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Guideline

Guidelines for the Management of Adult Subglottic and Tracheal Stenosis From the Korean Bronchoesophagological Society

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Subglottic stenosis (SGS) and tracheal stenosis (TS) are rare conditions that can cause significant breathing difficulties and, if not properly managed, may lead to life-threatening complications. Despite their clinical importance, debate continues regarding the optimal management of adult SGS and TS, and no comprehensive guidelines have been established to date. The Korean Bronchoesophagological Society appointed a task force to develop clinical practice guidelines with the goal of providing evidence-based recommendations for managing SGS and TS in adults. The task force conducted a systematic review of the relevant literature by searching PubMed, Embase, and the Cochrane Library using predefined search terms aligned with key clinical questions. The quality of evidence was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach, which also informed the formulation and reporting of the recommendations. The strength of each recommendation reflects the guideline panel's confidence that the benefits of an intervention outweigh its risks for eligible patients. After drafting the guidelines, feedback was obtained through Delphi questionnaires completed by members of the Korean Bronchoesophagological Society. Ultimately, the committee developed 17 evidence-based recommendations across four categories: initial evaluation, medical management, surgical treatment, and postoperative management and rehabilitation. These guidelines aim to support clinicians in delivering optimal care to adult patients with SGS and TS.

Keywords. *Airway Management; Evidence-Based Medicine; Practice Guideline; Tracheal Stenosis*

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INTRODUCTION

Subglottic stenosis (SGS) and tracheal stenosis (TS) in adults are potentially life-threatening conditions that may arise from various causes, including iatrogenic injury, inflammatory processes, trauma, tumors, or idiopathic origins [1]. The severity of the stenosis can markedly affect quality of life (QOL), producing symptoms such as dyspnea, persistent cough, and voice discomfort. Appropriate treatment is essential to prevent progression to life-threatening complications.

Adult SGS and TS are primarily caused by prolonged intubation and tracheostomy, typically resulting from aberrant wound-healing mechanisms that lead to hypertrophic scar formation and tracheal narrowing [2]. When the cuff pressure of an endotracheal tube exceeds the capillary perfusion pressure during intubation, ischemic necrosis and chondritis of the underlying tracheal cartilage may occur [3-5]. Although high-volume, low-pressure cuffs were developed to mitigate this risk, improper tube positioning can still damage the tracheal mucosa and potentially result in stenosis.

The incidence of SGS and TS varies depending on the clinical context. In the general population, post-intubation laryngotracheal stenosis (LTS) occurs at a rate of 4.9 cases per million per year [6]. Among patients requiring mechanical ventilation, 96 out of 1,000 (1,230 out of 624,918) were reported to develop LTS within 45 days of discharge [7]. The incidence of post-tracheostomy stenosis ranges from 1.5% to 1.7% [8], and one study reported a TS rate exceeding 1.8% following tracheostomy [9].

Managing adult SGS and TS typically requires a multidisciplinary team of healthcare professionals with diverse expertise. An accurate preoperative diagnostic workup is essential for determining appropriate treatment, as management strategies must be tailored to the severity and characteristics of the stenosis. Although various endoscopic and surgical treatments are available, no gold standard approach has been established due to limited comprehensive research. Existing data are predominantly derived from retrospective studies or small sample sizes, and standardized treatment protocols are lacking. Furthermore, the optimal surgical extent for SGS and TS management remains debated in the absence of randomized controlled trials (RCTs) and clinical guidelines. As a result, clinicians often rely on personal experience when making treatment decisions, leading to variation in clinical outcomes across physicians and institutions.

These guidelines aim to support clinicians in making safer and more effective clinical decisions for adult SGS and TS. The objectives are to improve life expectancy, enhance patients' QOL, and strengthen public health outcomes through standardized management. These guidelines were developed by the Korean Bronchoesophagological Society based on available scientific evidence and expert consensus, incorporating the perspectives of otolaryngologists, thoracic surgeons, and pulmonologists.

HIGHLIGHTS

- The Korean Bronchoesophagological Society has developed new clinical practice guidelines for managing adult subglottic and tracheal stenosis.
- The committee formulated evidence-based recommendations in four categories: initial evaluation (R1–3), endoscopic and adjuvant therapies (R4–6), surgical treatment (R7–9), and postoperative management (R10–12).
- The management of adult subglottic and tracheal stenosis requires a multidisciplinary approach, and these clinical practice guidelines aim to optimize clinical care and improve understanding among healthcare professionals, including otolaryngologists, thoracic surgeons, pulmonologists, anesthesiologists, primary care physicians, nurses, and policymakers.

MATERIALS AND METHODS

Target population

These guidelines focus on the management of acquired SGS and TS in adults over 18 years of age, explicitly excluding congenital or pediatric cases. SGS and TS represent a continuum of upper airway pathologies that often share etiological factors, clinical features, and therapeutic strategies. Prolonged intubation, idiopathic inflammation, and systemic diseases such as granulomatosis with polyangiitis are common contributors to concentric fibrotic narrowing across the subglottic and proximal tracheal segments [10-12]. In clinical practice, distinguishing between SGS and TS is frequently unnecessary because stenosis often spans both regions when proximal tracheal involvement is present. Diagnostic modalities—including endoscopy, computed tomography (CT) imaging, and spirometry—are applied similarly across these conditions [11,13], and the Myer-Cotton grading system, although originally designed for SGS, is commonly adapted for TS assessment [14,15]. Endoscopic interventions such as balloon dilation and laser resection, as well as open surgical procedures including cricotracheal or tracheal resection (TR) with primary anastomosis, serve as standard therapeutic approaches for both conditions [16-18]. Therefore, these guidelines adopt the unified term "subglottic and tracheal stenosis" to reflect their shared pathophysiology and management, while intentionally excluding glottic and supraglottic stenosis due to their distinct causes and treatment requirements.

These recommendations are intended to guide clinicians, patients, researchers, and health policymakers involved in the diagnosis and management of adult SGS and TS. The guidelines address initial evaluation, diagnostic assessment, medical therapy, endoscopic and surgical interventions, postoperative care, and rehabilitation. Separate recommendations are provided for each phase of care to promote evidence-based, patient-centered decision-making.

Organization of the committee

The clinical practice guidelines were developed by the Guideline Committee of the Korean Bronchoesophagological Society. A task force of 19 experts was appointed and divided into four specialized teams. The task force chairman (ISP), vice-chairman (JHC), and secretary (JKC) were appointed by the President of the Korean Bronchoesophagological Society (JPK) with Committee approval. The Guideline Committee operated with full editorial independence from the Korean Bronchoesophagological Society. A kick-off meeting marked the initiation of the guideline development process. Committee members participated in regularly scheduled online and in-person meetings to review and evaluate each stage of development.

Literature search and quality assessment

The committee performed a systematic literature search across PubMed, Embase, and the Cochrane Library databases. For PubMed and Cochrane Library searches, Medical Subject Headings (MeSH) terms were used, while Emtree terms were applied for Embase. Relevant text keywords were also incorporated. Boolean operators (AND, OR, NOT) were used to refine searches, which were limited to titles, abstracts, and keywords. The search included articles, reviews, and articles in press involving human subjects, without restrictions on publication year. After the search was completed, committee members independently screened titles and abstracts to exclude unrelated studies. The remaining articles were independently reviewed by two committee members to confirm eligibility. The inclusion criteria were as follows: (1) studies involving surgical treatment of adult SGS or TS; (2) stenosis etiology categorized as idiopathic, traumatic, or postintubation/tracheostomy; (3) publications reporting at least two cases; and (4) articles published in English. Exclusion criteria included: (1) inclusion of patients under 18 years of age; (2) etiologies other than idiopathic, traumatic, or postintubation/tracheostomy, or cases in which etiology was not reported; (3) case reports; (4) absence of discussion regarding decannulation or the need for additional surgery; and (5) duplicate patient series. The search strings for each key question and the number of identified documents are presented in Supplementary Table 1.

