Effective treatment of post-intubation subglottic stenosis in children with holmium laser therapy and cryotherapy via flexible bronchoscopy

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INTRODUCTION

Subglottic stenosis (SGS) is the narrowing of the proximal trachea within the subglottic region. When severe, it can lead to wheezing, stridor, dyspnea, dysphagia, and dysphonia. Endotracheal intubation is the most common cause of SGS. The incidence of post-intubation SGS is 6.63%–17.94%. As compared with open surgery, endoscopic therapies have benefits that include minimal invasiveness, reversibility, shorter operative time, and shorter hospital stay. These endoscopic techniques include balloon dilatation, laser therapy, cryotherapy, argon plasma coagulation, and T-tube and stent placement. For post-intubation SGS in children, there is no universally recommended endoscopic therapy and the various techniques are tailored on a case-by-case basis. Balloon dilatation with adjuvant supportive therapy is the most commonly used method, however, the efficacy is variable with success rates ranging from 40% to 82%.

The holmium laser delivers light energy at a wavelength of 2140 nm. At this wavelength, it is almost completely absorbed by water within 0.4 mm of the laser fiber tip. Holmium laser therapy at time of flexible bronchoscopy is a rarely performed modality. However, in pediatrics, the holmium laser exhibits effective hemostasis, precise ablation, and can be transmitted effectively through the flexible scope. It is the safest laser to use in pediatric interventional treatment. Cryotherapy, on the other hand, is a more common bronchoscopic modality. Cryotherapy is a safe and effective method for the treatment of airway obstruction, with less risk than laser therapy of causing cartilaginous injury. In fact, it can relieve thermal damage caused by laser treatment. We intend to assess the safety and feasibility of holmium laser combined with cryotherapy by flexible bronchoscopy for treatment of post-intubation SGS in children.

METHODS

Patients

This is a prospective study involving all patients of post-intubation SGS seen at the Interventional Pulmonology Department of Beijing Children’s Hospital between July 2014 and December 2016, whose parents refused to accept the alternative standard treatment at our hospital of tracheotomy and balloon dilation under direct laryngoscopy. Patients with congenital SGS, tracheomalacia, subglottic trauma, subglottic infection and SGS secondary to autoimmune disease were excluded.

The diagnosis of post-intubation SGS was made by the following criteria: 1) definite medical history of endotracheal intubation; 2) signs and symptoms of...
dyspnea; 3) multidetector CT and three-dimensional airway reconstruction showing thickening of subglottic tracheal wall without pressure from extratracheal tissue; and 4) microlaryngoscopy or bronchoscopy confirming visible evidence of SGS. The Cotton-Myer grading systems for SGS were applied. Airway–Dyspnoea–Voice–Swallow (ADVS) Scale, and Activity of Daily Living (ADL) Scale (Supplement 1) were for quality of life assessment.

Procedure

Treatments were performed by the same surgeon with experience in endoscopic procedures in the pediatric airway. The equipment for the procedure included flexible bronchoscopes (BF-P260F with 4.0 mm OD or BF-XP260F with 2.8 mm OD, Olympus Co., Tokyo, Japan), holmium laser therapeutic apparatus (Output Power: 30 W, laser wavelength 2140 nm, Dahua Co., Wuxi, China), cryotherapeutic equipment (cryoprobe with 1.9 mm OD, refrigerant CO2, ERBE, Germany), and a PTA balloon catheter (4 mm × 15 mm, Medtronic Inc, Italy).

General intravenous anesthesia was performed under the care of a certified anesthesiologist and was adjusted according to patients’ general condition and degree of SGS. Under general anesthesia, patients with Cotton-Myer grade I–III stenosis were given mechanical ventilation with laryngeal mask airway (LMA). In patients with Grade IV, tracheotomy was performed before treatment and continuous ventilation was performed through a tracheotomy tube to ensure the safety of the procedure.

Holmium laser was used to remove granulation and scar tissue, generally performed over 1 or 2 sessions. During laser treatment, we lowered the fractional inspiratory oxygen concentration below 40% to avoid airway fire. We set the output power of holmium laser as 8–10 W. Following laser treatment, CO2 cryotherapy was used on the treated stenotic region to prevent thermal damage. Cryotherapy was operated for 20–30 seconds and then rewarmed gradually per cycle. Bronchoscopic re-examination and laser/cryotherapy treatment was performed every 1–2 weeks. For Grade IV, we used balloon dilatation first. The balloon (4 mm × 15 mm) was inflated to 14 atmospheric pressure for 30 seconds and repeated twice.

