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Clinical Study

Flexible CO_2 Laser Fiber in the Pediatric Airway

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Objective. Our institution has been using a novel flexible laser fiber in pediatric surgical airway procedures, which has been quite successful. The purpose of this paper is to present our preliminary experience in the treatment of pediatric airway lesions using this laser technique. *Methods.* A case series reviewing 40 patients undergoing 95 laser procedures is reported. Indications included removal of suprastomal granulation tissue, removal of granulation after laryngotracheal reconstruction, subglottic and supraglottic stenoses, recurrent respiratory papillomas, subglottic hemangioma, laryngeal cleft, and left main stem bronchus stenosis. Procedures were performed via microdirect laryngoscopy and bronchoscopy. *Results*. No complications including postoperative glottic webs, concentric scar formation, or airway fires occurred in any of the patients (after the series was completed, we did experience an airway fire. It was a flash flame that was self-limited and caused no long-term tissue injury) . *Conclusions*. The endoscopic application of a new flexible carbon dioxide laser fiber for management of pediatric airways lesions provides good outcomes in selected patients. Distal respiratory papillomas, subglottic stenosis, and granulation tissue are, in our experience, appropriate indications.

1. Introduction

We have begun using a flexible carbon dioxide laser fiber for airway pathologies in the pediatric population. Our case series thus far is the largest series in the pediatric literature to our knowledge. We have had success using this new laser technology in pediatric airways for subglottic and supraglottic stenosis, removal of granulation tissue, and even for distal tracheal recurrent respiratory papillomas. Our aim is to present our outcomes and provide insight into indications for use of this flexible fiber technology in pediatric airway cases.

To review, carbon dioxide (CO_2) lasers are so-named because they are produced by exiting carbon dioxide gas within a sealed tube producing a beam of infrared light with principal wavelength bands centered around 9.4 and 10.6 microns [1, 2]. With 60–70% of tissue being water, high absorption of CO_2 laser energy in water implies high absorption in tissue. This in turn translates into a superficial effect, as CO_2 laser energy is limited in its spread within tissue. Thus, the CO_2 laser has a superficial action limited to the upper layers of tissue, leading to minimal damage to adjoining tissue volume [1, 2].

This novel laser is a CO_2 laser which institutes a BeamPath fiber system. This fiber system utilizes a photonic band gap mirror lining, which guides light through a hollow core via a hand-held flexible fiber. This hollow core delivers a constant flow of inert gas that clears the surgical field of blood and debris, improves coagulation, and minimizes tissue heating. This overcomes the previously limited CO_2 lasers which strictly entailed "line-of-sight" surgical procedures. This particular laser is activated with a footswitch, which delivers CO_2 energy ranging up from 1 to 25 watts, although we used a range of 1.5–14 watts in our series. The fiber can be used with a hand piece or through a flexible or rigid bronchoscope.

2. Methods

We performed a review of all pediatric patients with airway pathologies who were treated using the flexible CO_2 laser fiber system over the last 34 months by the senior author (G. P. Digoy). This laser was used in a total of 40 patients from January 2007 to October 2009. A total of 95 procedures were performed in that time period. The average age was 4.15 years with a range of 7 months to 17 years of age. In the following series, we used a rigid bronchoscope through which the flexible laser fiber was passed for distal airway pathologies including main stem bronchial stenosis, removal of granulation tissue after laryngotracheal reconstruction (LTR), and distal tracheal respiratory papillomas (Figures 2 and 3). A hand piece was used for more proximal lesions including subglottic stenosis and subglottic cyst excisions. This laser requires the use of an inert gas, usually helium, which is funneled through the fiber to ensure a clear pathway through its core and to keep the system cool. The inert gas used in this series was generally helium, though occasionally nitrogen was used. The flow rates were measured in psi and were usually in the range of 60–70. When the laser was used below the carina, the flow was decreased to around 15–20 psi in order to reduce the risk of air emboli.

The laser was used at a setting ranging from 1.5 to 8 watts initially, though more recently a higher setting of 10–14 was used. Bulkier lesions have required higher wattage in order to ablate the tissue more rapidly. The goal was always to use the lowest possible wattage to achieve the desired effect. All procedures were performed under general anesthesia, generally with the child breathing spontaneously.

The purpose of this study is to review an early experience of this instrument's applicability in certain airway pathologies in children.