Quality of literature and evidence, and the grading of recommendations

The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach, an internationally accepted standard for transparent recommendation development, was used to assess evidence quality and formulate recommendations. Guideline committee members received training in the GRADE process before the guideline meetings through online modules, publications, and presentations. The risk of bias assessment tool for nonrandomized studies was used to evaluate non-RCTs and observational studies, and a measurement tool to assess the methodological quality of systematic reviews was applied to assess systematic reviews and meta-analyses [19,20]. Evidence quality was independently assessed by two committee members, and disagreements were resolved through discussion. The GRADE approach categorizes evidence quality as high, moderate, low, or very low.

The strength of a recommendation reflects the panel's confidence that the benefits of an intervention outweigh its risks, or vice versa. Recommendations are categorized as strong, conditional, or no recommendation. Strong recommendations indicate high confidence in the benefit–risk balance, while conditional recommendations reflect lower confidence or variability in patient values and preferences. No recommendation is issued when evidence is insufficient to determine the direction of benefit–risk balance. Recommendation strength is determined by considering the balance of desirable and undesirable outcomes, evidence quality, confidence level, and variability in patient preferences.

Consensus development

The Delphi method was used to establish consensus among panel members of the Korean Bronchoesophagological Society. The Delphi questionnaire was distributed to active members of the society with more than 10 years of clinical experience since specialty certification, and 36 responses were received. Three responses were excluded due to incomplete or ineligible data, resulting in 33 responses in the final analysis. Among respondents, 27 were

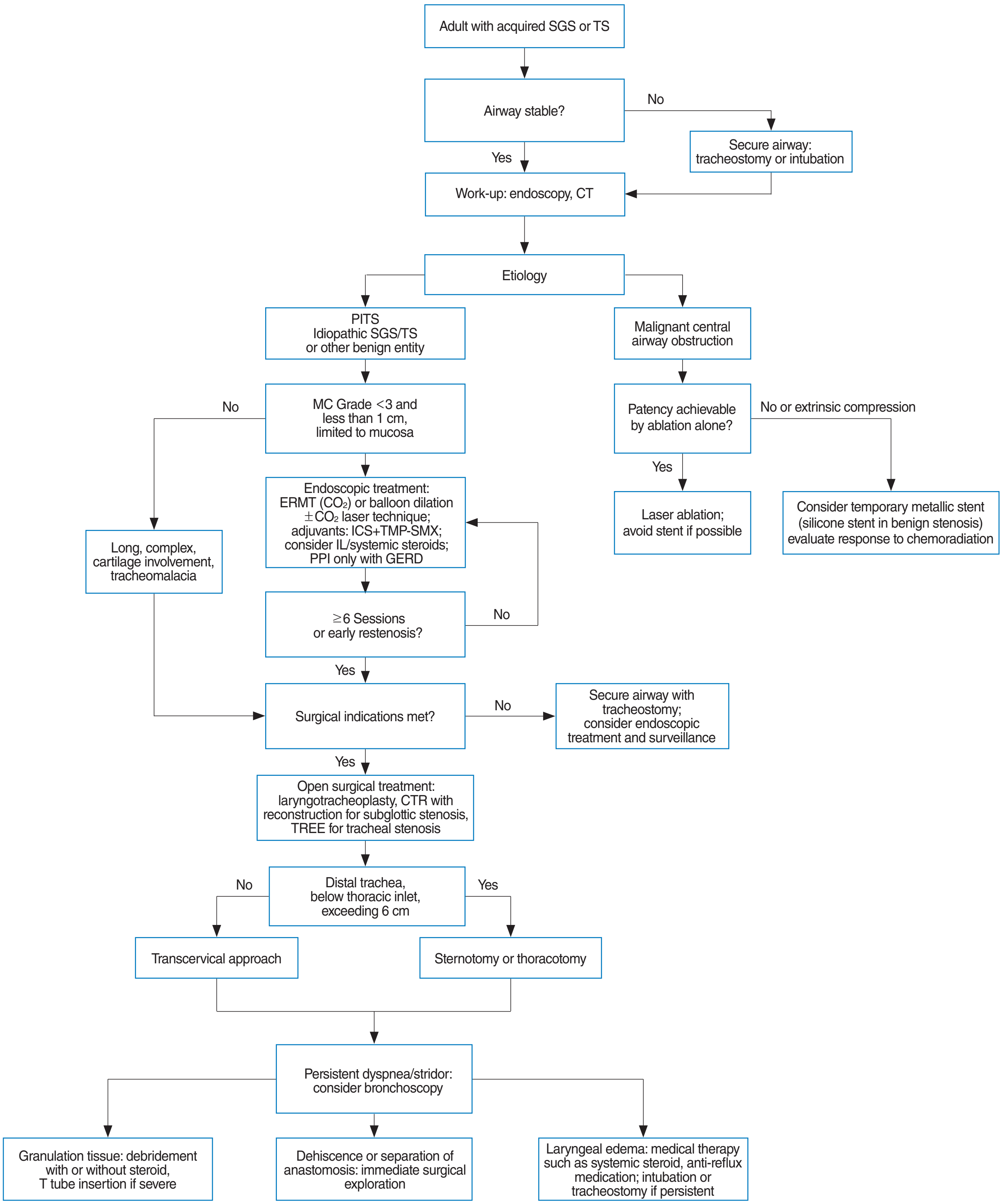

Fig. 1. A decision-support flowchart for the management of adult subglottic and tracheal stenosis. SGS, subglottic stenosis; TS, tracheal stenosis; CT, computed tomography; PITS, post-intubation tracheal stenosis; MC, Myer-Cotton; ERMT, endoscopic resection with adjuvant medical therapy; ICS, inhaled corticosteroid; TMP-SMX, trimethoprim/sulfamethoxazole; IL, intralesional; PPI, proton pump inhibitor; GERD, gastroesophageal reflux disease; CTR, cricotracheal resection; TREE, tracheal resection and end-to-end anastomosis.

head and neck surgeons (otolaryngologists), 3 were thoracic surgeons, and 3 were pulmonologists specializing in interventional pulmonology.

Each member reviewed the 17 recommendations via email and provided feedback. Members selected one of five responses for each recommendation: "fully agree," "agree," "neither agree nor disagree," "disagree," or "totally disagree." A recommendation was accepted if at least 70% of panel members selected "fully agree" or "agree." Although Delphi processes often involve multiple rounds, only a single round was required in this study because consensus was achieved for all recommendations (Supplementary Table 2). A visual summary of recommendations was created as a decision-support flowchart (Fig. 1), which all contributing authors reviewed and confirmed through a structured feedback process.

GUIDELINES FOR THE MANAGEMENT OF ADULT SUBGLOTTIC AND TRACHEAL STENOSIS

The organization of the Guidelines for the management of adult SGS and TS are summarized in Table 1, and the corresponding decision-support flow chart is presented in Fig. 1.

A. Initial evaluation

A1. What are the risk factors for subglottic and TS after endotracheal intubation and tracheostomy?

> Recommendation 1
> The risk factors for post-intubation and post-tracheostomy tracheal stenosis include obesity, prolonged cannulation, use of a larger endotracheal tube, and younger age.
> (Conditional recommendation, low-quality evidence)

SGS and TS may develop from a variety of causes, including iatrogenic injury, autoimmune diseases, radiation exposure, trauma, infections, congenital abnormalities, and idiopathic origins [2]. Each etiology is associated with distinct risk factors that influence the likelihood of developing stenosis. Among these causes, endotracheal intubation and tracheostomy are the most common, and the associated risk factors include obesity, the use of larger airway tube sizes, younger age, and prolonged cannulation duration [21,22]. Additionally, gastroesophageal reflux disease (GERD) and thermal inhalation injury may also contribute to the development of SGS or TS.