Adjuvant exogenous inhaled glucocorticoids and antibiotics were given to help prevent restenosis.

Follow-up

Follow-up included observation for any worsening respiratory symptoms bronchoscopy for endoscopic visualization. In general, follow-up evaluations were conducted once a week in first month, then at 3 months and 6 months. ADVS scale and ADL were recorded and analyzed.

Outcome measures

We collected clinical data before and after treatment. The severity of SGS, associated symptoms, degree of hypoxia, endoscopic appearance, complication rates, ventilation mode, partial pressure of arterial carbon dioxide (PaCO2), number of procedures, duration of the treatment course, ADVS Scale, and ADL Scale were recorded and analyzed. Clinical cure was defined when a patient exhibited no laryngeal stridor or hypoxia, successful tracheotomy tube decannulation, dramatic improvement in SGS grade, and no development of restenosis on follow-up visits. Clinical improvement was defined as improvement in symptoms and SGS grade, but tracheotomy tube decannulation was unsuccessful or the patient required supplemental intermittent oxygen. Clinical failure was defined as no improvement in symptoms and SGS grade, unsuccessful tracheotomy tube decannulation, and the need for continuous oxygen.

Statistical analysis

The statistical analysis was performed using SPSS 22.0. The differences of PaCO2 before and after treatment were compared by paired samples t test. A value of $P < 0.05$ was considered statistically significant.

Ethics

This study was approved by the Ethics Committee at Beijing Children’s Hospital. Informed consent was obtained prior to all procedures.

RESULTS

Sixteen patients with post-intubation SGS were treated with holmium laser and cryotherapy by flexible bronchoscopy. Fifteen patients completed the full treatment course and achieved clinical cure. One patient (with Grade IV stenosis) achieved clinical improvement, but was lost to follow-up (Table 1). There were no clinical failures. There were eight males and eight females, with ages ranging from 2 months to 12.25 years old. Ten patients (62.50%) were between 0–3 years old, four patients (25.00%) were between 3–6 years old, and two patients (12.50%) were greater than 6 years old. Etiologies regarding need for prior intubation included seven cases (43.75%) due to severe pneumonia and respiratory failure, one case (6.25%) due to viral encephalitis, five cases (31.25%) due to surgery, two cases (12.50%) due to a traffic accident injury, and one case (6.25%) due to airway burn. Before the treatment, patients had varying degrees of stridor, retraction, dyspnea, dysarthria, and dysphagia, reflected by the ADVS scale. The ability of daily life decreased in patients reflected by ADL scale (> 3 years old). According to the Cotton-Myer grading system, three cases were Grade II, 12 cases were Grade III, and one
case was Grade IV. According to the McCaffrey grading system, eight cases were Stage 1, two cases were Stage 2, and six cases were Stage 3. In all 16 patients, 10 patients (62.5%) needed respiratory support. Among them, two patients ventilated via tracheal intubation, two patients via tracheostomy tube, one patient via LMA and five patients by nasal continuous positive airway pressure (NCPAP).

After the first procedure, respiratory symptoms significantly improved in all patients. Immediately after treatment, all patients exhibited significant improvement in lumen patency on endoscopic view, complete resolution of hypoxia, and improvement in voice quality and swallowing function. At the end of treatment, the ADVS scale reached normal levels in all patients following completion of treatment. They didn’t need any respiratory support. Tracheostoma was closed smoothly in patients with tracheostoma assisted ventilation.

Fifteen patients underwent bronchoscopic follow-up after a minimum of 6 months. In all 15 patients, the subglottic lumen remained fully patent without stenosis, granulation, or scar formation, thus revealing satisfactory lasting treatment effect (Figures 1, 2). The ADL scale also showed improvement in all patients on 6-month follow-up (Table 2).