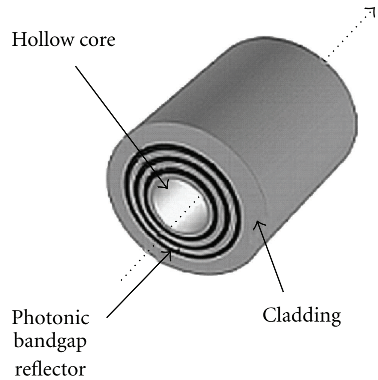


Figure 1: Micron thick layers of alternating glass and polymer form a photonic bandgap mirror which guides CO_2 laser energy through the fiber's hollow core.

3. Results

Laser intervention was applied for various lesions. Twenty-eight patients were male, and 12 patients were female. The most common indication in our series was the removal of suprastomal granulation tissue in 16 tracheostomy patients ranging from 11 months to 14 years of age. Tracheostomy had been performed for airway compromise, congenital glottic lymphatic malformation, and obstructive sleep apnea (Table 1).

The next most common indication was the removal of scar and/or granulation tissue after LTR ($n = 8$) in children ranging from 17 months to 13 years of age. The remaining pathologies included subglottic stenosis ($n = 8$), supraglottic stenosis ($n = 2$), recurrent respiratory papillomas of distal trachea ($n = 1$), soft palate papilloma ($n = 1$), subglottic hemangioma ($n = 1$), subglottic cyst ($n = 1$), laryngeal cleft ($n = 1$), and left main stem bronchus stenosis ($n = 1$). Procedures were performed via microdirect laryngoscopy and bronchoscopy. Retrospective review did not reveal any major or minor complications caused directly from the use of the flexible CO_2 laser fiber.

It was found that bulkier lesions required higher wattage in order to ablate the tissue more effectively. In this series, it was the goal of the senior author to use the lowest possible wattage to achieve the desired effect. The laser was used at a setting ranging from 1.5 to 8 watts initially, though more recently a higher setting of 10–14 has been used. It was found in this series that at levels below 7 watts the tissue was less responsive, and too much time was required to effectively ablate tissue. Rarely was there need to increase the wattage above 10 watts. Most lesions responded well to a power range of 7–10 watts.

No complications including postoperative glottic webs, concentric scar formation, or airway fires (after the series was completed, we did experience an airway fire. It was a flash flame that was self-limited and caused no long-term tissue injury) occurred in any of the patients during or after laser surgery.

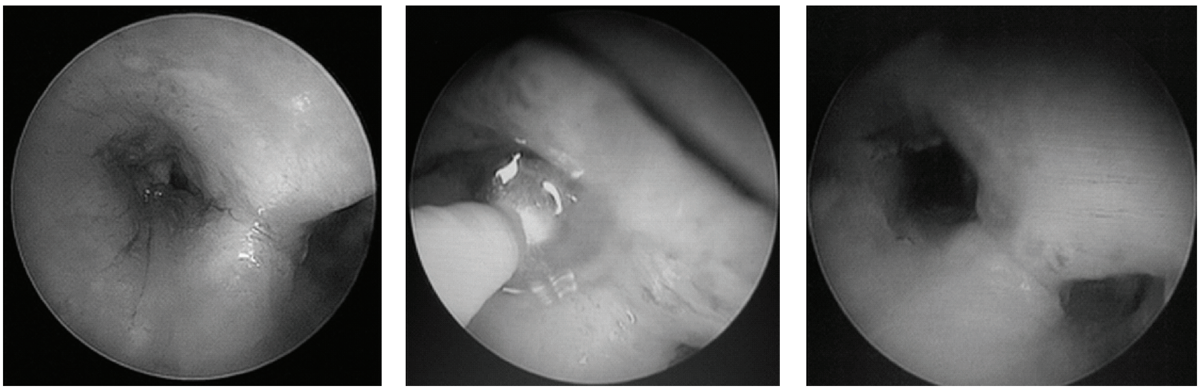
4. Discussion

The use of lasers in otolaryngology is increasing due to its precision, ablative and coagulative properties, and minimal thermal damage to adjacent healthy tissue. Different types of lasers have been used including potassium-titanyl-phosphate (KTP), carbon dioxide, neodymium-yttrium-aluminum-garnet (Nd:YAG), argon, and pulsed dye lasers which have been increasing in use since first used in the adult airway in 1972 [3]. Since then, use in the pediatric airway has become frequent. Clinically, lasers have been found to be a helpful tool for a myriad of pathologies such as choanal atresia, recurrent respiratory papillomas, laryngomalacia, saccular cysts, glottic scarring, subglottic stenosis, and subglottic hemangiomas [3, 4]. Laser light delivered via an optical fiber, however, until recently was only optimized for KTP and Nd:YAG lasers. The more recent development of a flexible CO_2 laser fiber has been reported in treatment of laryngotracheal amyloidosis in one adult and suprastomal tracheal fibromas in children under age 7 [1, 5].