Obesity is widely recognized as a major risk factor for SGS and TS following intubation or tracheostomy. However, the definition of obesity varies across studies, with thresholds set at body mass index (BMI) $\geq$30 kg/m^2 [6,8,23,24] or BMI $\geq$25 kg/m^2 [25]. In a retrospective observational study of 357 patients who underwent tracheostomy with prolonged mechanical ventilation, 114 patients (32%) developed mild to moderate TS. Obesity (BMI $\geq$30 kg/m^2) was identified as a significant risk factor (odds ratio, 2.16; 95% CI, 1.29–3.63, P<0.01) [23]. A combined retrospective cohort and case-control study also identified obesity

Table 1. Organization of the guidelines for the management of adult subglottic and tracheal stenosis

Location key	Section	Item
A	Initial evaluation	R1-3
A1	What are the risk factors for subglottic and TS after endotracheal intubation and tracheostomy?	R1
A2	Do low-pressure cuffs and short-term intubation reduce the risk of TS in intubated patients?	R2
A3	What initial evaluations should be conducted for patients with subglottic and TS?	R3A, 3B
B	Endoscopic and adjuvant therapies	R4-6
B1	Are endoscopic procedures effective in alleviating subglottic or TS symptoms and improving pulmonary function?	R4
B2	Is there a preferred treatment method among endoscopic methods, such as mechanical dilatation, laser resection, or airway stent insertion for a specific situation?	R5A, 5B
B3	Are adjuvant chemical treatments (steroid injections and MMC) necessary to prevent recurrence after endoscopic intervention for subglottic and TS?	R6A, 6B
C	Surgical treatment	R7-9
C1	What are the indications for open surgical treatment of subglottic and TS?	R7A, 7B
C2	What are the preferred open surgical methods for the treatment of subglottic or TS?	R8
C3	What is the appropriate postoperative management for subglottic or TS, including complications and immediate postoperative care?	R9
D	Postoperative management and rehabilitation	R10-12
D1	Is postoperative bronchoscopy required to assess anastomosis-related problems in patients who have undergone surgery for subglottic or TS?	R10
D2	Is postoperative rehabilitation necessary to improve the QOL in patients who have undergone surgery for subglottic or TS?	R11
D3	Is post-interventional adjuvant therapy, such as systemic steroids, steroid inhalation, or PPIs, necessary to prevent recurrence of subglottic or TS?	R12A, 12B

R, recommendation; TS, tracheal stenosis; MMC, mitomycin-C; QOL, quality of life; PPI, proton pump inhibitor.

(BMI >30 kg/m^2) and the use of an initial tracheostomy tube size >6 as independent risk factors in multivariable analysis [8]. In a multi-institutional cohort study involving 1,175 tracheostomy patients, obese individuals (BMI >30 kg/m^2) intubated with endotracheal tubes >7.5 in size had a 9.9% incidence of airway stenosis, compared to 1.9% among obese patients with smaller tubes and 0.4% among non-obese individuals [24]. Furthermore, in a 3-year retrospective study of 371 adults undergoing tracheostomy at acute rehabilitation facilities, 28.5% (106 patients) developed LTS, and obese individuals (BMI ≥25 kg/m^2) had an increased risk of decannulation failure [25].

The use of larger airway tubes is another important risk factor. Li et al. [8] reported that using an initial tracheostomy tube >6 increased the likelihood of TS. Similarly, Halum et al. [24] reported a higher incidence of airway stenosis when endotracheal tubes >7.5 in size were used. Younger age has also been identified as a risk factor. In a cross-sectional analysis of 624,918 ventilator users who survived hospitalization without initial airway stenosis, 1,230 patients developed airway stenosis within 45 days of discharge (362 with laryngeal stenosis and 920 with TS). In this study, younger age, female sex, and chronic steroid use were identified as significant risk factors [7]. Prolonged placement of endotracheal tubes is another critical contributor. In a retrospective comparative study involving 74 patients with LTS and 106 patients with suspected airway stenosis, intubation longer than 48 hours and non-airway-related surgeries were identified as risk factors [26]. Similarly, Ledl and Mertl-Roetzer [27] noted that prolonged cannulation may increase the likelihood of stenosis in patients with long-term tracheostomy tubes.

The timing and technique of tracheostomy, however, appear to have minimal impact on the development of SGS and TS. In a systematic review of critically ill patients undergoing prolonged mechanical ventilation, the timing of tracheostomy did not significantly affect the incidence of LTS. Among 966 patients, 8.9% developed stenosis when tracheostomy was performed within 7 days, compared to 8.1% when performed between 8 and 24 days [28]. Additionally, a systematic review of 29 studies (9 RCTs, 6 non-randomized comparative studies, and 14 cohort studies) found no significant difference in TS incidence between surgical and percutaneous tracheostomy techniques [29].

GERD has also been recognized as a risk factor for LTS [30]. In a case-control study of 22 patients with idiopathic SGS and asymptomatic reflux patients, 12 patients (55%) with idiopathic SGS exhibited symptoms of GERD, and pepsin was detected in 59% of cases. No pepsin was found in the control group. GERD was confirmed in 70% of patients using dual-probe 24-hour pH monitoring [31]. Thermal inhalation injuries represent an additional potential cause of LTS. In a retrospective cohort study of 129 patients with inhalation injuries, 8 patients (6%) developed LTS. Greater total body surface area burns, more severe inhalation injury grades, and stronger inflammatory responses were identified as significant risk factors [32].

A2. Do low-pressure cuffs and short-term intubation reduce the risk of TS in intubated patients?

> Recommendation 2
> Using low-pressure cuffs and limiting the duration of intubation may effectively reduce the risk of tracheal injury.
> (Strong recommendation, high-quality evidence)

In the setting of an overinflated tracheal cuff, the most common mucosal changes include hyperemia, ischemia, ulceration, and granuloma formation [33]. Stauffer et al. [34] reported that 95% (39/41) of intubated patients and 91% (20/22) of tracheostomy patients demonstrated laryngotracheal injuries at autopsy. However, data on the progression from ischemic tracheal lesions to clinically significant TS remain limited, as such lesions typically occur in the region of cuff contact. Patients who experience prolonged endotracheal intubation followed by tracheostomy are at higher risk for laryngeal injury and TS compared with those who undergo short-term intubation before tracheostomy [34]. Nevertheless, no significant correlation was found between the duration of intubation and the severity of mucosal injury at autopsy.

In a prospective study, 200 intubated patients were divided into three groups based on duration of intubation (group I: 2–5 days, group II: 6–10 days, group III: 11–24 days). Patients in group II exhibited a higher incidence of severe complications, and TS in this group tended to involve continuous damage extending from the posterior glottis to the cervical trachea [35]. Sugerman et al. [36] conducted a randomized, prospective study comparing early tracheostomy (days 3–5) with late tracheostomy (days 10–14). Although no statistically significant differences were found between groups, prolonged intubation was associated with a trend toward increased vocal cord ulceration and subglottic inflammation. Importantly, no patients in this study demonstrated late vocal cord or laryngeal stenosis based on clinical or laryngoscopic evidence of prolonged endotracheal tube–related injury.

Overinflation of the tracheal cuff above 30 cm H_2O has been identified as a major risk factor for tracheal injury [4]. The use of high-volume low-pressure cuffs has been associated with a lower incidence of clinically significant stenosis (0.01%–1%) in more recent studies [37,38]. Nonetheless, hyperinflation of the endotracheal cuff remains the most frequent cause of tracheal ischemia and related complications [39]. Current guidelines recommend maintaining cuff pressure around 25 cm H_2O in critically ill, intubated, mechanically ventilated patients [40]. In a RCT involving 28 patients requiring intubation and mechanical ventilation for 24 hours, participants were assigned to either a high-volume low-pressure cuff or a low-volume high-pressure cuff. Fiberoptic bronchoscopy at extubation revealed significantly fewer ischemic tracheal lesions in the high-volume low-pressure cuff group [3]. However, ischemic tracheal injury can still occur in patients intubated with high-volume low-pressure cuffs [41,42]. Patients exposed to prolonged intubation and elevated cuff pressures remain at increased risk for ischemic tracheal damage.

A3. What initial evaluations should be conducted for patients with subglottic and TS?

> Recommendation 3A
> Direct visualization of subglottic or tracheal stenosis is essential for determining its location, severity, extent, and features. This can be achieved through endoscopic techniques, such as bronchoscopy or laryngoscopy.
> (Strong recommendation, moderate-quality evidence)

The initial evaluation of patients with SGS and TS begins with a comprehensive assessment of medical history and physical examination [43]. Preoperative evaluation should focus on determining the severity, location, extent, and clinical features of the stenosis using bronchoscopy and CT. Additional assessments, including pulmonary function tests and laboratory workups, may be necessary, as factors such as etiology, prognosis, life expectancy, and tolerance to procedures are critical in selecting the appropriate treatment strategy.