### Table 1: Patient demographics and the features of treatment

| Patient | Sex | Age  | Indications for intubation | Cotton-Myer | McCaffrey | Airway status | ADVS scale | Procedures | Number of procedures | Duration of treatment (days) | Outcome | Follow-up |
|---------|-----|------|---------------------------|-------------|-----------|---------------|------------|-------------|----------------------|----------------------------|----------|-----------|
| 1       | M   | 6y2m | Respiratory distress      | II          | 1         | Tracheal intubation | A,D,V,S, Ho*1, Cryo*9 | 9           | 98                    | Cure | No restenosis |
| 2       | F   | 5y6m | Respiratory distress      | II          | 2         | -              | A,D,V,S, Ho*2, Cryo*5 | 5           | 38                    | Cure | No restenosis |
| 3       | M   | 5y9m | Respiratory distress      | II          | 3         | Tracheal intubation | A,D,V,S, Cryo*4 | 4           | 28                    | Cure | No restenosis |
| 4       | F   | 8m15d| Craniopharyngioma resection | III         | 1         | -              | A,D,V,S, Ho*2, Cryo*9 | 10          | 100                   | Cure | No restenosis |
| 5       | M   | 6m   | Head trauma caused by traffic accident | III         | 1         | -              | A,D,V,S, Ho*1 | 1           | 18                    | Cure | No restenosis |
| 6       | M   | 1m27d| Respiratory distress      | III         | 1         | NCPAP          | A,D,V,S, Ho*1, Cryo*1 | 2           | 14                    | Cure | No restenosis |
| 7       | M   | 8m20d| Respiratory distress      | III         | 1         | Tracheostomy   | A,D,V,S, Ho*1, Cryo*3 | 3           | 32                    | Cure | No restenosis |
| 8       | F   | 5m   | Surgery of congenital heart disease | III         | 1         | -              | A,D,V,S, Ho*2, Cryo*3 | 3           | 27                    | Cure | No restenosis |
| 9       | M   | 1y5m | Respiratory distress      | III         | 1         | NCPAP          | A,D,V,S, Ho*1, Cryo*2 | 2           | 14                    | Cure | No restenosis |
| 10      | F   | 1y1m | Surgery of congenital heart disease | III         | 1         | -              | A,D,V,S, Ho*1, Cryo*1 | 1           | 7                     | Cure | No restenosis |
| 11      | F   | 8m   | Congenital esophageal atresia surgery | III         | 2         | LMA            | A,D,V,S, Ho*2, Cryo*5 | 5           | 84                    | Cures | No restenosis |
| 12      | M   | 2m10d| Respiratory distress      | III         | 3         | NCPAP          | A,D,V,S, Ho*1, Cryo*9 | 9           | 101                   | Cure | No restenosis |
| 13      | F   | 1y8m | Burn                       | III         | 3         | NCPAP          | A,D,V,S, Ho*1, Cryo*9 | 9           | 101                   | Cure | No restenosis |
| 14      | F   | 12y3m| Traffic accident injuries  | III         | 3         | -              | A,D,V,S, Ho*2, Cryo*6 | 6           | 65                    | Cure | No restenosis |
| 15      | M   | 4y   | Viral encephalitis        | III         | 3         | NCPAP          | A,D,V,S, Ho*1, Cryo*7 | 7           | 102                   | Cure | No restenosis |
| 16      | F   | 5y3m | Surgery of congenital heart disease | IV          | 3         | Tracheostomy   | A,D,V,S, Ho*4, Cryo*9, BL*2 | 9           | 140                   | Improvement | Lost to follow-up |

ADVS, Airway–Dyspnoea–Voice–Swallow; M, male; F, female; LMA, laryngeal mask airway; Ho, holmium laser; Cryo, cryotherapy; BL, balloon dilatation; NCPAP, nasal continuous positive airway pressure.
PaCO₂ was abnormal in seven patients before treatment and showed marked improvement after treatment ($P = 0.005$) (Table 3).

Among all 16 patients, the average number of individual treating sessions (i.e. holmium laser and cryotherapy) until completion of the treatment course was 4.88 sessions. The average number of laser therapy and cryotherapy were 1.44 and 4.69 times respectively. The time range between individual treatment sessions was between 7 days and 140 days, with an average of 55.31 days.

