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D.J. Verret

Arneya Jategaonkar

Samuel Helman

Sameep Kadakia

Arash Bahrami

Philadelphia College of Osteopathic Medicine

See next page for additional authors

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Authors

D.J. Verret, Arneya Jategaonkar, Samuel Helman, Sameep Kadakia, Arash Bahrami, Eli Gordin, and Yadranko Ducic

Holmium Laser for Endoscopic Treatment of Benign Tracheal Stenosis

D. J. Verret¹ Ameya Jategaonkar² Samuel Helman² Sameep Kadakia² Arash Bahrami³
Eli Gordin⁴ Yadranko Ducic⁵

¹ Department of Facial Plastic Surgery, Innovations Facial Plastic Surgery, Plano, Texas, United States

² Department of Otolaryngology, New York Eye and Ear Infirmary, New York, New York, United States

³ Department of Otolaryngology, Philadelphia College of Osteopathic Medicine, Philadelphia, United States

⁴ Department of Otolaryngology, SUNY Downstate Medical Center, Brooklyn, New York, United States

⁵ Department of Facial Plastics, Otolaryngology and Facial Plastic Surgery Associates, Fort Worth, Texas, United States

Address for correspondence Yadranko Ducic, MD, Department of Otolaryngology, New York Eye and Ear Infirmary, 310 East 14th St., 321 East 13th Street, New York, NY 10003, United States (e-mail: yducic@sbcglobal.net).

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Abstract

Introduction Laryngotracheal stenosis is a difficult problem with varied etiology and various treatment options. The holmium laser represents another tool for the treatment of benign tracheal stenosis.

Objectives To determine the utility of holmium laser treatment for benign tracheal stenosis with regards to safety and efficacy.

Methods This was a retrospective case study examining patients with benign tracheal stenosis from 1998–2016 who underwent holmium laser treatment. Determining the safety of this procedure was the primary goal, and complications were monitored as a surrogate of safety.

Results A total of 123 patients who underwent holmium laser treatment for benign tracheal stenosis were identified. In total, 123 patients underwent 476 procedures, with follow-up ranging from 1 month to 14 years. No intraoperative or post-operative complications were identified as a direct result of the use of this particular laser.

Conclusions The holmium laser is an effective and safe laser to use for tracheal stenosis treatment. It is a contact laser with a short acting distance, which reduces the risk of injury to distal airway structures. Given the favorable experience reported here, the holmium laser should be considered when tracheal surgery is attempted.

Keywords

- ▶ tracheal stenosis
- ▶ holmium laser
- ▶ endoscopic surgical procedure

Introduction

Albert Einstein laid the theoretical foundation for lasers in 1917 when he predicted that as light passed through a substance, it could stimulate the emission of additional photons.¹ In 1954, Charles Townes and Arthur Schawlow invented the precursor to the laser in the microwave spectrum, the maser (microwave amplification by stimulated emission of radiation). In 1958, Schawlow and Townes pro-

posed that this could be translated into the visible spectrum.² Theodore Maiman did just this when he utilized a ruby to construct the first laser in 1960.³ Lasers quickly began to be used within medicine, with early work described by Noyori, Ritter, Campbell, and Koester in retinal surgery.^{4,5} Today, there is a wide variety of lasers and applications of them within medicine. Lasers are used today in surgical fields ranging from ophthalmology to urology and otolaryngology.

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Carbon dioxide (CO₂) lasers use CO₂ gas as the gain medium, and have a wavelength of 10.6 microns (10,600 nm), placing the CO₂ laser radiation in the infrared spectrum. With this wavelength, the CO₂ laser is preferentially absorbed by water. The CO₂ laser creates a characteristic wound of vaporized and thermally necrosed tissue 100 microns wide. As such, surgically, the laser can be used to “cut” tissue, and is frequently utilized in surgery of the upper aerodigestive tract.^{6,7} There are reports of utilization of the CO₂ laser for repair of subglottic and tracheal stenosis.⁸ However, some of the limitations of the CO₂ laser hinder its use in surgery of the distal airway. Given that the CO₂ laser is almost exclusively absorbed by water, its function is limited to wet environments. Furthermore, the CO₂ laser is ill-suited for hemostasis, as anything but minimal bleeding can impede laser surgery. The laser coagulates blood as it appears, producing an expanding mass of charred blood product. The CO₂ laser is also a “line of sight” laser, and the laser pulse will travel until it is absorbed by tissue or another protective material (such as a saline-soaked sponge). As such, there is risk of damage to distal structures if the laser is not aimed correctly. The use of a flexible fiber allows for better control and aiming of the CO₂ laser. Finally, there is significant risk of airway fire, though proper precautions can reduce this risk.^{9–11}

The holmium laser utilizes an yttrium aluminum garnet (YAG) that has been impregnated with holmium as the gain medium, and produces radiation with a wavelength of 2.1 microns. The laser functions as a pulsed laser, and can be delivered with a flexible quartz fiber with side or end firing capabilities. The laser can be used in either contact/non-contact modes, and penetrates 0.5 mm regardless of tissue pigmentation. The holmium laser also has a short distance of action from its point of emission from the fiber. As such, there is a reduced risk of inadvertent injury to distal structures. Another major advantage of the holmium laser is that it is capable of delivering energy to the target tissue through air, saline, or blood. Thus, it is particularly effective in wet environments such as the tracheobronchial tree. The ease of use with a fiber also enables this laser to be used endoscopically with flexible scopes.

