Use of a flexible hollow-core carbon dioxide laser for microsurgical resection of vestibular schwannomas

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OBJECTIVE The CO₂ laser has been used on an intermittent basis in the microsurgical resection of brain tumors for decades. These lasers were typically cumbersome to use due to the need for a large, bulky design since infrared light cannot be transmitted via fiber-optic cables. Development of the OmniGuide cable, which is hollow and lined with an omnidirectional dielectric mirror, has facilitated the reintroduction of the CO₂ laser in surgical use in a number of fields. This device allows for handheld use of the CO₂ laser in a much more ergonomically favorable configuration, holding promise for microneurosurgical applications. This device was introduced into the authors' practice for use in the microsurgical resection of skull base tumors, including vestibular schwannomas.

METHODS The authors reviewed the initial 41 vestibular schwannomas that were treated using the OmniGuide CO₂ laser during an 8-month period from March 2010 to October 2010. The laser was used for all large tumors, and select medium-sized tumors were treated via both the translabyrinthine and retrosigmoid approaches. The estimated time of tumor resection and estimated blood loss were obtained from operating room records. Data regarding complications, facial nerve and hearing outcomes, and further treatment were collected from hospital and clinic records, MRI reports, and direct review of MR images. Time of resection and blood loss were compared to a control group (n = 18) who underwent surgery just prior to use of the laser.

RESULTS A total of 41 patients with vestibular schwannomas were surgically treated. The median estimated time of tumor resection was 150 minutes, and the median estimated blood loss was 300 ml. The only operative complication was 1 CSF leak. Thirty-eight patients had normal facial nerve function at late follow-up. The median MRI follow-up was 52 months, and, during that time, only 1 patient required further treatment for regrowth of a residual tumor.

CONCLUSIONS The OmniGuide CO₂ laser is a useful adjunct in the resection of large vestibular schwannomas. This device was used primarily as a cutting tool rather than for tumor vaporization, and it was found to be of most use for very large and/or firm tumors. There were no laser-associated complications, and the results compared favorably to earlier reports of vestibular schwannoma resection.

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KEY WORDS carbon dioxide laser; vestibular schwannoma; acoustic neuroma; microsurgery; omnidirectional dielectric mirror

LASERS have been used in neurosurgery for decades. Stellar et al. reported use of a CO₂ laser for resection of an intracranial tumor in 1970.³⁴ The rationale for laser use in tumor resection is both to allow for “no-touch” cutting and for tissue debulking, with hemostatic benefit. The CO₂ laser has particular advantages in surgery. Its infrared wavelength (10.6 μm) penetrates water very poorly, confining its area of action to the surface of the biological

structures being dissected and minimizing collateral tissue damage.^{5,29}

The benefits of the CO₂ laser, however, have been tempered by ergonomic and practical difficulties.²⁸ All materials usable for fiber-optic transmission in the infrared spectrum at 10.6 μm are opaque to light.³⁶ Thus, fiber-optic cables cannot be used. Previously, CO₂ laser energy could only be transmitted through a housing with mirrors

ABBREVIATIONS AAO-HNS = American Academy of Otolaryngology–Head and Neck Surgery; CPA = cerebellopontine angle; EBL = estimated blood loss; ETR = elapsed time of tumor resection; H-B = House-Brackmann; RS = retrosigmoid; TL = translabyrinthine.

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and bulky articulating arms. While used successfully, including for microsurgical resection of vestibular schwannomas, practical limitations prevented widespread adoption.²⁶

Development of a hollow fiber, lined internally with an omnidirectional dielectric mirror, allows for transmission of a CO₂ laser through an easily manipulatable cable.¹² When attached to an ergonomically favorable dissector, practical difficulties of CO₂ laser use for intracranial micro-neurosurgery can be minimized.²⁰ We present our series of case experience using the OmniGuide (ARC Laser GmbH) CO₂ laser for microsurgical resection of vestibular schwannomas.

