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The role of the CO_2 laser in the management of laryngotracheal stenosis: a survey of 100 cases

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Abstract Over the last decade, improvement of CO_2 lasers with the microspot and ultrapulse technologies has broadened the indications for endoscopic CO_2-laser resection of benign laryngotracheal stenosis (LTS). This article reviews 100 patients treated solely by endoscopic means for a LTS. There were 47 grade III, 41 grade II and 12 grade I stenoses according to the Myer-Cotton classification. The postoperative results show that the improvement to a nearly normal (>80% luminal size) airway declines from 92% (11/12 patients) for grade I to 46% (19/41 patients) for grade II and 13% (6/47 patients) for grade III stenoses. When compared to open surgery for more severe grades of stenosis (31 grade IV, 66 grade III and 3 grade II stenoses), the results of the endoscopy group is much less favorable: 36% of patients in the endoscopy group versus 76% of patients in the open surgery group were rehabilitated to a normal respiration without exertional dyspnea and 38% versus 5% patients remained tracheotomy dependent. However, if strict selection and therapeutic criteria are respected, a significant number of grade I and II stenoses, and to a lesser degree of grade III stenoses, can be improved to a nearly normal airway by endoscopic means only. The endoscopic treatment is potentially less invasive and risky and only needs a short hospital stay. To try this as a first treatment modality in a selected group of patients is worthwhile, provided that this endoscopic treatment is not repeated a second time, if the stenosis recurs to its initial grade after a primary CO_2-laser treatment. Some guidelines for safe endoscopic treatment modalities with of the CO_2 laser, dilatation and/or stenting are proposed.

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Introduction

The management of laryngotracheal stenosis (LTS) is a challenging problem with no fixed treatment algorithm among the multiple options that are available to the surgeon. The latter includes endoscopic treatments (CO_2 laser, dilatation and/or stenting) [2, 7, 9, 10, 13, 14, 20, 22, 24, 25, 31, 35, 37, 38, 44, 45, 48] and open surgery with enlargement procedures or resections, both with or without stenting [1, 3, 4, 5, 6, 15, 16, 17, 18, 21, 26, 27, 28, 32, 36, 39, 42]. Each case is unique and has to be judged according to the patient's characteristics, the site and severity of the stenosis and the function of the vocal cords [26]. This renders the comparison of success rates with different treatment modalities difficult. The final result depends not only on the severity of the initial condition, but also greatly on the quality of the indication for the appropriate type of surgery. The preoperative assessment is thus essential; it has been published in detail elsewhere [26]. Notwithstanding, the final outcome can be judged on the restoration of an adequate airway and on the preservation of a satisfactory voice. Needless to say that selecting the right patient for the right type of treatment is the key issue, although this may turn out to be a very difficult task, especially in multilevel stenoses associated with glottal scarring or extensive tracheal damage.

Several authors have published guidelines for the management of LTS by open surgery [3, 4, 6, 15, 17, 27, 39] and by endoscopy [7, 10, 37, 45, 46]. Unfortunately, some endoscopists tend to set up their own criteria based on their level of expertise in their own discipline. This leads to some unacceptable primary treatments with an inappropriate type of laser (Nd-YAG used at a low power-density in a non-contact mode, for example) and long-term stenting, where a simple resection and anastomosis would have straightforwardly solved the

problem [16, 28, 39]. It must be clearly stated here that an endoscopic treatment can seldom restore an anatomically normal subglottis or trachea [44, 45]. However, the improvements of CO_2 lasers with the microspot and superpulse/ultrapulse technologies have recently broadened the indications for endoscopic CO_2 laser resection of LTS.

Materials and methods

Patients

From 1991 to 2003, 115 patients with a benign LTS were treated solely by endoscopic means at the University Hospital CHUV, Lausanne, Switzerland. There were 51 males and 64 females with a mean age of 22 years (range: 6 months to 73 years). Sixty-three (55%) were in the pediatric age group. Preoperatively, 39 patients were tracheotomy dependent, 46 had some dyspnea at rest and 30 only some exertional dyspnea.