**Complications**

During the treatment, there were no significant complications (such as hypoxemia, unexpected bleeding, pneumothorax, pneumomediastinum, or anesthesia complications). A few patients had minimal bleeding when eschars were removed with biopsy forceps after laser, with hemostasis easily achieved after applying a small amount of epinephrine (1:10 000).
TABLE 2 Activity of Daily Living (ADL) Scale before and after treatment

| Patient number | Before treatment | After the first treatment | After treatment |
|----------------|------------------|---------------------------|-----------------|
| 4 (6y2m)       | 0                | 40                        | 85              |
| 5 (12y3m)      | 80               | 85                        | 90              |
| 14 (4y)        | 30               | 65                        | 90              |
| 15 (5y9m)      | 0                | 75                        | 85              |
| 16 (5y6m)      | 75               | 75                        | 85              |

TABLE 3 Comparison of PaCO₂ (mmHg) before and after treatment

| Patient number (Stenosis grade) | PaCO₂ before treatment | PaCO₂ after treatment |
|---------------------------------|-------------------------|-----------------------|
| 2 (III,1)                       | 55.0                    | 35.4                  |
| 4 (II,1)                        | 44.0                    | 38.0                  |
| 9 (III,3)                       | 67.5                    | 48.1                  |
| 10 (IIII,1)                     | 65.0                    | 35.3                  |
| 12 (III,1)                      | 49.3                    | 41.6                  |
| 14 (III,3)                      | 46.3                    | 39.4                  |
| 15 (II,3)                       | 65.5                    | 35.8                  |

PaCO₂, partial pressure of carbon dioxide in artery. PaCO₂ showed significant improvement after treatment ($P = 0.005$).

Twenty-four hours post-procedure, one patient experienced labored breathing and hypoxemia. Bronchoscopic examination was immediately performed revealing necrosis and mucus plugging. The obstruction was easily removed bronchoscopically and the patient suffered no lasting complication or restenosis.

DISCUSSION

Post-intubation SGS in children accounts for 90% of acquired SGS. When it occurs, it can have a significant effect on quality of life and even become life threatening. In this study, the majority of patients were under 3 years old (62.50%). The most common etiology regarding the need for prior intubation was respiratory failure in the setting of congenital heart disease and congenital esophageal atresia surgery (68.75%).

We hypothesize that younger age patients are more susceptible to post-intubation SGS due to smaller subglottic lumen diameters, looser basal mucosal tissue, and more abundant lymphatic and vascular tissue. In this setting, every 1 mm reduction in lumen diameter can result in 60% reduction of the effective ventilatory area, thus greatly increasing airway resistance.

Classification on the severity of SGS plays an important role in providing prognostic information and guide treatment decision making. As such, patients in our study were symptomatic from their stenosis and required urgent treatment. The majority of our patients were Cotton-Myer Grade III (81.25%) and McCaffrey Stage 2 or above (50%). ADVS and ADL scales revealed that the majority of our patients suffered from dyspnea, dysphagia, and dysphagia prior to treatment. Ten patients (62.5%) needed respiratory support with mechanical ventilation before treatment.

In all 16 patients, signs and symptoms immediately improved following treatment with holmium laser and cryotherapy (i.e. significant improvement in endoscopic lumen diameter, respiratory symptoms, hypoxemia, voice quality, and swallowing function).

Fifteen patients achieved clinical cure. Follow-up endoscopy after a minimum of 6 months revealed no restenosis. This therapeutic effect and duration appears superior to prior published treatments. For example, balloon dilatation combined with cryotherapy has been performed, but did not achieve a satisfactory treatment effect for SGS.
In several previous studies, tracheotomy was a precondition for the treatment of SGS, however, tracheotomy itself confers certain risk. These risks include infection and granulation around the tracheotomy tube which can further complicate the treatment course of the SGS. In addition, tracheotomy tube placement can lead to an enormous psychological trauma in children. In this study, patients with SGS Grade I-III underwent treatment safely without the need for tracheotomy.

Furthermore, long segment SGS has been a difficult clinical problem. In our study, SGS with length ≥ 1cm accounted for 50%, and in all cases, satisfactory therapeutic effect was achieved with holmium laser and cryotherapy.