CO_2 laser energy has been used in the field of otolaryngology since the 1970s for its precision and control over penetration depth into tissue [1]. Until recently, its delivery mechanism posed a distinct disadvantage to the surgeon in that they had to use a microsuspension laryngoscope with an articulated arm, making exposure to target tissue difficult and sometimes impossible. In 2006, a Massachusetts

(a) (b) (c)

Figure 2: Intraoperative photograph of subglottic scar banding after laryngotracheal reconstruction (a). Use of flexible CO_2 laser (b), and 3 months postoperative subglottic view (c).



(a) (b) (c)

Figure 3: Intraoperative photograph of left main stem stenosis before treatment (a). Balloon dilation after flexible CO_2 laser treatment (b) with resultant left main stem bronchus patency (c).

Institute of Technology invention enabled for the first time transmission of the preferred CO_2 wavelength through a flexible fiber. This fiber has the maneuverability and diameter requirements to access lesions and locations that would not be possible using direct visualization [1, 2]. The flexible fiber consists of a mirror surrounding a hollow core (Figure 1). The mirror reflects CO_2 laser energy along the hollow core of the fiber. Inert gas, usually helium, is funneled through the fiber to ensure a clear pathway through its core. This current is helpful in firing accuracy in that it creates a "target dimple" in the tissue of concern. It is also important to keep the fiber from overheating. The fiber (150 mm length, 1.2 mm outer diameter, 320 μm spot size) was passed down a rigid bronchoscope to gain access to target tissue in this study.

This paper is limited as it does not measure the cost-effectiveness of this laser nor does it compare flexible CO_2 laser to other techniques/instruments. This paper was intended to present a preliminary experience of this instrument's applicability in certain airway pathologies. It is important that certain disadvantages be considered in the use of this device.

One of the main disadvantages is the cost of the fiber. Our hospital is charged approximately 1000 dollars per fiber, and in some cases multiple fibers were necessary. We found that as the surgeon and operating room staff gained experience with this instrument, fewer fibers were used per case. It is a concern that this initial learning curve could be quite costly.

In cases of indurated suprastomal scar tissue, the senior author's (G. P. Digoy) practice is to first attempt transstomal removal of the mass as this is an established and cost-effective method to remove this type of lesion. When the suprastomal tissue is still in its granulomatous (soft/friable) stage, the senior author's (G. P. Digoy) preference is to use the microdebrider over the flexible CO_2 laser or the transstomal approach. However, in cases when the suprastomal mass is indurated and more sessile, especially when the stoma is deep, we find that the flexible CO_2 laser can remove the lesion endoscopically with minimal bleeding and surrounding tissue injury and may be superior to both the transstomal method and the microdebrider.

In cases of indurated subglottic scar tissue, the senior author (G. P. Digoy) has used the line-of-site laser and

Table 1: Patient demographics.

Pt no.	Age, sex	Diagnosis	No. of surgeries	Watts
1	22 mo, F	Suprastomal granulation	1	7
2	18 mo, M	Suprastomal granulation	1	7
3	19 mo, F	Subglottic hemangioma	1	7
4	19 mo, M	Suprastomal granulation	3	7
5	11 mo, M	Suprastomal granulation	5	2–7
6	5, M	Post-LTR granulation	5	2–10
7	3, M	Recurrent respiratory papillomas	23	7
8	20 mo, M	Suprastomal granulation	1	7
9	17, M	Subglottic stenosis	1	10–12
10	7, F	Suprastomal granulation	1	7
11	3, M	Suprastomal granulation	1	10–14
12	7, F	Subglottic stenosis	1	7
13	6, F	Recurrent respiratory papillomas	1	7
14	4, F	Post-LTR granulation	1	7
15	3, M	Suprastomal granulation	5	10
16	2, M	Suprastomal granulation	1	7
17	2, M	Subglottic stenosis	3	7
18	17 mo, M	Post-LTR granulation	7	7–10
19	9 mo, M	Main stem bronchus stenosis	1	7
20	20 mo, M	Suprastomal granulation	1	7
21	7 mo, M	Laryngeal cleft	1	1.5
22	7, F	Supraglottic stenosis	1	2
23	3, F	Subglottic stenosis	1	7
24	13, M	Suprastomal granulation	1	7
25	3, M	Post-LTR granulation	1	7
26	2, M	Subglottic cyst	1	7
27	2, M	Suprastomal granulation	1	7
28	8, M	Subglottic stenosis	3	7
29	5, F	Post-LTR granulation	1	7
30	3, M	Subglottic stenosis	1	10
31	6, M	Suprastomal granulation	1	7
32	14, M	Suprastomal granulation	1	7
33	2, M	Suprastomal granulation	1	7
34	2, F	Subglottic stenosis	1	7
35	1, M	Subglottic stenosis	1	7
36	21 mo, F	Post-LTR granulation	5	6
37	4, F	Post-LTR granulation	4	7
38	13, M	Post-LTR granulation	2	5
39	3, M	Suprastomal granulation	2	7
40	8 mo, M	Supraglottic stenosis	1	10
Total	28 M, 12 F		95	