Almost half (52/115 ~45%) of the patients had already undergone one or several (1 to 50) previous endoscopic treatments or open surgeries elsewhere. In these cases, a further CO_2 laser resection with or without additional dilatation was only proposed when the aspect of the stenosis showed as a residual web-like synechia [46], a prolapse of one arytenoid [43] or a bilateral vocal cord immobility [11, 41].

Stenosis

The stenosis was congenital in 8 patients, acquired after intubation or external trauma in 98 patients and of mixed etiology (congenital and acquired) in 9 patients. According to the Myer-Cotton classification (Table 1), there were 47 (41%) patients with grade III stenoses, of which 39 were tracheostomized and 8 had a severe dyspnea at rest. In the group of 50 (44%) grade II stenoses, 36 patients had a severe grade II (~70% airway obstruction) with slight dyspnea at rest and 14 a mild grade II stenosis with exertional dyspnea only. Finally, the 18 (15%) patients with only grade I stenosis were essentially adults complaining of slight dyspnea during sport activities. For combined stenoses, the size of the most severe stenosis was taken into consideration for the preoperative and postoperative grading.

Table 1 Myer-Cotton classification for benign pediatric subglottic stenosis [34]

Grade	Obstruction
I	≤ 50%
II	51–70%
III	71–90%
IV	No lumen

It must be clearly stated here that the above-mentioned indications diverge from the general recommendations for the use of the CO_2 laser in benign LTS [46], but in this series, grade II and grade III stenoses always presented as thin diaphragms.

Except for 7 (6%) solely supraglottic stenoses, the other sites were almost equally distributed with 26 (23%) glottic, 26 (23%) subglottic, 29 (25%) tracheal and 27 (23%) combined glotto-subglottic stenoses.

Treatment modality

The CO_2 laser (Coherent Ultrapulse Encore) was always used in the ultrapulse mode with a fluence of 150 mJ/cm^2 at a frequency of 10 Hz to avoid any charring and heat diffusion into the surrounding tissues [33]. Dilatation was performed with tapered Savary-Gilliard dilators (Wilson-Cook Medical) after radial laser incisions [45], and when necessary stenting was achieved with our own laryngotracheal mold (Easy LT-Mold) [29].

When mitomycin-C was additionally used after the endoscopic treatment, it was topically applied over the raw surface of the laser wound at a dose of 2 mg/ml for 2 min [30].

Early in our experience, we also treated some tracheal stenoses with the Nd-YAG laser in a contact mode using a sapphire tip or with the KTP-laser. Currently, we only use a rigid Storz bronchoscope with a CO_2 laser coupler (Storz 10316 LC).

The type of treatment applied is summarized in Table 2. It must be noted that treatment modalities were often combined to give the best possible result. Fifty-five (48%) patients underwent a single and 54 (47%) patients less than three endoscopic treatment sessions. In six patients, the improvement at each session inclined us to perform subsequent endoscopic treatments (maximum 5) to optimize the final result. In 13 patients, open surgery was eventually proposed to achieve a satisfactory result.

In 15 cases, a temporary stenting with an Easy LT-Mold [29] was deemed necessary for the treatment of a posterior glottic stenosis (PGS). All these patients were tracheotomy-dependent. Five other patients without tracheotomy were kept intubated with a soft blue-line Portex tube (Rüsch, Germany) for a mean duration of 1 week. The last five patients had a severe anterior synechia of the vocal cords that was treated by a CO_2 laser division and stenting with a silicone keel for 3 weeks.

Table 2 Types of endoscopic treatment for 115 LTS

CO_2-laser section/resection	84	~	73%
Nd-YAG/KTP laser	16	~	14%
Dilatation	37	~	32%
Temporary stenting	25	~	22%
Topical mitomycin-C (2 mg/ml for 2 min)	56	~	49%

Treatments were often combined (for instance laser + dilatation + mitomycin), hence a total number exceeding 115 (100%)

Assessment of results

The improvement in airway patency was assessed at each postoperative outpatient visit and with questionnaires when patients could not attend follow-up examination. The following items were recorded: no exertional dyspnea, exertional dyspnea without airway restriction at rest, dyspnea at rest and tracheotomy dependence.