Endoscopy performed with either bronchoscopy or laryngoscopy (rigid or flexible) is a conventional diagnostic tool for SGS and TS. Bronchoscopy provides direct visualization and detailed information regarding the location, severity, vertical extent, and characteristics of the lesion with high precision and reliability [44]. It is also useful for detecting concurrent conditions such as dynamic airway lesions and posterior glottic stenosis, and for differentiating soft, pliable tissue from dense scar tissue [45].

Historically, rigid bronchoscopy was considered the gold standard for diagnosing SGS and TS. However, this technique requires specialized training, technical expertise, and sedation, which may not be available in all healthcare settings. As a result, flexible bronchoscopy is widely used for diagnosing and assessing tracheal lesions before surgery. During the procedure, precautions are required in patients with severe airway obstruction, as endoscopy may further compromise the airway. In such cases, rigid bronchoscopy under appropriate anesthesia and ventilation support is recommended, potentially combined with dilation procedures when needed [46]. As an invasive procedure, endoscopy carries potential complications, including laryngeal and expiratory reflex responses, laryngeal spasm, and issues related to low patient compliance. Despite these risks, endoscopic examination is essential for providing surgeons with accurate information about the patient's airway status before surgical intervention.

> Recommendation 3B
> Computed tomography with image processing is a noninvasive diagnostic tool that provides accurate measurements and dimensions of subglottic and tracheal stenosis.
> (Strong recommendation, moderate-quality evidence)

CT has become an essential noninvasive diagnostic modality for evaluating SGS and TS, particularly in patients with severe LTS [47,48]. Although earlier concerns were raised regarding CT limitations, technological advances such as three-dimensional reconstruction and virtual bronchoscopy have strengthened its diagnostic role [49-51]. Multiple studies comparing CT with endoscopic evaluation have demonstrated CT's high precision in assessing LTS [52-54]. Nevertheless, CT should complement rather than replace bronchoscopy. Bronchoscopy remains superior for detecting dynamic airway abnormalities, such as vocal fold paralysis and tracheomalacia, and for evaluating tissue color changes and mucosal irregularities [55]. However, continued improvements in CT image resolution and processing suggest an increasingly important role for CT in LTS assessment.

Effective treatment planning for SGS and TS requires a reliable system for staging disease severity. Several classification systems have been proposed, and the Myer-Cotton grading system is among the most widely used [56-58]. This system determines the maximum percentage of airway obstruction based on external diameters of endotracheal tubes and assigns stenosis grades accordingly. Although useful, the Myer-Cotton system largely focuses on the upper airway and does not fully capture the diverse features of TS. Consequently, newer classifications have been introduced, including one by Freitag et al. [59], which differentiates stenosis into structural and dynamic types and incorporates degree of obstruction, location, and transition zone features [60]. While no classification system provides definitive treatment guidance, staging assists in selecting appropriate therapeutic approaches. Therefore, accurate LTS staging should be accomplished through combined bronchoscopy and CT evaluation.

Pulmonary function testing (PFT) is an additional noninvasive diagnostic tool that can provide early indications of LTS [61]. The expiratory disproportion index is particularly useful for distinguishing LTS from other respiratory disorders. Studies have shown that PFT results correlate with the severity of anatomical stenosis and the degree of patient-reported dyspnea [62-64]. PFT can also be used to quantify treatment outcomes following endoscopic management of SGS. Given its noninvasiveness, cost-effectiveness, and clinical utility, PFT is beneficial for both assessment and follow-up of patients with TS [65]. Ultrasonography is another emerging noninvasive imaging technique that offers real-time evaluation with high mobility [66]. Studies have demonstrated that ultrasonography can effectively detect intrinsic tracheal wall lesions and extrinsic compressive abnormalities, with findings correlating well with CT results. Ultrasonography may serve as a practical diagnostic option, particularly in bedside assessments or in urgent situations where CT is not available.

B. Endoscopic and adjuvant therapies

B1. Are endoscopic procedures effective in alleviating subglottic or TS symptoms and improving pulmonary function?

Recommendation 4
Endoscopic procedures are recommended as a non-open surgical treatment option for subglottic and TS to alleviate symptoms and improve pulmonary function.
(Conditional recommendation, low-quality evidence)

The management of SGS and TS varies depending on severity and underlying etiology. SGS refers to airway obstruction occurring between the glottis and the first two tracheal rings. Treatment is often challenging due to high restenosis rates. When symptoms are mild, conservative management is generally preferred over surgical intervention. In more severe cases, laryngotracheal framework surgery to remove the stenotic segment is considered the most definitive treatment [67,68]. Although open surgery can be effective, it carries substantial risks of irreversible complications. Therefore, non-surgical approaches—including endoscopic treatment, balloon dilation, laser surgery, steroid therapy, and the application of mitomycin-C (MMC)—are frequently proposed as alternatives [69-75].

Shadmehr et al. [71] reported that steroid therapy combined with balloon dilation effectively managed TS caused by intubation within 6 months, significantly reducing the number of patients requiring surgical intervention. Maldonado et al. [72] demonstrated that in patients with idiopathic SGS, a regimen combining 220 mcg fluticasone inhalation twice daily, endoscopic treatment using a CO_2 laser, topical MMC, and medical therapy with proton pump inhibitors (PPIs) and antibiotics resulted in a low recurrence rate. Similarly, Nouraei et al. [73] found that early endoscopic dilation (ED) with steroid therapy improved symptoms and pulmonary function in TS caused by intubation. Queiroga et al. [74] also reported that MMC improved symptoms when combined with ED. These studies highlight the value of ED in conjunction with adjuvant medical therapy in the management of SGS and TS.

However, several studies have indicated limitations. Lorenz [67] found that although ED can temporarily relieve stenosis, restenosis occurs in 40%–70% of patients within months. Yung et al. [76] reported no significant improvement in stenosis or pulmonary function when MMC was used during endoscopic procedures for LTS. The effectiveness of medical therapies for SGS and TS remains difficult to standardize due to limited large-scale, prospective studies and insufficient evidence supporting their efficacy.

B2. Is there a preferred treatment method among endoscopic methods, such as mechanical dilatation, laser resection, or airway stent insertion for a specific situation?

Recommendation 5A
Endoscopic resection using a CO_2 laser with adjuvant medical therapy is recommended as a first-line treatment for patients with idiopathic SGS. For the adjuvant regimen, consider inhaled corticosteroids and trimethoprim–sulfamethoxazole. PPIs may be included in patients with confirmed reflux symptoms or objective evidence of GERD.
(Conditional recommendation, low-quality evidence)

Currently, well-designed RCTs comparing endoscopic treatment modalities for specific airway conditions remain scarce. However, an international prospective cohort study evaluated outcomes among 603 patients treated with ED using balloon or rigid bougie dilation, 121 patients undergoing endoscopic resection with adjuvant medical therapy (ERMT) using a CO_2 laser, and 86 patients undergoing cricotracheal resection (CTR) [77]. In the ERMT group, the stenotic airway was resected in quadrants using a CO_2 laser, followed by long-term adjuvant therapy consisting of inhaled corticosteroids, PPIs, and trimethoprim/sulfamethoxazole. In this study, the recurrence rate was lowest in the CTR group (1.2%) compared to the ERMT group (12.4%) and the ED group (28.0%). However, Voice Handicap Index-10 scores among successfully treated patients were poorest in the CTR group (13.0 points), compared with 3.5 points in the ERMT group and 10.0 points in the ED group. Moreover, serious complications were more common in the CTR group, including temporary tracheostomy or T-tube placement (9.3%), additional unplanned operations (9.3%), permanent unilateral vocal cord palsy (8.1%), and anastomotic leakage (3.5%). In contrast, complications in the ERMT group included medication-related rash or nausea (22.3%), temporary tongue paresthesia (11.6%), and dental injury (3.3%), while the ED group experienced temporary tongue paresthesia (13.9%), dental injury (5.6%), and transient subcutaneous emphysema (0.5%). These complications were largely transient or clinically insignificant.