Methods

An institutional review board waiver was obtained prior to review of any data for this study. During an 8-month period from March 2010 to October 2010, the OmniGuide CO₂ laser was used by the first author as an adjunct in the resection of medium to large vestibular schwannomas. All operations were carried out by a team consisting of a single neurosurgeon and one of 6 neurotologists. For large tumors (> 2.5 cm in the cerebellopontine angle [CPA]), the laser was used for all consecutive cases with the exception of a single, very soft, cystic tumor. For medium tumors (1.5–2.5 cm in the CPA), the laser was used for selected cases on an ad hoc basis. All consecutive cases of laser use are reported.

Outcome Measures

Given that the primary benefits of CO₂ laser usage were thought to be related to operative time and blood loss, we chose elapsed time of tumor resection (ETR) and estimated intraoperative blood loss as primary outcome measures. Data regarding these measures were obtained retrospectively through review of the hospital chart. ETR was determined from the facial nerve monitoring record, in which the times of “neurosurgeon begins” and “tumor out” were recorded. Of note, for retrosigmoid cases this included drilling of the porus and exposure of the intracanalicular portion of the tumor. Estimated blood loss (EBL) was obtained from the anesthesia record and could only be determined for the entire procedure.

Secondary outcome measures were obtained from a prospectively generated database in a manner suitable for statistical analysis. These measures included facial nerve function, which was graded from I to VI according to the House-Brackmann (H-B) scale, and hearing, which was categorized as per the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) classification system.^{17,22} Complications, totality of tumor resection, MRI results, and the need for subsequent treatment were also recorded.

Patient Population

A total of 41 patients were surgically treated in this series. Demographic data are presented in Table 1. Patients with neurofibromatosis type 2 and those who had previously been treated with stereotactic radiosurgery were included. No patient who underwent surgery during the

TABLE 1. Characteristics of 41 patients undergoing surgery for vestibular schwannoma using the OmniGuide CO₂ laser

Characteristic	Value
Age in yrs	
Mean (SD)	48.3 (15.2)
Median (range)	47 (19–95)
Sex, % M/F	53.7/46.3
Side, % rt/lt	58.5/41.5
Total tumor size in cm	
Mean (SD)	3.1 (0.8)
Median (range)	3.1 (1.8–5.3)
CPA tumor size	
Mean (SD)	2.8 (0.9)
Median (range)	2.7 (1.5–5.3)
Tumor size, % large/medium	58.5/41.5
Preop AAO-HNS hearing class, n (%)	
A	15 (36.6)
B	4 (9.8)
C	1 (2.4)
D	21 (51.2)
Neurofibromatosis type 2, n (%)	5 (12.2)
Prior stereotactic radiation, n (%)	4 (9.8)

study period had previously undergone microsurgical resection. In addition, a representative control group of 18 patients who had undergone surgery immediately prior to the study period without the use of the laser were included for analyses regarding blood loss and operative time. The mean age at surgery, total tumor size, and size of tumor extension into the CPA did not differ significantly between the control group and the OmniGuide group. The control group appeared to have a greater prevalence of medium-sized tumors than the OmniGuide group (61.1% vs 41.5%, respectively). This difference did not achieve statistical significance ($p = 0.16$).

All large tumors were approached via the translabyrinthine (TL) route. The retrosigmoid (RS) approach was reserved for patients with medium-sized tumors and good hearing. Patients with good hearing and with tumors small enough and configured so as to provide a reasonable chance of hearing preservation were offered the option of the RS approach. The decision about which operation to perform was made on a case-by-case basis. The rate of use of the RS approach was similar in the OmniGuide and control groups (9.8% and 11.1%, respectively).