At each control endoscopy, the size of the airway was assessed with Savary-Gilliard tapered bougies (Wilson-Cook Medical) and the Myer-Cotton classification applied [34]. No thorough evaluation of the voice was carried out.

Results

Fifteen (13%) patients with either grade I (6 cases) or grade II (9 cases) were lost to follow-up. All patients with grade III stenoses were available for the present study. The median follow-up of the 100 patients left for this study is 18 months with extremes of 6 months to 11 years.

The results on airway patency are shown in Table 3, in comparison with the preoperative condition. In no case did the endoscopic treatment aggravate the initial condition. Either the patients were improved or they recurred to a similar grade of stenosis. Preoperatively, 85 (74%) patients had a severe dyspnea at rest or were tracheotomy dependent. After one or several endoscopic treatment(s), there were only 19 (19 %) patients left in the same category. Thirty-six patients lived fully normally with no exertional dyspnea, while 45 (45%) patients pursued normal daily activities with only exertional dyspnea while practicing sports.

Six patients with a severe residual grade II stenosis remained slightly dyspneic at rest and only 26 of the 39 (66%) tracheostomized patients could be decannulated. The other 13 initial grade III stenoses recurred to a similar degree of obstruction and required open surgery.

The analysis of the results according to the preoperative grade of stenosis is shown in Table 4. All but one grade I stenosis were improved to a nearly normal (≥80% luminal size) airway. Conversely, the results were much less favorable for grade III stenoses. Thirteen (28%) recurred to a similar grade of obstruction and prevented the patient from being decannulated. Nineteen (40%) improved to a grade II stenosis with significant residual exertional dyspnea or even slight dyspnea at rest. Only 6 (13%) grade III stenoses were improved to a nearly normal airway with no residual respiratory symptoms, while 9 (19%) ended up with a grade I stenosis. The intermediate group of 41 patients with a grade II stenosis either improved to a nearly normal airway 19/41 (~46%) or to a grade I stenosis 20/41 (~49%) (Fig. 1).

Looking at these results in a different way, the rate of improvement to a nearly normal airway declines from 92% (11/12 patients) for grade I to 46% (19/41 patients) for grade II and 13% (6/47 patients) for grade III stenoses. In a similar fashion, grade II stenoses were improved to grade I stenoses in almost half of the patients (20/41~49%), whereas only 9 of 47 (19%) grade III stenoses were upgraded to the same level of improvement.

The results of this series of 115 patients who underwent an endoscopic treatment for the management of a benign cicatricial LTS were compared to another series of 104 patients treated for the same condition with open surgery at our institution. Fifteen patients in the endoscopy and four patients in the open surgery groups were not available for the analysis of the postoperative results. In the endoscopy group, there were 12 grade I, 41 grade II and 47 grade III stenoses and no grade IV stenosis, whereas in the open surgery group, there were no grade I, 3 grade II, 66 grade III and 31 grade IV stenoses. The postoperative results on respiratory symptoms are shown in Table 5. Although the grades of stenosis were significantly worse in the open surgery group (97% grades III-IV stenosis) than in the endoscopy group (0 grade IV, 47% grade III stenosis), the final outcome was much superior in the open surgery group. Seventy-six percent versus only 36% of patients were rehabilitated to a normal respiration without any exertional dyspnea and only 5 versus 33% remained tracheotomy dependent in the open surgery group when compared to the endoscopy group.

Table 3 Comparison of preoperative and postoperative respiratory symptoms. Insufficient follow-up: $n = 15 \sim 13\%$

Breathing	Preoperative	Postoperative
·Tracheotomy	39	13
·Dyspnea at rest	46	6
·Exertional dyspnea	30	45
·No exertional dyspnea	0	36
Total	115	100

Table 4 Comparison (grade by grade) of preoperative and postoperative degrees of stenosis ($n = 100$)

Preoperative	Postoperative results			
Degree of stenosis	≤ 20%	Grade I ≤ 50%	Grade II ≤ 70%	Grade III ≤ 99%
Grade I: 12	11	1	0	0
Grade II: 41	19	20	2	0
Grade III: 47	6	9	19	13