Overall, ED was associated with higher recurrence rates, whereas CTR provided the most durable airway patency but carried greater perioperative risk and resulted in the poorest long-term voice outcomes. ERMT demonstrated better disease control than ED and had minimal impact on vocal function, making it a favorable treatment option. Although GERD is commonly observed in idiopathic SGS and TS and is considered a contributing factor, clinical evidence supporting PPI use is inconsistent and generally of low quality [30,31]. Retrospective studies suggest a possible reduction in recurrence with aggressive adjuvant regimens—including inhaled corticosteroids, PPIs, and trimethoprim–sulfamethoxazole—but these findings have not reached statistical significance [72]. Given these limitations, these guidelines do not recommend routine PPI use as first-line adjuvant therapy after endoscopic intervention; instead, PPIs may be considered for patients with confirmed GERD symptoms or objective evidence of reflux.

Recommendation 5B
For TS other than idiopathic SGS, the panel does not recommend a single specific endoscopic method due to the lack of comparative studies. It is advisable to employ a combination of techniques tailored to each patient's clinical condition, considering the strengths and limitations of each procedure.
(Expert opinion)

Endoscopic interventions, such as mechanical dilation (ballooning or rigid bougie), laser therapy, and stent insertion (silicone or metallic), have been used in conditions including malignant central airway obstruction (MCAO), post-intubation tracheal stenosis (PITS), and post-tuberculous tracheobronchial stenosis. However, these approaches lack standardization, as most available studies are retrospective, single-center, and include small patient samples, making it difficult to draw definitive conclusions.

A recent RCT (the SPOC trial) evaluating bronchoscopic interventions in MCAO did not meet statistical significance for its primary endpoint [78]. However, the stent arm demonstrated sustained improvement in dyspnea scores at 1 year for a secondary endpoint. Subgroup analysis showed significant benefits of stent placement in patients who concurrently received chemotherapy, radiotherapy, or palliative treatment. A retrospective study comparing silicone and metallic stents in 70 patients with MCAO reported higher complication rates in the metallic stent group, although the difference was not statistically significant after multivariable adjustment [79]. Based on these findings, stent insertion should be used cautiously, and only if airway patency cannot be restored through ablation therapy alone. Stents may be considered in cases involving extrinsic compression from tumors. In treatment-naïve patients, however, it is advisable to observe the response to chemo-radiation therapy before considering stent placement. Given the known complications associated with stents, silicone stents are preferred over metallic stents due to their lower complication rates and ease of management. No head-to-head comparative studies have evaluated outcomes of silicone versus metallic stents in benign stenosis. Some reports indicate that metallic stents carry a risk of severe complications, including stent fracture and esophageal fistula formation [80,81], whereas silicone stents have fewer complications and are easier to manage, making them the preferred option for benign airway stenosis [82,83]. Metallic stents may be temporarily useful for approximately 30 days in situations where silicone stent insertion is technically difficult [84]. Among metallic stents, uncovered types are preferred over covered stents because they better preserve mucociliary clearance, thereby reducing stent-related complications [85].

Studies on benign airway stenosis have also been heterogeneous regarding target conditions and procedural approaches, making it difficult to determine the comparative effectiveness of specific interventions. Tables 2 [77-79,85-89] and 3 [80-82,84,90] summarize recent studies involving homogeneous target diseases and procedure types with sample sizes exceeding 50. In general, procedures can be categorized into non-stent interventions (e.g., mechanical bougination, balloon dilation, laser cauterization) and stent-based interventions. Non-stent procedures have demonstrated favorable success rates in cases of simple stenosis [86]. Balloon dilation has shown better outcomes compared with rigid bougie dilation [87], and combining laser cauterization to release fibrotic bands with balloon dilation has been shown to be more effective than balloon dilation alone [86]. Consequently, balloon dilation has become the preferred method for treating tracheal and SGS , offering clear advantages over rigid dilation techniques such as bougies and endotracheal tubes [91]. Compared with rigid dilation, balloon dilation applies uniform radial force, expanding the stenotic segment without producing the shear-related trauma associated with rigid bougination. This minimizes mucosal injury and reduces the likelihood of subsequent restenosis [92,93]. Although rigid dilation methods have historically resulted in variable and frequently suboptimal outcomes, balloon dilation has consistently demonstrated improved efficacy with fewer complications [94,95]. Recent systematic reviews highlight that balloon dilation is particularly effective in cases of acute stenosis, where the immature, pliable scar tissue responds more favorably than in chronic lesions [91]. Despite these advantages, clinicians should exercise caution regarding balloon size, inflation pressure, and inflation duration to minimize the risk of airway trauma [96,97]. Balloon dilation often requires multiple treatment sessions, with long-term success rates increasing significantly up to six sessions. However, additional sessions beyond this point do not appear to yield further benefit. If more than seven sessions become necessary, alternative approaches should be considered [90].

B3. Are adjuvant chemical treatments (steroid injections and MMC) necessary to prevent recurrence after endoscopic intervention for subglottic and TS?

> Recommendation 6A
> The use of adjuvant MMC may be considered following endoscopic intervention for the management of subglottic and TS.
> (Conditional recommendation, low-quality evidence)

Several adjuvant therapies, including MMC and steroids, have been evaluated to reduce the risk of restenosis following treatment of LTS. Basic science research indicates that topical MMC may be beneficial in airway stenosis by inhibiting fibroblast proliferation, decreasing collagen deposition, and inducing fibroblast apoptosis [98]. Although preclinical findings are promising, the clinical evidence supporting MMC in LTS remains uncertain. Most available studies suggest that topical MMC may prolong symptom-free intervals and extend the time between surgical interventions, but these observations largely rely on retrospective case series [88,99-101]. An RCT in pediatric patients aged 2 to 17 years assessed the effect of MMC following laryngotracheal reconstruction. During bronchoscopy at extubation or stent removal, patients received either 0.2 mg/mL MMC (n=11) or saline (n=13) applied for 2 minutes. At the 1-year interim analysis, the Data Safety and Monitoring Committee recommended discontinuing the trial due to lack of observable benefit (Fisher's exact test=1.00), failing to reject the null hypothesis for MMC in pediatric LTS [102]. Another RCT compared two MMC appli-

Table 2. Comparative studies on endoscopic methods

Study	Study design (registration period)	Etiology of airway stenosis	Compared procedure	Results
Glikson et al. (2021) [87]	Retrospective single center (2011–2017)	Benign (PITS=55, idiopathic=9, others=5)	Balloon (n=40) vs. rigid bougie (n=29)	Remission after >8 weeks: 71% vs. 31% (P<0.05) Complication: 2.9% vs. 4.2%
Ortiz-Comino et al. (2021) [79]	Retrospective single center (2012–2017)	Malignant obstruction (lung cancer=52, others=18)	Silicone stent (Dumon=29) vs. metallic stent (aerstent=41)	Adjusted HR of complication risk for aerstent=1.41; P=0.49 HR of mucostasis risk for aerstent=1.77; P=0.04
Gelbard et al. (2020) [77]	Prospective multicenter cohort study (2015–2017)	Idiopathic subglottic stenosis (n=810)	Endoscopic dilatation (n=603) vs. endoscopic resection with adjuvant medical therapy (n=121) vs. open surgery (n=86)	Recurrence: 28.0% vs. 12.4% vs. 1.2% VHI-10 score: 10.0 points vs. 3.5 points vs. 13.0 points
Dutau et al. (2020) [78]	Multicenter RCT (2009–2011)	Malignant obstruction (NSCLC=78)	Silicone stents (n=40) vs. no stents (n=38)	Due to limited academic grants and French regulations, failure to achieve goals (planning=170 in each group) The main endpoint (1-year survival rate) could not be statistically answered due to too small number of patients Improvement in dyspnea score was maintained longer in the stent arm compared to the no-stent arm
Wu et al. (2020) [89]	Retrospective single center (2016–2019)	Benign (PTBS=24, PITS=19, POTS=9)	Montgomery T-tube (n=25) vs. balloon (n=27)	Efficiency (effective+cured): 84% vs. 63% (P<0.05) Secondary outcomes (PaO_2, $PaCO_2$, dyspnea score, QOL, complication): all excellent in T-tube group than balloon group
Xiong et al. (2019) [85]	Retrospective single center (2003–2016)	Benign (PTBS=55, PITS=53, others=8)	Covered stent (n=59) vs. uncovered stent (n=72)[a]	Resolution: 53% vs. 77% Complication (sore throat, granulation tissue, mucostasis, recurrent stenosis): all excellent in uncovered stent group than covered stent group
Bo et al. (2018) [86]	Retrospective single center (2013–2016)	Benign (PITS=43)	Electrocautery needle knife with balloon (n=32) vs. ballooning only (n=11)	Cure rates in each situation Simple web-like stenosis: 18/18 vs. 3/5 Bottleneck stenosis: 3/8 vs. 0/3 Mixed constriction: 3/6 vs. 0/3
Feinstein et al. (2017) [88]	Retrospective single center (1995–2015)	Benign (idiopathic=47, PITS=31, GPA=9, others=14)	Laser with balloon (n=117) vs. balloon (n=96) vs. laser (n=6)[a] Mitomycin application (n=144) or not (n=75)[a] Steroid injection (n=93) or not (n=126)[a]	The interval to subsequent operation 398±502 days (laser with balloon) vs. 463±530 days (balloon) vs. 179±193 days (laser): no difference 474±570 days (with mitomycin) vs. 317±351 days (without mitomycin): significant difference 415±530 days (with steroid) vs. 424±496 days (without steroid): no difference