Procedures

Operative techniques of both TL and RS approaches to resection have previously been described in detail.^{10,32} TL procedures were carried out in the supine position with the patient's head freely positioned on the operating table in contralateral rotation. RS procedures were carried out in the lateral park-bench position with the patient's head immobilized using a Mayfield device (Integra LifeSciences). Continuous facial nerve monitoring using the Xomed-NIM system (Medtronic) was used for all cases. For cases

FIG. 1. Photographs of the OmniGuide cable and handpiece. **A:** The tip of the handpiece also functions as a microdissector, facilitating tissue manipulation and ensuring proper positioning. **B:** When properly set up, the end of the cable rests in the midpoint of the oval-shaped aperture at the dissector tip.

of attempted hearing preservation, evoked auditory brainstem responses were recorded continuously (Cadwell Cascade, Cadwell Industries). In most cases, we begin surgery with the goal of gross-total tumor resection. If the tumor is found to be highly adherent to the facial nerve, or if facial nerve function is otherwise in jeopardy, we prioritize the facial nerve over gross-total tumor resection. Our philosophy regarding aggressiveness of tumor resection has been described.^{13,31}

After tumor resection, patients were observed in the intensive care unit overnight and began mobilization on the 1st postoperative day. Patients were discharged from the hospital after meeting discharge criteria, including tolerance of diet and safe ambulation. Facial nerve function was assessed immediately postoperatively and throughout the postoperative period. Any patient who had not experienced any facial weakness as of 1 month postoperatively was deemed to have an ultimate result of normal facial nerve function (H-B grade I). For patients with any postoperative facial weakness, late facial nerve function was determined at 1 year. Postoperative audiograms were obtained in all patients who underwent RS resection.

As per our usual practice, MRI was not performed in the immediate postoperative period unless there were specific clinical indications. A schedule for postoperative imaging was determined individually for each. A first postoperative scan was generally recommended at some point between 4 and 12 months after surgery.

Device Description

The OmniGuide CO₂ laser system consists of a laser source generator, a flexible hollow-core fiber, and a hand-held dissector housing the end of the fiber (Fig. 1). We used the OmniGuide FELS-25A laser (ARC Laser GmbH) using the continuous mode. Power output was limited to the 20-W maximum specified for the OmniGuide fiber. Flow of helium through the cable acts as a coolant and as the gaseous substrate. This ensures that the laser wavelength is calibrated to the cable's omnidirectional dielectric mirror, allowing for proper propagation of the laser energy.

We used the Beam Path Neuro-L fiber (OmniGuide), which has an outer diameter of 1.2 mm. At the operative end of the cable, the laser energy is defocused, resulting in decreasing intensity proportional to the square of the distance from the fiber tip. The end of the fiber fits within a rigid handpiece, allowing for manipulation within a deep corridor. We used the Neuro-HP-5 medium length, straight handpiece in all cases (OmniGuide).

Data Analysis

Descriptive statistics, including mean, standard deviation, median, minimum, and maximum values, were computed for all interval-level variables and frequency distribution for all categorical variables. The OmniGuide and control groups were compared using independent group t-tests (after confirmation of homogeneity of variance) for interval-level data and chi-square or Fisher's exact test for categorical variables.

Results

Operative Technique

The flexible hollow-core CO₂ laser was used as an adjunct to tumor resection rather than as the only tool. The OmniGuide Neuro-HP-5 handpiece was ergonomically well suited to visibility and surgical manipulation in all cases. Laser power can be adjusted in 2-W increments, and a setting of 12 W was found to be generally most useful for bulk tumor resection. Lower settings, in the 6- to 10-W range, were useful for more delicate work, especially in proximity to cranial nerves.

We quickly realized that the laser functioned best as a cutting tool rather than a vaporizing tool. As is our usual method, central tumor debulking was carried out primarily using an ultrasonic aspirator. After debulking, the periphery of the tumor could be dissected from surrounding structures and then further removed in a piecemeal fashion using the laser, with the tip of the device held very close to tumor tissue (Fig. 2). The laser was found to have several advantages over microscissors. First, it could cut through even the firmest tissue, including portions of tumors that were not amenable to division using metal scissors. Second, tumor could be cut while simultaneously being re-

FIG. 2. Bar graph showing facial nerve results. Of the 41 patients who underwent surgery, 12 had some degree of temporary facial weakness; 38 had normal facial nerve function at late follow-up.

tracted centrally by a suction device held in the nondominant hand. This avoided the typical pushing action of microscissors and allowed for the resection of larger pieces of tumor in fewer steps. Third, cutting tumor always resulted in some vaporization, further speeding resection. Finally, while the hemostatic action of the CO₂ laser on larger vessels was minimal, small vessels were easily cauterized, resulting in the perception of less ongoing blood loss.