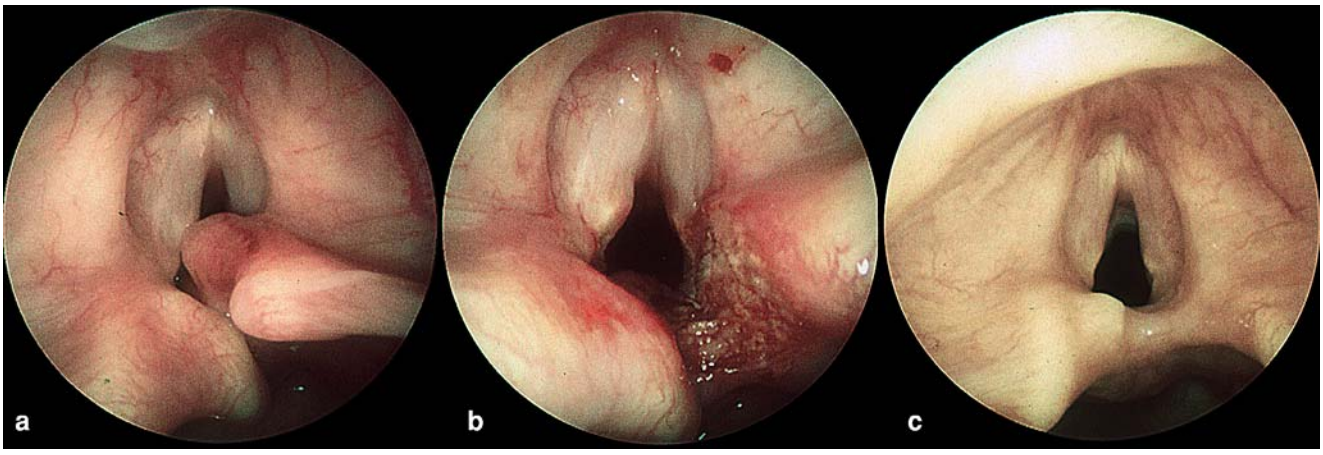

Fig. 1 Supraglottic stenosis combined with a glotto-subglottic stenosis. **a** Posterior obstruction of the glottis by a tilted arytenoid after partially successful laryngotracheal reconstruction. **b** Immediate endoscopic view after partial right arytenoidectomy and laser resection of a grade II subglottic stenosis (glotto-subglottic web). **c** Endoscopic view 1 year after the endoscopic treatment. Persistence of a small anterior subglottic web. No residual dyspnea, very good voice

Discussion

Back in 1982, Simpson et al. [46] set up predictive factors of success or failure in the endoscopic management of laryngeal and tracheal stenosis. Over the last 2 decades, the advent of the microspot and super- or ultrapulse technologies have somewhat broadened the indications for the use of the CO_2 laser in this field [33]. More recently, the topical application of mitomycin C as adjuvant therapy to the endoscopic management of LTS has decreased the risk of restenosis [30, 40], although contradictory results have been published in the medical literature [12, 19, 30, 40, 47]. These are mainly due to significant differences in the concentration doses of mitomycin that were applied, and in the indications for this adjuvant therapy.

This present study of 100 patients undergoing an endoscopic treatment for a benign cicatricial LTS confirms that some grade II and even grade III stenoses can be improved to a nearly normal (≥80% luminal size) airway. The success rate however diminishes drastically from preoperative grade I to grade III stenoses, according to the Myer-Cotton classification [34]. It must be emphasized here that this classification has been used in a broader sense than originally proposed for pediatric SGS, since it was applied to all adult and pediatric LTS (supraglottic, glottic, subglottic and combined stenoses).

Except for congenital cartilaginous LTS, grade I stenoses are amenable to endoscopic management with a potentially high success rate (≥90% of cases with a nearly normal airway). In the present series, almost half (19/41∼46%) of grade II stenoses were improved to a better than 80% luminal size, whereas in only 6 of 47 (∼13%) grade III stenoses could a similar result be achieved, despite severe selection criteria, namely a craniocaudal extension of less than 1.5 cm and the absence of loss of cartilage support. However, a thin cicatricial web-like and circumferential subglottic stenosis was not considered an exclusion criterion in this series, as in Simpson's predictive factors of success or failure [46].