PITS, post-intubation or tracheostomy tracheal stenosis; HR, hazard ratio; VHI-10, Voice Handicap Index-10; RCT, randomized controlled trial; NSCLC, non-small cell lung cancer; PTBS, post-tuberculous bronchobronchial stenosis; POTS, post-operative tracheobronchial stenosis; PaO_2, arterial partial pressure of oxygen; $PaCO_2$, arterial partial pressure of carbon dioxide; QOL, quality of life; GPA, granulomatosis with polyangiitis.
[a]These numbers refer to the number of procedures, not the number of patients.

cations (n=14), administered 3–4 weeks apart, with a single application (n=12) following surgical treatment. Although the two-application group showed lower restenosis rates during the initial 2–3 years, recurrence rates were similar at 5 years (69% for two applications vs. 70% for one application), suggesting that MMC may delay but not ultimately prevent restenosis [103]. The most recent RCT involving 15 patients (9 placebo, 6 MMC) found no significant differences in outcomes such as time between interventions, peak inspiratory flow, or symptom scores [76]. Because these studies are limited by small sample sizes, definitive conclusions regarding MMC's efficacy in LTS remain elusive.

At present, the optimal timing, dosage, and duration of MMC application have not been established. A large-scale, well-designed RCT is needed to clarify the efficacy and safety of MMC as an adjuvant treatment for LTS [98].

Recommendation 6B
Intralesional corticosteroid injections may be considered as an adjuvant therapy following endoscopic intervention.
(Conditional recommendation, low-quality evidence)

In a preclinical RCT using a rabbit subglottic model, steroids were shown to reduce the risk of iatrogenic SGS. Administration of systemic dexamethasone prior to procedures that may injure the subglottis, such as traumatic intubation, was effective in reducing the development of iatrogenic SGS [104]. Most clinical

Table 3. Research results for each method of bronchoscopy

Study	Study design (registration period)	Etiology of airway stenosis	Procedure	Results
Zhou et al. (2021) [84]	Retrospective single center (2015–2019)	Benign (PTBS=58)	SEMS as a transition to silicone stenting (n=45), silicone stenting only (n=13)	SEMS placement=28±11 days, no complications Temporary SEMS implantation could serve as a bridge to silicone stenting.
Liang et al. (2019) [90]	Retrospective single center (2005–2012)	Benign (PTBS=76, PITS=23, others=12)	Flexible bronchoscopic balloon dilatation	Cumulative long-term effective rate was significantly increased up to the 6th session of treatment (93.7%), but was no longer significantly increased after the 6th session.
Karush et al. (2017) [82]	Retrospective single center (2002–2015)	Benign (n=63, PITS=49)	Silicone stent (n=243)	Cause of re-intervention Mucostasis=60%, stent migration=28%, respiratory failure and intubation=8%
Fortin et al. (2017) [81]	Retrospective single center (2011–2015)	Benign (PITS=20, lung transplantation=8, idiopathic=2)	Third-generation SEMS (Silmet stent)	Clinical success rate=40.7% Stent removal due to stent-related complications=50%
Serrano et al. (2013) [80]	Retrospective single center (1997–2005)	Benign=74, malignant=12	Metallic stents (variable brands) under flexible bronchoscopy	Technical success=100% Complication=26.7% (restenosis caused by granulation/fibrosis=15.1%, stent fracture=5.8%, esophageal fistulization=2.3%)

PTBS, post-tuberculous bronchial stenosis; SEMS, self-expanding metallic stent; PITS, post-intubation tracheal stenosis.

studies investigating steroid therapy for LTS support the use of systemic corticosteroids or serial intralesional steroid injections as effective treatments, either as primary therapy or as adjuvants to surgical procedures such as balloon dilation. These therapies have been associated with longer symptom-free intervals and extended periods between interventions, although most studies are retrospective case series [105-113]. In a study of 105 patients with PITS (50 receiving steroids, 55 not receiving steroids), systemic corticosteroid therapy (prednisolone 15 mg/day) significantly increased the interval between bronchoscopic dilation procedures (22 days) and reduced the number of required operations (17% in the steroid group vs. 73% in the non-steroid group). Additionally, the required resection length of stenotic airway was significantly shorter (5.3 mm) in the steroid group, suggesting that early, low-dose systemic corticosteroid therapy may have a meaningful therapeutic effect [71]. Conversely, an RCT evaluating the use of inhaled fluticasone propionate following balloon dilation for LTS found no significant benefit in spirometry parameters during short-term postoperative follow-up [68]. Although the timing, dosage, and duration of steroid therapy for LTS remain undefined, available evidence suggests that serial intralesional steroid injections have peak systemic effect 1 day after injection, with homeostasis restored within 1 week or shortly thereafter. A regimen involving serial injections every 3 to 5 weeks, as proposed by Franco et al. [114], is considered appropriate and minimizes the risk of complications from prolonged supraphysiologic glucocorticoid exposure [109]. Although further large-scale, rigorous RCTs are needed to establish standardized protocols for steroid use in LTS, current evidence indicates that systemic corticosteroids and intralesional steroid injections may provide meaningful benefit as adjuvant therapies.

C. Surgical treatment

C1. What are the indications for open surgical treatment of subglottic and TS?

> Recommendation 7A
> Tracheal or CTR with airway reconstruction should be considered when endoscopic management fails to achieve a successful outcome.
> (Strong recommendation, high-quality evidence)

The effective management of SGS or TS must be guided by the etiology, severity, and anatomical location of the stenosis. Endoscopic approaches are typically preferred as first-line treatment due to their minimally invasive nature and relatively low morbidity. Commonly used techniques include balloon dilation, laser therapy, and stent placement [115]. However, endoscopic treatment may not provide durable long-term relief, especially in cases involving complex or recurrent stenosis.

PITS and post-tracheostomy TS are the most common forms of benign LTS, followed by idiopathic, autoimmune, and infectious etiologies [116]. Although endoscopic and medical treatments are often used initially, the overall management strategy should be based primarily on the complexity, length, and depth of the stenosis, as well as the presence of cricoid cartilage involvement [16]. Endoscopic therapy is appropriate for simple, web-like stenoses less than 1 cm in length and limited to mucosal involvement without cartilage destruction. In contrast, patients with more complex stenoses (i.e., those exceeding 1 cm, classified as higher Myer-Cotton grades, or involving cartilage damage) are better candidates for surgical resection of the affected airway segment. In such cases, surgery should be offered before attempting endoscopic procedures [117]. Careful patient selection is essential because both modifiable and non-modifiable factors, such as diabetes mellitus, prior tracheostomy, high subglottic involvement, and longer required resections (greater than 4–5 cm), are associated with increased risk of anastomotic complications [118]. Additionally, open surgical intervention must be approached cautiously in patients with active obstructive autoimmune inflammatory disorders, as these conditions may behave unpredictably and have a greater tendency to progress [11].