To prevent the potentially dangerous action of the laser at a distance, we were careful to always point the laser toward the center of the tumor mass so that when tissue was cut through, the ongoing beam was still confined within the tumor. Furthermore, we were careful to always keep the depths of the field bathed in saline solution, thus protecting submerged structures. As the laser output is defocused, objects distant from the tip of the laser were also relatively protected from laser energy, proportional to the square of the distance, in any.

The CO₂ laser was also used to debulk tumor more delicately using a no-touch technique in areas in which cranial nerve traction was a concern. Typically, this was close to the porus of the internal auditory canal. When working near cranial nerves, we took care to ensure that these structures remained irrigated. Except when the laser was used at the lowest power, small fragments of char could be seen floating away from the site of cutting. While there was no evidence that these fragments deposited any significant heat, we typically protected the facial nerve with a moist cotton patty when working nearby. The OmniGuide laser was never used for dissection of tumor tissue directly from cranial nerves or other vital structures.

The laser fiber proved to be fragile under certain cir-

cumstances. Use at a power greater than 12 W for prolonged periods was not practical due to device failure. This problem may have since been corrected as a result of improvements in manufacturing. Furthermore, obstruction of the aperture at the outlet of the cable occasionally led to failure due to overheating in the absence of flowing helium. Finally, any kinking of the fiber always resulted in breakage. Our operative technique is demonstrated and discussed further in the accompanying Video 1.

VIDEO 1. Brief video demonstrating the use of the OmniGuide CO₂ laser as an adjunct to resection of a large vestibular schwannoma via the translabyrinthine route. Gross-total tumor resection was achieved, and the patient's facial nerve function remained normal. Copyright Marc S. Schwartz. Published with permission. [Click here to view.](#)

Operative Time and Blood Loss

The median ETR for the OmniGuide patients was 150 minutes (mean 152.1 minutes, SD 61.8 minutes, range 64–333 minutes) and did not differ significantly from that of the control group (median 105 minutes, mean 129.7 minutes, SD 63.7 minutes, range 62–283 minutes), which had a similar range and variability in resection time. The median EBL was 300 ml (mean 351.2 ml, SD 155.9 ml, range 200–1000 ml), which is also not significantly different from that of the control group (median 300 ml, mean 338.9 ml, SD 113.4 ml, range 200–650 ml). No patient in either group required transfusion of blood products.

Facial Nerve, Hearing, and Complications

Facial nerve outcomes are detailed in Fig. 2. Preoperatively, only 1 patient (2.4%), who had a giant tumor, had

FIG. 3. **A:** Preoperative axial, enhanced T1-weighted MR image obtained in a patient who later underwent Gamma Knife radiosurgery for growing residual tumor. **B:** First postoperative MR image showing a small residual tumor. **C:** Later MR image demonstrating growth of a residual tumor.

facial weakness. This mild weakness improved to normal postoperatively. Immediately following surgery, 2 patients (4.9%) had new facial weakness. Ten additional patients developed some degree of delayed facial weakness in the days after surgery (total of 12 patients [29.3%]). Most of these resolved completely. Ultimately, 38 (92.7%) patients had normal facial nerve function. Two patients (4.9%) were left with H-B grade III function and 1 (2.4%) with H-B grade IV function.

Of the 4 patients undergoing attempted hearing preservation surgery with the use of the CO₂ laser via the RS route, 2 (50%) had preserved hearing at the preoperative level (1 each in class A and class B) and 2 lost hearing entirely.

One patient (2.4%) developed CSF rhinorrhea postoperatively, which was successfully treated by blind sac closure of the external auditory canal and direct packing of the eustachian tube.¹¹ This was the only complication. Excepting one nonagenarian patient, who was transferred to an inpatient rehabilitation facility, all patients (97.6%) were discharged from the hospital directly to home or a hotel.