When compared to open surgery for more severe grades of stenosis, the results of the endoscopic treatments are much less favorable (cf. Table 5). However, the endoscopic approach is less invasive and less risky and requires only a very short hospital stay for postoperative surveillance in non-tracheostomized patients. The key issue lies here in the proper selection of patients and in the adherence to strict treatment criteria to avoid any worsening of the initial condition (Fig. 2).

According to tissue interactions [33], the CO_2 laser (10,600 nm) in the ultrapulse mode is the preferred type of laser for treating benign cicatricial stenoses. It should be used either in suspension microlaryngoscopy for laryngeal and subglottic stenoses, or with a rigid bronchoscope and a CO_2 laser coupler for tracheal and bronchial stenoses. Nd-YAG (1,064 nm), diode (980 nm) and KTP (532 nm) lasers, even in the contact mode, induce much more heat diffusion into the surrounding tissues and potentially higher rates of restenosis. Anecdotal reports of success for benign subglottic or tracheal stenoses [25] do not support the routine use of these types of lasers for such indications.

Grade I to grade III stenoses presenting as web-like diaphragms without loss of cartilage support represent good indications for a first try endoscopic laser treatment, provided that the latter is not repeated in case of

Table 5 Comparison of postoperative results in 100 endoscopic and 100 open surgery treatments for benign cicatricial LTS

Condition	Endoscopic treatment	Open surgery
	$n = 100$	$n = 100$
No dyspnea	36	76
Exertional dyspnea	45	19
Dyspnea at rest	6	0
Tracheotomy	13	5