For patients in whom endoscopic treatment fails or is inappropriate, surgical options such as CTR or TR with airway reconstruction should be considered [119]. Strong recommendations supporting surgery after endoscopic failure are based on substantial clinical evidence demonstrating that surgical resection and reconstruction provide superior long-term outcomes. Studies consistently show lower recurrence rates following surgical intervention compared with repeated endoscopic procedures [120-122]. Furthermore, surgery corrects underlying structural abnormalities contributing to stenosis and thereby reduces the risk of recurrence [120,123]. In summary, while endoscopic approaches remain important first-line options, open surgical intervention should be prioritized when long-term resolution of stenosis is required.

> Recommendation 7B
> Tracheal or CTR with airway reconstruction should be considered for patients with TS involving tracheomalacia or cartilage collapse.
> (Strong recommendation, moderate-quality evidence)

Tracheomalacia is characterized by weakening and collapse of the tracheal cartilage, resulting in airway obstruction. This condition frequently coexists with LTS [124,125]. In such cases, endoscopic treatments are often insufficient because they cannot address the underlying mechanical instability of the airway. Surgical resection and airway reconstruction provide a more definitive solution by correcting the structural abnormalities associated with tracheomalacia or cartilage collapse [126]. These surgical approaches may reduce the need for repeated interventions and improve long-term QOL in affected patients [77,120,127,128]. As noted above, surgical management should be considered when endoscopic treatments fail or are unsuitable. For patients with SGS or TS complicated by tracheomalacia or cartilage collapse, CTR or TR with airway reconstruction may offer the most reliable and durable outcome.

C2. What are the preferred open surgical methods for the treatment of subglottic or TS?

> Recommendation 8
> TR with end-to-end anastomosis or CTR with laryngotracheal reconstruction should be considered for patients with multi-segmental TS or subglottic TS.
> (Strong recommendation, moderate-quality evidence)

Multi-segmental TS involves multiple tracheal segments and is associated with reduced endoscopic treatment efficacy and higher recurrence rates [129]. In these cases, TR with end-to-end anastomosis or CTR with laryngotracheal reconstruction is recommended, as both approaches have demonstrated satisfactory functional outcomes in terms of airway patency and voice quality [130].

Among available surgical techniques, TR with primary anastomosis is widely considered the standard of care for adult cases involving less than two-thirds of the tracheal length, consistently yielding favorable outcomes [131-134]. The choice of surgical approach depends on the location and length of stenosis. A transcervical incision typically provides adequate exposure for stenoses confined to the upper and mid trachea, with resections of up to approximately 4 cm [135-137]. Longer stenotic segments, particularly those exceeding 6 cm or involving the mid to distal trachea, may require a more extensive approach, such as median sternotomy or thoracotomy. Sternotomy is particularly indicated when stenosis extends into the distal third of the trachea or below the thoracic inlet, offering optimal access and mobilization needed for tension-free anastomosis [132,138,139]. Extensive intrathoracic dissection, such as right hilar mobilization or dissection of pulmonary ligaments and vessels, may also necessitate sternotomy [140].

The recommendation for surgical resection and reconstruction in multi-segmental TS is strongly supported by clinical studies [133,134]. These studies report improved long-term outcomes, lower recurrence rates, and enhanced QOL following surgical resection compared with endoscopic interventions. TR or CTR involves excising the stenotic tracheal segments or affected cricoid cartilage and reconstructing the airway through end-to-end anastomosis [141]. By removing the entire stenotic region, including associated fibrosis or scar tissue, surgical resection effectively restores airway patency and reduces recurrence risk [142]. A systematic review found that adult LTS patients who underwent laryngotracheal resection with anastomosis required fewer surgical procedures compared with those treated with endoscopic interventions or laryngotracheal reconstruction involving cartilage augmentation or grafting [143]. However, in cases with glottic involvement, cartilage grafting may be required to expand the glotto-subglottic space [144].

C3. What is the appropriate postoperative management for subglottic or TS, including complications and immediate postoperative care?

> Recommendation 9
> Early extubation, combined with the use of appropriate pharmacologic agents, can help prevent reintubation or additional surgical interventions.
> (Conditional recommendation, low-quality evidence)

Complications following TR with end-to-end anastomosis or CTR with laryngotracheal reconstruction can be broadly categorized into anastomotic and non-anastomotic complications. Anastomotic complications include granulation tissue formation, tracheal restenosis, varying degrees of anastomotic separation, and fistula formation involving the innominate artery (tracheoinnominate fistula) or esophagus (tracheoesophageal fistula). Non-anastomotic complications include laryngeal edema and glottic dysfunction, which occur with moderate frequency following TR. Additional postoperative problems may include wound infections (3%–10%), impaired swallowing (2%–4%), and postoperative hoarseness (5%) [118,145].

Immediate extubation in the operating room is preferred for patients undergoing TR or CTR with airway reconstruction. When extubation is delayed due to edema, a temporary uncuffed endotracheal tube may be placed until a second extubation attempt becomes feasible. If extubation continues to be unsuccessful, tracheostomy may be required [118,146]. Postoperatively, the neck is typically maintained in gentle flexion using a guidance suture when necessary, although some institutions omit this suture to shorten hospital stay [147].

Minimizing complications requires meticulous perioperative care. Prophylactic antibiotics, GERD management, and appropriate sedation protocols can decrease intensive care unit stays and reduce the risk of unplanned extubation [148]. Vomiting and retching can be catastrophic in patients with a fresh tracheal anastomosis due to the risk of sudden neck hyperextension and aspiration of gastric contents. Prevention and management of postoperative nausea, using non-narcotic pain control and antiemetics, are therefore essential [145].

Granulation tissue formation may range from mild mucosal changes to severe airway obstruction and typically occurs days to weeks after surgery [149]. Symptoms of airway obstruction should prompt bronchoscopy to confirm the diagnosis. Local debridement is often sufficient, and corticosteroid injections may provide additional benefit [150]. In severe cases where granulation tissue causes significant obstruction, placement of a Montgomery T-tube may be necessary, and in the most extreme cases, reoperation may be required [151]. Although endoscopic laser treatment has been used to manage granulation tissue in patients with airway stents, its efficacy at airway anastomoses remains inconclusive.

Tracheal restenosis may result from anastomotic issues or from the patient's underlying pathology. Patients with PITS are particularly vulnerable because diseased tracheal segments may remain following the initial surgery. Restenosis usually develops over months and can arise due to factors such as tension on the anastomosis, ischemia, subclinical anastomotic separation, or a combination of these [152]. When balloon dilation fails to provide sustained relief, reoperation is indicated. A Montgomery T-tube may be used temporarily to stabilize the airway before re-resection or serve as a permanent solution when insufficient healthy tracheal tissue remains for further reconstruction [153].

Laryngeal edema is a relatively common complication following cricoid cartilage resection [145,154]. Patients may present with hoarseness, a husky voice, and, in more severe cases, stridor. Flexible endoscopic evaluation is typically diagnostic and helps exclude anastomotic separation. Mild edema is managed with steroids, diuretics, nebulized epinephrine, and head elevation. When airway compromise is suspected, intubation with a small, uncuffed endotracheal tube may be required. For edema that persists despite several days of medical therapy and intubation, tracheostomy is indicated [155]. Successful postoperative management of TR requires vigilant perioperative monitoring and timely intervention. Early recognition and treatment of complications are essential for maintaining airway patency.

D. Postoperative management and rehabilitation

D1. Is postoperative bronchoscopy required to assess anastomosis-related problems in patients who have undergone surgery for subglottic or TS?

> Recommendation 10
> Bronchoscopy should be considered after subglottic or TS surgery. In cases of airway symptoms such as stridor, urgent bronchoscopy is recommended to identify anastomosis-related complications.
> (Conditional recommendation, very low-quality evidence)

Although the efficacy and optimal timing of postoperative bronchoscopy have not been clearly established, most review articles and expert opinions recommend routine surveillance bronchoscopy following LTS surgery. Postoperative bronchoscopy allows early detection of complications and facilitates timely treatment. Follow-up bronchoscopy is generally recommended 1 week [145, 156-160] or 2 weeks after surgery [158,160,161]. Frequent bedside bronchoscopy combined with pulmonary toileting is also important for managing secretion clearance at the anastomosis site [162].