Holmium laser has a cutting ability similar to the CO₂ laser and a coagulation ability similar to the Nd: YAG laser. As such, it can remove granulation and scar tissue effectively. Application of the holmium laser delivered via flexible endoscopy is precise and effective. It is widely used in fields of otolaryngology, urology and gastroenterology. Fong et al reported the first application of holmium laser for disorders of the pediatric airway. An 8-year experience of holmium laser ablation via bronchoscopy confirmed safety and feasibility for benign and malignant tracheobronchial obstructions. Since the airway diameter in children is small and the effective operation area is restricted, the holmium laser was felt to be a good alternative treatment method. When compared with balloon dilation, the holmium laser may be superior for removing granulation tissue and scar formation by causing destruction of vasculature and blood flow to the diseased region.

In response to concerns that laser destruction could itself lead to additional granulation tissue formation, laser treatment can be followed by cryotherapy to prevent granulation regeneration and maintain lumen diameter. The pathophysiology is felt to arise from the effect of cryotherapy on further reducing blood supply, inhibiting hyperplasia of granulation, and increasing the synthesis of collagen. Cryotherapy promotes cicatricial fibroblast differentiation into normal fibroblasts so as to reduce scar and granulation tissue hyperplasia. Zhang et al showed that cryotherapy has good curative effect on the treatment of SGS and is effective in preventing restenosis. Early and repeated intervention may be one reason for the high success rate in children.

In our study, treatment was safe with no serious complications (both during and after treating sessions). One patient experienced transient labored breathing and hypoxemia 24 hours after the procedure, but no lasting complication. This was felt to arise from necrotic epithelium obstructing the airway. From our experience, the aftereffect of cryotherapy may be the contributor to the complication in this case. Therefore, within the first 72 hours post-cryotherapy, we recommend close attention and monitoring of patients’ respiratory status.

Success of combined holmium laser-cryotherapy treatment can be confounded by other factors, including the experience of the surgeon as well as the patients’ adherence to routine and continued intervention and care. In our study, the surgeon performing these procedures had significant experience with pediatric endoscopic techniques and the patients exhibited good compliance to their regular follow-up treatments.

Our study has some limitations. These limitations include the small sample size which has an effect on the power of our conclusions. In addition, because the one patient with SGS Grade IV was lost to follow-up, we have limited understanding on the longstanding effect of our treatment on SGS Grade IV.

Our study supports the conclusion that holmium laser treatment combined with cryotherapy by flexible bronchoscopy appears to be a safe and feasible treatment for post-intubation SGS in children. This includes SGS with lengths ≥ 1cm. Furthermore, this therapeutic technique can be considered a viable alternative option when performed by a practitioner with appropriate training and supervision.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest. All authors have read the manuscript and agree with the submission.

REFERENCES

1. Schweiger C, Marostica PJ, Smith MM, Manica D, Carvalho PR, Kuhl G. Incidence of post-intubation subglottic stenosis in children: prospective study. J Laryngol Otol. 2013;127:399-403.
2. Maresh A, Preciado DA, O’Connell AP, Zalzal GH. A comparative analysis of open surgery vs endoscopic balloon dilation for pediatric subglottic stenosis. JAMA Otolaryngol Head Neck Surg. 2014;140:901-905.
3. Yamamoto K, Kojima F, Tomiyama K, Nakamura T, Hayashino Y. Meta-analysis of therapeutic procedures for acquired subglottic stenosis in adults. Ann Thorac Surg. 2011;91:1747-1753.
4. Hetzel M, Hetzel J, Schumann C, Marx N, Babiak A. Cryorecanalization: a new approach for the immediate management of acute airway obstruction. J Thorac Cardiovasc Surg. 2004;127:1427-1431.
5. Myer CR, O’Connor DM, Cotton RT. Proposed grading system for subglottic stenosis based on endotracheal tube sizes. Ann Otol Rhinol Laryngol. 1994;103:319-323.
6. McCaffrey TV. Classification of laryngotracheal stenosis. Laryngoscope. 1992;102:1335-1340.
7. Nouraei SA, Kourey EF, Sandhu GS. A proposed system for documenting the functional outcome of paediatric laryngotracheal stenosis. Clin Otolaryngol. 2011;36:284-
286.

