcoming ergonomic obstacles that limited the efficient use of line-of-sight CO₂ lasers. Reports of OmniGuide CO₂ laser use in the surgical management of numerous central nervous system pathologies has recently been described.^{24,27,28} Laboratory studies have shown the CO₂ laser to be particularly adept in creating incisions in nervous tissue that are limited in the volume of damage to surrounding tissue and precise in the depth of the incision. Moreover, by adjusting the power settings of the CO₂ laser, the user can vary the depth of tissue penetration according to desired use. Compared with bipolar electrocautery, sharp incisions with microscissors and scalpels, and ultrasonic aspiration, the CO₂ laser provides a more exact and predictable profile of tissue interaction within the central nervous system.^{18,32} For these reasons, the CO₂ laser has proven useful in the resection of lesions located in eloquent regions of the nervous system, including lesions in the speech area, brainstem tumors, cavernomas, intramedullary spinal cord tumors, craniopharyngiomas adherent to the hypothalamus, and tumors invol-

ing cranial nerves,^{24,27} as well as for corpus callosotomies.³³ We have found the precision of the CO₂ laser useful in the disconnection procedures for epilepsy surgery, as well. One limitation observed has been the inability of the CO₂ laser to penetrate calcified lesions.²⁴ Malone, however, recently reported a novel technique using the OmniGuide CO₂ laser to vaporize the cellular components of a highly vascular and calcified intraventricular choroid plexus papilloma, allowing subsequent resection of the calcified shell using a drill.²⁸

We have found the laser to be most useful in cases of firm tumors adherent to eloquent nervous tissue. Typically we will have the CO₂ laser available in cases where preoperative imaging is suggestive of a firm tumor that abuts or encases sensitive structures (e.g., brainstem, cranial nerves, optic nerves, hypothalamus). In all cases, ultrasonic aspiration is used as the first-line instrument for tumor resection. This familiar technique, more often than not, proves adequate for safe tumor resection. However, in cases where the ultrasonic aspirator at its most aggressive settings remains ineffective, the CO₂ laser has regularly proven to be a successful option.

Both in our experience and in other reports,²⁴ the CO₂ laser is an ineffective tool when the operative field is saturated with fluid (blood, irrigation, or CSF). Additionally, the CO₂ laser is not primarily a hemostatic tool; when focused on a blood vessel, it lacerates the vessel, producing subsequent bleeding, which further impairs its efficacy. Moreover, use of the laser produces smoke which, particularly in deep operative fields, impairs visibility and may slow the progress of an operation. In our prior experience, particularly with highly vascular lesions, the use of the OmniGuide CO₂ laser alone can disrupt the fluidity of a procedure. As described in the cases above, we have found that the use of a laser-suction tip has overcome this limitation, allowing efficient and continuous use of the

laser while the surgical field is kept dry with concurrent use of the attached suction and bipolar electrocautery. This novel device allows the two-handed surgeon to effectively operate with three critical instruments—bipolar, suction, and laser—all of which remain in the operative field during the procedure, thereby avoiding repeatedly disruptive instrument exchanges. The OmniGuide CO₂ laser has led to a significant advance in the applicability of the CO₂ laser in neurosurgical procedures. We found that use of the laser-suction device further enhances its functionality and streamlines operative flow.

Conclusion

The CO₂ laser is particularly useful in resecting firm tumors that are resistant to bipolar, suction and ultrasonic aspiration. It is also useful in cases where precise tissue incisions³² and minimal tissue manipulation is desired. The laser-suction device enhances the functionality of the CO₂ laser. We have found that it improves operative efficiency by enabling the surgeon to overcome smoke and bleeding without exchanging instruments.

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