This recommendation applies not only to open surgical procedures but also to ED [163]. Bronchoscopy is essential for evaluating complications and performing additional interventions when necessary, including further dilation, stent placement, or electrocautery. Postoperative bronchoscopy plays a major role in diagnosing edema, managing secretion retention, and evaluating anastomotic healing [156]. Surveillance bronchoscopy performed within 1 week is important for detecting anastomotic complications before progression to wound infection [157]. Direct visualization of the anastomosis remains the most accurate method for assessing healing [145].

Early bronchoscopic evaluation is indicated whenever anastomotic complications are suspected, as these may lead to significant morbidity or mortality. Symptoms warranting urgent bronchoscopy include stridor, severe cough, hemoptysis, voice changes, excessive secretions, subcutaneous air, and wound infection [145,157]. Bronchoscopy can identify airway tears, rupture, hemorrhage, and granulation tissue formation. When indicated, rigid bronchoscopy may be employed for granulation removal, steroid injection, laser ablation, brachytherapy, balloon dilation, or stent placement [157]. If dehiscence or separation of the anastomosis is identified, immediate surgical exploration is recommended. A tracheostomy or T-tube may be necessary to secure the airway [164].

D2. Is postoperative rehabilitation necessary to improve the QOL in patients who have undergone surgery for subglottic or TS?

> Recommendation 11
> The panel is unable to make a recommendation for or against postoperative rehabilitation following subglottic or TS surgery due to insufficient evidence demonstrating its impact on improving QOL.
> (No recommendation, insufficient evidence)

Studies investigating the role of postoperative rehabilitation in improving QOL for patients who have undergone surgical or interventional treatment for SGS or TS are currently scarce. Existing literature is largely limited to retrospective analyses with small sample sizes. However, several studies have evaluated QOL and dyspnea outcomes and demonstrated significant improvements following surgical and interventional therapies [89,165-168].

Reconstructive surgery is associated with deterioration in voice function [167,169,170]. Houlton et al. [171] reported significant reductions in mean fundamental frequency (F0) and mean F0 for connected speech following CTR. Compton et al. [172] recently conducted serial assessments using the Voice Handicap Index after CTR and observed an initial decline in voice quality, which subsequently improved over time, returning to baseline by 2 years after surgery. In contrast, endoscopic approaches such as ED have been associated with improved voice outcomes [168,173,174]. Factors associated with favorable voice recovery after endoscopic procedures include greater distance from the vocal folds [175], lack of glottic involvement [173], and greater increases in airway caliber following intervention [174].

Swallowing function is generally preserved following airway reconstructive surgery, and dysphagia often improves as postoperative pain and edema resolve. Most patients can resume their preoperative diet shortly after surgery [175,176]. However, Haywood et al. [176] reported impaired swallowing and an increased risk of airway penetration during the acute postoperative period. Based on these findings, instrumental swallowing evaluations may help guide decisions regarding reintroduction or advancement of oral intake. Although current evidence regarding the benefits of postoperative rehabilitation is limited, targeted rehabilitation addressing voice and swallowing issues may help improve QOL and functional outcomes following treatment.

D3. Is post-interventional adjuvant therapy, such as systemic steroids, steroid inhalation, or PPIs, necessary to prevent recurrence of subglottic or TS?

> Recommendation 12A
> Corticosteroid therapy may be cautiously considered for patients with subglottic or TS after endoscopic dilatation.
> (Conditional recommendation, low-quality evidence)

The selection of postoperative adjuvant treatments for SGS or TS is not standardized. The limited number of cases and variations in clinical practice make drawing definitive conclusions difficult. Corticosteroids have traditionally been considered for adjuvant treatment of SGS and TS, and several studies support their use [10,177]. These therapies aim to reduce ongoing inflammation and influence tissue remodeling and scar formation [178]. Prior reports suggest that inhaled or locally applied corticosteroids may reduce granulation tissue formation, mucosal edema, and stricture severity, although the quality of evidence remains low [179,180]. Additionally, several studies propose that combining anti-reflux medications, oral trimethoprim–sulfamethoxazole, and inhaled corticosteroids with endoscopic interventions may have synergistic effects in reducing recurrence risk [72,77, 181]. However, the clinical utility of inhaled corticosteroids remains uncertain, as recent studies report mixed or negative results. A recent RCT involving 14 adults with LTS found no significant improvement in spirometry outcomes following balloon dilation among patients receiving inhaled corticosteroids compared with non-users [68]. Similarly, a prospective North American cohort study reported that inhaled corticosteroids were prescribed in approximately 7% of idiopathic SGS cases without demonstrating clear benefit [177].

In contrast, an RCT by Shadmehr et al. [71] suggested potential benefits of systemic corticosteroid therapy (prednisolone 15 mg/day) following ED for PITS. Although the trends toward longer intervals between ED procedures and fewer required operations did not reach statistical significance, the required airway resection length was significantly shorter in corticosteroid-treated patients. Despite these findings, systemic steroid use remains limited due to the potential risk of adverse effects and toxicities.

For open surgical interventions, corticosteroids are typically recommended during the first 48–72 hours postoperatively but should be avoided beyond this period because prolonged administration may impair wound healing. Although several studies have described adjuvant steroid use following open surgeries, their role in reducing recurrence remains unclear, and additional evidence is needed to determine their effectiveness [131,182]. Overall, the evidence regarding optimal timing, dosing, and route of corticosteroid administration remains insufficient. While systemic corticosteroids may improve certain therapeutic outcomes, the benefit of inhaled corticosteroids is not clearly supported by current data. Therefore, adjuvant corticosteroid therapy should be considered cautiously, balancing the potential benefits in reducing recurrence or procedural burden against the risk of adverse effects.

> Recommendation 12B
> PPI therapy may be considered for patients with subglottic or TS, presenting with evidence of GERD following ED. Although PPIs are commonly used in this setting, the evidence supporting their effectiveness in preventing stenosis recurrence remains inconclusive.
> (Conditional recommendation, low-quality evidence)

GERD is recognized as an important factor in the development and progression of idiopathic TS [30]. It is thought to contribute to collagen proliferation, disrupt the local microbiome, and promote granulomatous inflammation that ultimately leads to stenosis [30,183]. Although the exact pathogenesis remains unclear, clinical experience demonstrating symptom improvement with anti-reflux therapy has led to widespread adoption of PPIs as adjuvant treatment following endoscopic intervention [184,185].

Evidence suggests a high prevalence of GERD among patients with idiopathic SGS, and reflux-related mucosal inflammation and edema are believed to exacerbate airway narrowing [31,186]. However, recent findings have been mixed regarding the benefit of PPI therapy. For example, in a large international prospective cohort study of 810 patients, PPI use after ED did not significantly affect time to recurrence or pulmonary function test results, although PPI use was associated with improved pulmonary disease questionnaire scores [177]. Likewise, a retrospective cohort analysis demonstrated a trend toward reduced recurrence with aggressive medical therapy—including PPIs and inhaled corticosteroids—but this difference did not reach statistical significance [72].

Despite the lack of definitive evidence, PPIs are commonly incorporated into standard adjuvant therapy after endoscopic treatment for SGS and TS. Systematic reviews have supported their use based on observational data [10,82], and most clinical studies evaluating surgical or endoscopic interventions include PPI administration as part of their routine postoperative regimen [72,187].

Therefore, although the true impact of PPIs on preventing restenosis remains uncertain, their use is reasonable in patients with documented GERD or symptoms suggestive of reflux, as they may help reduce mucosal inflammation and improve symptom control. It should be noted, however, that evidence supporting their benefit after resection and end-to-end anastomosis is limited, and additional research is needed to clarify their role in this setting.

CONCLUDING REMARKS

The evidence-based recommendations presented in this study, developed through systematic analysis of clinical literature, are intended to assist healthcare professionals in making more confident and effective decisions regarding the optimal management of adult SGS and TS. While differing opinions may arise, the most appropriate treatment strategy for each patient will depend on individual clinical characteristics and the specific medical environment. These guidelines are not mandates and do not carry legal authority. Responsibility for treatment outcomes in real-world clinical settings rests solely with the clinicians providing care.

CONFLICT OF INTEREST

Seung Hoon Woo and Jeon Yeob Jang are editorial board members of the journal but were not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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SUPPLEMENTARY MATERIALS

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