8. Oh SK, Park KN, Lee SW. Long-term results of endoscopic dilatation for tracheal and subglottic stenosis. Clin Exp Otorhinolaryngol. 2014;7:324-328.

9. Wang G. The management of benign central airway stenosis. Chin J Tuberc Respir Dis. 2010;33:14-16. (In Chinese)

10. Edmundson NE, Bent JR. Serial intralesional steroid injection combined with balloon dilation as an alternative to open repair of subglottic stenosis. Int J Pediatr Otorhinolaryngol. 2010;74:1078-1081.

11. Miller FR, Eliachar I, Tucker HM. Technique, management, and complications of the long-term flap tracheostomy. Laryngoscope. 1995;105:543-547.

12. Lyons M, Vlastarakos PV, Nikolopoulos TP. Congenital and acquired developmental problems of the upper airway in newborns and infants. Early Hum Dev. 2012;88:951-955.

13. Avelino M, Maunsell R, Jube WL. Predicting outcomes of balloon laryngoplasty in children with subglottic stenosis. Int J Pediatr Otorhinolaryngol. 2015;79:532-536.

14. Maksoud-Filho JG, Goncalves ME, Cardoso SR, Tamuri U. Early diagnostic and endoscopic dilatation for the treatment of acquired upper airway stenosis after intubation in children. J Pediatr Surg. 2008;43:1254-1258.

15. Zhang L, Yin Y, Zhang J, Zhang H, Wang Wei, Zhu M. Balloon dilation combined with cryotherapy in the treatment for subglottic stenosis in infants and young children. Chin J Prac Pediatr. 2014;12:403-405. (In Chinese)

16. Guarisco JL, Yang CJ. Balloon dilation in the management of severe airway stenosis in children and adolescents. J Pediatr Surg. 2013;48:1676-1681.

17. Gungor A. Balloon dilation of the pediatric airway: potential for disaster. Am J Otolaryngol. 2012;33:147-149.

18. Murgu SD, Egressy K, Laxmanan B, Doblare G, Ortiz-Comino R, Hogarth DK. Central airway obstruction: Benign Strictures, tracheobronchomalacia, and malignancy-related obstruction. Chest. 2016;150:426-441.

19. Kryukov AI, Tsarapkin GY, Arzamazov SG, Panasov SA. The application of lasers in otorhinolaryngology. Vestn Otorhinolaryngol. 2016;81:62-66. (In Russian)

20. Gravas S, Buchmann A, Reich O, Roehrborn CG, Gilling PJ, De La Rosette J. Critical review of lasers in benign prostatic hyperplasia (BPH). BJU Int. 2011;107:1030-1043.

21. Hazey JW, McCreary M, Guy G, Melvin WS. Efficacy of percutaneous treatment of biliary tract calculi using the holmium: YAG laser. Surg Endosc. 2007;21:1180-1183.

22. Fong M, Clarke K, Cron C. Clinical applications of the holmium: YAG laser in disorders of the paediatric airway. J Otolaryngol. 1999;28:337-343.

23. Squiers JJ, Teeter WA, Hoopman JE, Piepenbrok K, Wagner R, Ferguson R, et al. Holmium: YAG laser bronchoscopy ablation of benign and malignant airway obstructions: an 8-year experience. Lasers Med Sci. 2014;29:1437-1443.

24. Iwamoto Y, Miyazawa T, Kurimoto N, Miyazu Y, Ishida A, Matsuo K, et al. Interventional bronchoscopy in the management of airway stenosis due to tracheobronchial tuberculosis. Chest. 2004;126:1344-1352.

25. Collins NC. Is ice right? Does cryotherapy improve outcome for acute soft tissue injury? Emerg Med J. 2008;25:65-68.

26. Dalkowski A, Fimmel S, Beutler C, Zouboulis C. Cryotherapy modifies synthetic activity and differentiation of keloidal fibroblasts in vitro. Exp Dermatol. 2003;12:673-681.

27. Zhang Q, Zhang J, Wang H. Endoscope assisted coblation surgery for treating subglottic stenosis. J Clin Otorhinolaryngol Head Neck. 2013;27:587-589. (In Chinese)

SUPPORTING INFORMATION

Additional supporting information may be found online in the supporting information tab for this article.

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