Completeness of Tumor Resection and Need for Additional Treatment

In 40 of 41 OmniGuide cases, we carried out surgery with the goal of gross-total tumor resection but prioritizing facial nerve function. Based on intraoperative findings, gross-total tumor resection was achieved in 19 cases (47.5%). Radical subtotal tumor resection, defined as only small scraps of tumor left along the facial nerve, was obtained in 5 cases (12.5%). Subtotal or partial resection, defined as anything less, was obtained in 16 cases (40.0%).

All of these 40 patients underwent one or more postoperative MRI sessions at least 3 months after surgery. On MRI, no nodular enhancement was seen in 24 cases (60.0%), including 4 of the 5 cases deemed intraoperatively to have been radical subtotal resections and 1 case judged as a subtotal resection. Initial MR images obtained in the other 16 patients revealed residual enhancing masses measuring in the axial plane from 3 × 2 mm to 13 × 12 mm.

The median MRI follow-up for all OmniGuide patients was 52.3 months (mean 48.4 months, SD 22.5 months, range 11–81 months). For the 16 patients with residual enhancing masses, the median follow-up was 65 months (range 11–80 months). During follow-up, only 1 patient was found to have a growing residual tumor, which was treated with Gamma Knife radiosurgery (Fig. 3); 12 of

the remaining 15 patients have had at least 2 MR images showing stable residual tumors.

One patient, who was 95 years old, underwent planned debulking only. The tumor was a rapidly growing, large mass, and the patient had been rendered wheelchair and nursing-home bound due to symptoms of brainstem compression. Postoperatively, after a brief course of inpatient rehabilitation, the patient returned home and was living independently. Approximately 2 years postoperatively, she again developed symptoms consistent with brainstem compression. She refused further intervention or even imaging and died 30 months after surgery.

Discussion

Although never having gained widespread acceptance, the use of lasers for intracranial tumor resection has been described numerous times. Various lasers have been used, including CO₂, Nd:Yag, Argon, and KTP.^{2,9,14,16,19,24,35} More recently, laser energy has been used to thermally ablate intraaxial brain lesions under MRI guidance as a minimally invasive procedure.^{21,25}

Of those lasers used for microneurosurgical applications, the CO₂ laser has the major advantage of producing a beam within the infrared spectrum (10.6 μm). Water is opaque to light at this wavelength, and there is very little penetration of biological tissue, which consists mostly of water. CO₂ laser energy can be used very precisely with little thermal spread and little risk to adjacent structures compared with other lasers.²⁹ Unfortunately, CO₂ lasers cannot be used via fiber-optic transmission, since all possible materials used in the construction of fiber-optic cables are opaque at this wavelength as well.

In 1998, Fink reported efficient propagation of infrared energy through a hollow-core fiber lined with an omnidirectional dielectric mirror.¹² Among other applications, this led to the development of the OmniGuide CO₂ laser system. In this system, the mirror, which consists of alternating layers of high- and low-refractive index materials, is precisely calibrated to guide light generated by the CO₂ laser through the flexible fiber in a helium medium. Helium flowing through the fiber also acts as a coolant.

In recent years, the OmniGuide system has become well established for applications in head and neck surgery and gynecological surgery.^{1,15,27,33} Its use has also been reported in the treatment of various types of neurosurgical pathologies, including intracranial tumors, vascular malformations, laminectomy, cord untethering, and corpus callosotomy.^{4,6–8,18} A variety of fibers are available for

different applications, with the Beam Path Neuro-L fiber developed specifically for neurosurgery.

Vestibular Schwannoma Surgery: Safety and Efficacy

In this series, we have demonstrated that the OmniGuide laser is safe to use in the resection of medium and large vestibular schwannomas via both the TL and RS approaches. There were no complications attributable to the use of the laser. Of course, unlike metal instruments, lasers have the potential to act at a distance. While this allows for no-touch dissection techniques, it also raises the possibility of untoward effects. We took care to always point the laser handpiece toward the tumor's center when working through tissue in the belief that this provided the best assurance of safety. Keeping the depth of the resection cavity filled with saline solution and protecting the facial nerve with cotton patties provided further layers of security. The defocused configuration of the laser exiting the fiber also inherently made injury to distant structures less likely.