The holmium laser has been extensively used in urology.¹² Within otolaryngology, there are reports of its use in endoscopic sinus surgery, dacryocystorhinostomy, and in the treatment of choanal stenosis.^{13–16} While a larger series of pulmonary use of the holmium laser exists,¹⁷ the exploration of this laser in the distal airway has been largely limited to animal studies.¹⁸ Reporting our favorable experience, we present the largest series in the literature focusing on the use of the holmium laser for the treatment of benign tracheal stenosis.

Methods

Institutional review board (IRB) approval was granted prior to initiating the study. A retrospective chart review was performed on all patients who underwent holmium laser excision of tracheal stenosis between 1998 and 2016. A total

of 123 patients were identified, and no patients were excluded. Patients ranged in age from 18 to 89. The cohort was composed of 73 males and 50 females. Follow-up ranged from 1 month to 14 years. The reasons for stenosis included granulation tissue around the tracheotomy tube, idiopathic tracheal stenosis, gunshot wound, Wegener granulomatosis, or stenosis after prolonged intubation.

Technique

Patients who were identified with tracheal stenosis in acute airway distress or those who preferred not to undergo tracheal resection were given the option of undergoing holmium laser excision of their tracheal stenoses. Once informed consent was obtained and the options were explained to the patients, they were taken to the operating room. If a previous tracheotomy had been placed, the patients were anesthetized, and the tracheotomy tube replaced with a laser-proof endotracheal tube for ventilation purposes. At this point, the oxygen concentration was decreased to room air until the oxygen concentration in the lungs was $\leq 30\%$. Suspension laryngoscopy was then performed with intermittent ventilation, the saturation not falling below 90%. The endotracheal tube was removed, and the endoscope with laser fiber running through the instrument port was inserted through the visualized endolarynx. Proper laser safety was undertaken, and the laser was started at a setting of 10 Joules, 8 pulses per second. Excision was undertaken under apneic technique until the anesthesiologist requested the endotracheal tube be reinserted due to the patient's oxygen saturation decreasing. This process was continued until the area of ablation was completed. In cases of tracheal stenosis, care was taken to only ablate half of the diameter of the lumen to attempt to prevent circumferential scarring. Any significant char formation was removed with microforceps introduced via the bronchoscope at the completion of the procedure. ► **Fig. 1** and ► **Fig. 2** each show an image of the equipment used in this procedure, including a holmium laser, bronchoscope cart, and laryngoscopy set.

Results

The 123 patients underwent a total of 476 procedures. No intraoperative complications were identified, including pneumothorax, hemorrhage, tracheal wall tear, distal airway damage, airway fire, or injury to the lips, teeth, or gums. Our range of procedures per patient was between 1 and 34 (average: 3.87). The patient who underwent 34 procedures was a 20-year-old patient who also underwent 2 nitinol stent placements in addition to his multiple holmium laser procedures. He had failed other treatment modalities, including CO₂ laser and Argon laser in the past. The average length of the stenotic segment was 2.5 cm, and the average initial obstruction percentage was 80% of the luminal diameter. A total of 18 patients went on to receive tracheal resections during the follow-up period. These were patients that were felt to have collapse of the tracheal cartilage into the airway over a broad segment. Following initial evaluation under anesthesia with holmium laser resection of any amenable



Fig. 1 Bronchoscope cart and holmium laser equipment displayed.



Fig. 2 Table with laryngoscope set used for suspension prior to the use of the holmium laser.

stenosis to temporize them, this subset of patients was returned to the operating room for definitive surgical resection. Only one patient required postoperative intensive care unit monitoring due to underlying medical conditions; otherwise, patients were either discharged home the same day or were admitted to a telemetry floor for 23 hours of observation (only 27 treatments were performed with postoperative monitoring for 23 hours).

Discussion

The holmium laser has grown in popularity over the years, and it has seen extensive use within the field of urology. However, its exploration in otolaryngology has remained limited to case reports and laboratory studies. Gleich reported the most varied experience with the holmium laser when he reported on 37 procedures including endoscopic sinus surgery, dacryocystorhinostomy, treatment of choanal stenosis, ablation of obstructive tracheopathia osteoplastica, and removal of a sphenoid sinus mucocele without any complications related to laser use.¹³ Fong reported several cases of distal airway (tracheobronchial) use of the holmium laser in a report of 26 pediatric patients undergoing 42 airway procedures.¹⁹ Fong's experience was over a broad range of procedures, including correction of choanal atresia, endoscopic sinus surgery, tracheal granuloma excision, tracheal web excision, subglottic stenosis excision, hemangioma of the tongue excision, and oral cavity papilloma excision. Building on this experience, we report our 18-year experience with the holmium laser in treating tracheal stenosis.