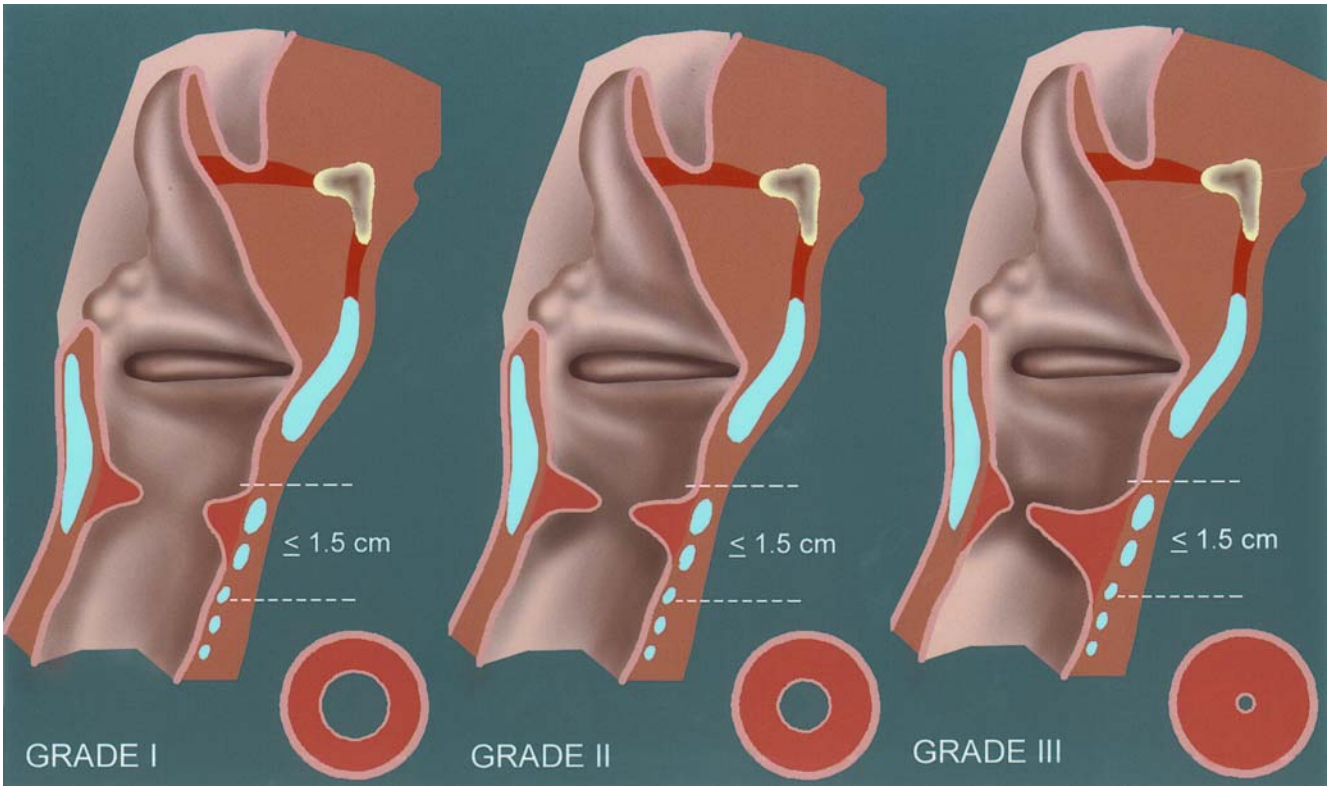

Fig. 2 Indications for CO_2-laser treatment of subglottic and tracheal stenoses. Grades I and II subglottic or tracheal stenoses definitely represent good indications for endoscopic CO_2 laser resection with or without additional dilatation. The expected result is superior if the stenosis does not involve the posterior wall of the airway, especially at the level of the membranous trachea. For grade III stenosis, the risk of recurrence is much higher, despite a limited cranio-caudal extension of less than 1.5 cm

recurrence to the initial grade of stenosis (Fig. 3). Healy et al. have stressed the importance of a trial of endoscopic laser treatment in patients with acquired stenosis, before an open procedure is attempted. Their experience

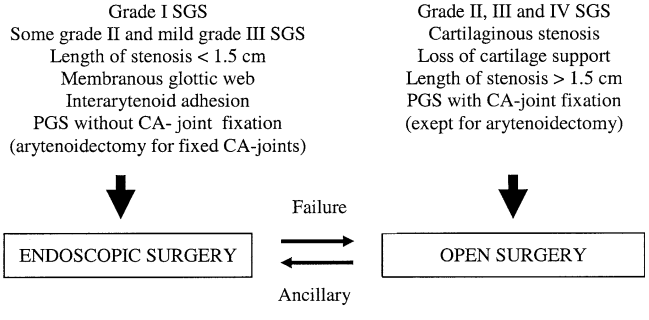

Fig. 3 Algorithm for the endoscopic treatment of benign laryngotracheal stenosis. After a primary endoscopic treatment (CO_2 laser/dilatation/stenting), a recurrence of the stenosis to its initial grade precludes any further endoscopic treatment. Open surgery should be considered instead. If a first endoscopic treatment improves the initial condition, a second or third session can further optimize the final result. Stents should be used with extreme caution as they may worsen the initial craniocaudal extension of a stenosis, rendering further open surgery much more difficult

is based on the successful laser treatment of 177 pediatric patients with LTS, granuloma and papilloma [20].

Reports in the literature following primary endoscopic treatment of LTS show success rates between 40 to 94%, depending on the appropriateness of the indication [2, 7, 9, 10, 14, 20, 25, 37, 44, 45]. In most cases of acquired grade I stenosis, conservative endoscopic laser therapy is effective. The choice of treatment is more crucial in grade II and mild grade III stenoses. The extensive use of the CO_2 laser in such cases can worsen the initial condition. Vaporization of cartilaginous structures is strictly contraindicated as it will expose denuded cartilage into the lumen, weaken the laryngotracheal framework and induce restenosis to a more severe grade. This complication never occurred in our series of 100 patients treated with the CO_2 laser.

The excellent decannulation rates (≥90%) for grade III and grade IV stenoses with partial cricotracheal resection in children and adults offer the proper alternative of treatment for severe grade III and IV stenoses, with an acceptable morbidity [15, 16, 27, 39, 42]. For mild grade III and grade II stenoses, laryngotracheal reconstructions with costal cartilage graft are another option in children [3, 4, 5, 18, 21, 32, 36].