Interestingly, we found optimal use of the fiber-based CO₂ laser system in microsurgical resection of vestibular schwannomas to be very different from use of the CO₂ laser with articulating arms described by Robertson et al. in 1983.²⁶ In the earlier study, the laser was used as a focused beam at higher power to cavitate tumors. With the OmniGuide, the laser was used at close quarters, with the dissector nearly touching the tumor, as a cutting tool. At least within the power limitation of 20 W necessitated by the OmniGuide fiber, we found the laser to be quite limited in vaporization.

While we subjectively found the OmniGuide laser to be highly efficacious in vestibular schwannoma surgery, proving this quantitatively is problematic. Cranial nerve preservation and tumor control compare favorably to those in other reports.^{3,23,30,31} No-touch tumor resection near the porus may help avoid traction on nerves in this particularly delicate location. Use of the CO₂ laser may also encourage more complete tumor resection without threat to surrounding structures, leading to smaller residual tumor masses and less chance of regrowth.

We could not statistically demonstrate improvements in ETR or EBL when laser cases were compared directly with controls. The CO₂ laser is limited in hemostasis, and it is likely that there was no real benefit in terms of blood loss. On the other hand, it was our strong impression that use of the laser did facilitate more rapid tumor resection. As these were our initial OmniGuide cases, it is possible that there was a learning curve for both the surgeon and operating room staff charged with setting up and running the device. Possibly, at least at first, gains in time of tumor resection were offset by technical time losses. There was also wide variability within both the OmniGuide and control groups.

Utility of the CO₂ Laser for Vestibular Schwannoma Surgery

The utility of the OmniGuide laser must be balanced against its cost. The hospital cost for each fiber is well over \$1000. We have continued to use the OmniGuide CO₂ laser in all cases of very large and giant vestibular schwannomas. In these cases, we believe that there are gains in

operative time, and that these gains are probably sufficient to offset the device cost. Certainly, it is our clear perception that the laser reduces the surgeon's fatigue. With very large tumors, the surgeon reaches later stages of the case more energized and ready to face the challenge of facial (and cochlear) nerve dissection.

We also continue to use the laser on an ad hoc basis for tumors that are found intraoperatively to be very firm or otherwise resistant to cutting with scissors. Interestingly, this includes both solid and some cystic tumors. One might conclude that in these cases the usefulness of the CO₂ laser is inversely proportional to sharpness of available microscissors. The threat of laser use, and its associated cost, may convince a hospital to maintain sharp scissors in excellent condition on an ongoing basis.

The occurrence of device failures must also be factored into the economic equation of laser use. On several occasions, we experienced burnout of the OmniGuide fiber. In addition to the usual training of operating room personnel in the general use of lasers, staff must also be trained to handle fibers to avoid kinking and to keep dissector tips properly free of debris. Indeed, we have found that more regular use of the laser has reduced the rate of device failure and that failures tend to be more common after longer periods of nonuse or with unfamiliar staff.

Conclusions

The OmniGuide CO₂ laser is a safe and effective tool when used as an adjunct in the resection of medium to large vestibular schwannomas. This device is most useful as a cutting tool and as an aid to piecemeal tumor removal rather than as a tissue vaporizer. The benefit of the OmniGuide laser may be greatest for very large or giant tumors or for very firm tumors resistant to cutting using microscissors.

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Disclosures

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Author Contributions

Conception and design: Schwartz. Acquisition of data: Schwartz. Analysis and interpretation of data: Schwartz. Drafting the article: Schwartz. Critically revising the article: both authors. Reviewed submitted version of manuscript: Schwartz. Approved the final version of the manuscript on behalf of both authors: Schwartz.

Supplemental Information

Videos

Video 1. <https://vimeo.com/250124133>.

Previous Presentations

Preliminary data were previously presented in abstract form at the AANS Annual Scientific Meeting, Denver, Colorado, April 9–13, 2011.

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