the flexible CO_2 laser. Below the glottis, the flexible CO_2 laser appears to provide superior visibility that becomes more pronounced the more distal the lesion. The limitation of the flexible CO_2 laser is the absence of an aiming beam. However, the helium often creates a small tissue indentation that reveals where the laser will fire. This laser changes the focus of the beam by moving closer or farther from the lesion, requiring some time for the surgeon to become acclimatized. Furthermore, its advantage over the line-of-site CO_2 laser is its ability to aim around corners, access difficult to reach areas, and directly approach the lesion with the bronchoscope without the need for vocal cord spreaders or other instruments. It is the senior authors' preference to use line-of-site CO_2 laser for most supraglottic lesions.

Another challenge in the use of this laser is the displacement of oxygen by the helium used to cool the fiber. This problem can become more significant in children with chronic pulmonary disorders. A number of cases required that laser use be intermittently halted and the helium (or nitrogen) be disconnected in order to allow the child's oxygen saturation to remain above 90%. We found that it is a challenge knowing exactly how much oxygen is actually being delivered due to this dilution effect. Our goal was to always keep the oxygen level being delivered at or below 40% in order to reduce the risk of an airway fire. Because the extent of dilution of oxygen by the helium (or nitrogen) is not well known, the anesthesiologist and the surgeon need to be cognizant of this dilemma and realize that in some patients there may be a need to disconnect the helium (or nitrogen) as oxygen saturation begins to decrease.

The use of this instrument is not advised distal to the carina as the cooling gas (helium/nitrogen) could produce an air embolism. On rare occasions when no other options were available, we used this fiber distal to the carina by turning the flow of gas down from around 70 to 15 psi and reducing the wattage to 5 or less.

Another challenge in the use of this laser fiber is the ability to accurately place the fiber in the rigid bronchoscope for distal airway lesions. We find that it is preferable to have a tight fit of the fiber in the bronchoscope; the surgeon will need to use a bronchoscope and telescope combination that decreases the amount of excess space in the lumen of the bronchoscope. With the fiber tight in the lumen of the bronchoscope, the surgeon can then rotate the bronchoscope (keeping the camera head in the upright position) with subsequent rotation of the fiber. As the fiber rotates with the bronchoscope, the surgeon can fire the fiber more precisely. This maneuver requires experience and can be perfected over time.

The closer the fiber is to the lesion, the more focused the energy will be. Moving the fiber away from a lesion has the advantage of better coagulation if needed. However, once blood sits between the laser and the lesion, the blood absorbs much of the energy and char is produced. For more vascular lesions prone to bleeding, we use a combination of 1 : 100,000 epinephrine and frequent suction to reduce this effect. We have also found that the buildup of burned tissue and/or blood around the tip of the fiber may lead to fiber malfunction.

In more recent procedures, it has been found that increasing our wattage to 10–14 did not lead to increased complications. For more extensive lesions, the greater wattage had the advantage of decreasing the time needed to ablate the lesion. However, this increase in wattage appears to shorten the duration of the fiber. When bulkier lesions were being treated, we found that more than one fiber was often required.

Finally, we emphasize our concern that the use of this product may add a significant increase in cost to the patient and to our health care system. In our use of this instrument, we made an effort to use this product only when suitable less expensive options were not fitting or available for use.

5. Conclusion

The endoscopic application of the flexible CO_2 laser fiber for the management of pediatric airways lesions (proximal and distal) provides good outcomes in selected patients. Distal tracheal respiratory papillomas, subglottic stenosis, main-stem bronchial stenosis, suprastomal granulation tissue posttracheostomy, and scar tissue after laryngotracheal reconstruction appear to be suitable indications. Though this instrument is expensive and should not replace other established and more cost-effective alternatives, its flexibility, accuracy, and minimal adjacent tissue damage make this laser useful in the management of certain airway lesions in children.

Abbreviations

CO_2:	Carbon dioxide
LTR:	Laryngotracheal reconstruction
KTP:	Potassium-titanyl-phosphate
Nd:YAG:	Neodymium-yttrium-aluminum-garnet.

Acknowledgments

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