Endoscopic CO_2 laser resection of subglottic or upper tracheal stenosis with dilatation and indwelling stents should be proscribed. The necessity of prolonged stenting merely reflects the weakness of the cartilaginous framework of the larynx and trachea. Whenever possible, open surgery with resection or reconstruction of the diseased segment should be envisaged [5, 13, 49]. Indwelling stents for a period of several months or years

are only justified when no further airway resection or reconstruction is possible. However, self-expandable metallic stents should not be used in children, because the rate and severity of complications are too high [23]. In adult patients who are unfit for open surgery, a self-expendable metallic stent or a Dumon silicone stent [8] can be envisaged as the ultimate solution, but this should remain an exception. The subglottic location of the stenosis adds to the therapeutic challenge of stenting. When sitting in the supraglottic or subglottic regions, the proximal end of the stent may induce ulceration and granulation tissue formation with subsequent supraglottic or glotto-subglottic restenosis. In the trachea, an indwelling stent can also induce granulation tissue formation at both extremities and change a short stenosis into a long inoperable stenosis. Stents should thus be used with extreme caution for the primary treatment of benign airway stenoses, but they are often indispensable after a LTR for a complex LTS. The precise anatomical configuration of the stent and its hardness are of the utmost importance [29, 48].

The management of posterior glottic stenosis (PGS) requires expertise in the selection of the appropriate candidate for the right type of treatment. Interarytenoid adhesion with a residual posterior opening is usually not associated with a cricoarytenoid (CA) joint fixation. Division of the scar with the CO_2 laser is thus the first appropriate choice of treatment with a potentially high success rate. True PGSs without residual posterior opening deserve a first try endoscopic treatment with the CO_2 laser and adjuvant topical application of mitomycin-C at a dose of 2 mg/ml for 2 min [30]. Five to 7 days of postoperative intubation with a soft blue-line Portex tube help achieve a satisfactory result. If CA joint mobility is restored, the abductive force of both posterior cricoarytenoid muscles will prevent recurrence of the PGS at least to some degree. In tracheostomized patients, 2 to 3 weeks of stenting with an Easy LT-Mold [29] ensures reepithelization of the posterior commissure in abduction, thus recreating an adequate airway for breathing. In case of true fixation of the CA joints, a laser arytenoidectomy, a posterior cordotomy or a posterior costal cartilage graft should be envisaged. When PGS is combined with a subglottic stenosis, open surgery is mandatory in most cases. In 1989, Langman et al. [20] reported failures of endoscopic treatment associated with arytenoid fixation and Duncavage et al. [9] of laser vaporization for combined glotto-subglottic stenoses in 20 patients.

Conclusion

The appropriate management of LTS requires a high degree of expertise in endoscopic and open surgery. The numerous treatment modalities available for both approaches render the selection of the right patient for the right type of treatment difficult. Notwithstanding, a few basic principles should always be respected in the endoscopic management of LTS. Due to its tissue interactions, the CO_2 laser is the laser of choice for mature cicatricial LTS. It should be used in the ultrapulse mode (150 mJ/cm^2) with a microspot (250 mu at 400-mm focal distance). For dilatation, tapered bougies (Savary-Gilliard or laryngeal dilators) should be gently passed through mature stenoses after radial incisions with the CO_2 laser according to Shapshay's technique and a single adjuvant topical application of mitomycin-C at a dose of 2 mg/ml for 2 min may help improve the final outcome. Stenting of the airway after an endoscopic treatment should be used with extreme caution in order to avoid any worsening of the initial condition.

The adage "primum nihil nocere" should be of primary concern for the endoscopic treatment of LTS, knowing that open surgery can always solve the problem, albeit with potentially more invasiveness and morbidity. This report of 100 consecutive patients treated by endoscopic means for grade I to III stenoses demonstrates that a significant number of grade I and II stenoses (and, to a lesser degree, grade III stenoses) can be improved to a nearly normal airway by endoscopic means only.

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