Laryngotracheal stenosis is a difficult and heterogeneous problem with varied presentation, severity, and etiology. The incidence of tracheal stenosis is not precisely known, with only a recent estimate of 4.9 cases per million persons per year by Nouraei et al in the literature.²⁰ Various techniques have been employed and reported in the literature, ranging from CO₂ laser incisions and dilations to stent placement and open surgical techniques.^{21,22}

The authors feel that a large majority of technique usage and outcome is highly operator-dependent. Training with certain techniques and the success with them is highly dependent on the frequency with which they are employed. More so, it is certainly possible to treat this condition successfully with other lasers, endoscopic techniques, or even more invasive open procedures. However, despite whether or not the practitioner chooses to perform all procedures, it is important to have a working knowledge of the indications, contraindications, advantages and drawbacks prior to making an informed decision for the patient. A full discussion of the aforementioned techniques is beyond the scope of this paper, but the reader is encouraged to consult the literature for a thorough understanding.

The holmium laser offers several advantages compared with other options for the management of tracheal stenosis. Many of the patients who were successfully treated with the holmium laser had failed previous balloon dilation. The holmium laser also has advantages over other lasers. As discussed before, the CO₂ laser has been used in surgery of

the tracheobronchial tree.^{23,24} However, until recently, the CO₂ laser could not be used with a flexible fiber, and remained a line of site laser. Therefore, it is often necessary to use rigid endoscopes while aiming the laser from a binocular microscope at a distance. As the laser is effective at great distances, if it is not fired correctly or reflects off of the metal endoscope, laser damage can occur away from the desired site of action. In addition, some patients have anatomy that is not conducive to the placement of long rigid endoscopes, and thus, utilization of a CO₂ laser may be impossible in these cases. Another limitation of the CO₂ laser is its poor functionality in a bloody field, as identified by Shapshay.²⁵ For use in the tracheobronchial, tree the holmium laser has several advantages.

Since the holmium laser can be sent through a fiber-optic delivery system, it does not require a direct line of sight for use. It may be used with flexible endoscopes and placed through large endotracheal tubes if necessary. Our standard practice is to use microsuspension laryngoscopy before the introduction of a flexible fiber-optic endoscope into the trachea, though we have placed the endoscope through an intubating laryngeal mask in difficult cases. We find that this increases the flexibility and control at the level of the distal bronchoscope. The use of endoscopic equipment also makes photodocumentation possible. In addition, it allows us to reach bronchial areas of obstruction as well. The holmium laser can also be used in both a contact and non-contact mode, though in the non-contact mode, the maximal effective distance of the laser is only 5 mm. This short distance of action limits unwanted firing of the laser into normal tissue. We always use it in the contact mode. In addition, in vitro testing confirms that the holmium laser, though attenuated through biologic liquid medium, can be used in wet fields.²⁶ It is used in ureters for calculi, and is useful in the respiratory tract with mucus secretions. The holmium laser technique is also relatively easy to use, as residents were capable after an average of three cases. The holmium laser is a versatile tool that we have used for submucosal resection of turbinates, and it is already widely used by other surgical disciplines. It is readily available in the hospitals where the senior author (Y.D.) practices due to its wide use by our urology colleagues.

The safety of the holmium laser has been shown previously, and has been borne out in our study.^{13,19,25} No patients suffered vocal cord damage or changes beyond those considered to be from intubation. All patients with post-intubation vocal cord changes had returned to their baselines within one month. No patients who underwent holmium laser treatment of their stenoses developed longer segments of stenosis. As with any laser, airway fire is a concern.^{27,28} It is also important not to overlook any electrocautery as a source of ignition.²⁹ Risk of airway fire can be further minimized by maintaining a low fraction of inspired oxygen (FiO₂). Oxygen concentrations below 27% can minimize fire risk. The use of a laser-proof tube further reduces the risk of airway fire. The short distance of action of the holmium laser also reduces the risk of combustion. Ultimately, with proper precautions, airway fires can essentially be eliminated, as evidenced in the literature and demonstrated in our study.³⁰

While our study does demonstrate the efficacy of the holmium laser in a large group of patients, it does have limitations. The generalizability of our study is limited, as it represents the experience of a single surgeon. Furthermore, the varying follow-up in this study limits our ability to evaluate the long-term results of holmium. Ultimately, our study shows that the holmium laser is a safe tool for the treatment of tracheal stenosis, and warrants further investigation as a tool in airway surgery.

Conclusions

Given its ease of use, versatile application, and low complication rate, the holmium laser can be a feasible tool in the treatment of benign tracheal stenosis.

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