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CASE REPORT

ECMO-assisted bronchoscopic therapy for severe tracheal stenosis: a case report and literature review

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Abstract

Background Severe tracheal stenosis is a life-threatening condition that often requires immediate intervention. Traditional surgical approaches may be challenging in critically ill patients, and bronchoscopic therapies have emerged as a less invasive alternative. However, maintaining adequate oxygenation and ventilation during these procedures can be challenging, especially in patients with near-complete airway obstruction. The manipulation of the already compromised airway during bronchoscopy can exacerbate respiratory insufficiency, leading to hypoxemia, hypercapnia, and even cardiac arrest. To address these challenges, extracorporeal membrane oxygenation (ECMO) has been increasingly utilized as a supportive measure during high-risk airway interventions. The use of ECMO in managing severe tracheal stenosis is a relatively recent development, with growing evidence supporting its role in facilitating complex airway interventions. By ensuring hemodynamic stability and adequate gas exchange, ECMO enables the safe and effective application of bronchoscopic techniques in critically ill patients who would otherwise be deemed unsuitable for such procedures. This approach can improve outcomes and expand treatment options for patients with severe tracheal stenosis.

Case presentation A 49-year-old woman, who underwent metal stent placement in her upper trachea 24 years ago due to tuberculous tracheal stenosis, was hospitalized due to worsening dyspnea. A thorough evaluation showed that the entire tracheal section was narrowed, with the smallest diameter measuring approximately 4–5 mm. Traditional respiratory support was inadequate for maintaining the patient's oxygen levels during bronchoscopy. We conducted bronchoscopic treatment with ECMO support, significantly alleviating the patient's dyspnea symptoms post-treatment. This is the first documented case of ECMO being utilized alongside bronchoscopy for patients with tracheal narrowing caused by tuberculosis.

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Conclusion The case study described a patient experiencing severe tracheal scar stenosis due to tuberculosis, who underwent successful treatment that included bronchoscopy supported by ECMO. Our effective handling of this case has provided crucial insights and strategies for managing similar situations in the future.

Keywords Extracorporeal membrane oxygenation, Severe airway stenosis, Benign cicatricial airway stenosis, Bronchoscopic interventional therapy

Background

Airway stenosis refers to the narrowing of the trachea and main stem bronchi caused by benign and malignant lesions [1]. This definition may also include lobar bronchi, such as the right intermediate bronchus [2]. The onset of malignant airway stenosis is frequently associated with primary or metastatic tumors. It can also result from the invasion or compression by thyroid and esophageal cancers, with lung cancer being the main cause in most instances. Benign airway stenosis is often influenced by factors like tracheal intubation, post-tracheotomy stenosis, tracheobronchial tuberculosis, and autoimmune diseases [3]. Severe airway stenosis poses a life-threatening risk that necessitates either surgical or bronchoscopic intervention. However, both surgical and bronchoscopic treatments can lead to hypoxemia or respiratory failure in patients with critical airway problems. Patients experiencing mild airway stenosis who are in good overall health may receive treatment using standard respiratory support techniques, including nasal oxygen therapy, masks, intubation, and ventilation. Severe airway stenosis can result in profound hypoxemia or respiratory failure, further complicating conventional respiratory support and challenging surgical or bronchoscopic interventions.

ECMO technology has advanced significantly and is now commonly applied in conditions like acute respiratory distress syndrome, cardiopulmonary failure, and during cardiopulmonary surgeries [4]. In 1999, Onozawa et al. documented the initial successful application of ECMO for adult airway obstruction due to thyroid carcinoma [5]. Since then, it has been used in various surgical procedures related to the respiratory system to facilitate gas exchange and provide hemodynamic support during stenting, tracheotomy, and intubation. Its use during surgeries or bronchoscopic interventions can ease airway blockages and ensure adequate oxygenation, thereby providing a safer treatment alternative for patients with severe tracheal stenosis [6–8]. Kim et al. indicated that ECMO is recommended when the airway diameter falls below 5 mm [9]. To date, there are no recorded cases of ECMO being used as an adjunct therapy for patients with tuberculous airway stenosis who have previously received stents. We present a case study involving a patient with severe tracheal tuberculous scar stenosis, as standard anesthesia and mechanical ventilation pose safety risks during the procedure. Veno-venous (VV)-ECMO was successfully implemented for bronchoscopic intervention. Post-treatment, symptoms like chest tightness, shortness of breath, and dyspnea significantly improved without adverse events.

Case presentation

Over twenty years ago, a 49-year-old woman was diagnosed with tracheobronchial tuberculosis and tracheal tuberculous scar stenosis at The First Affiliated Hospital of Second Military Medical University after experiencing breathing difficulties. An uncovered metallic stent (1.8 cm inner diameter, 9 cm in length) was placed in her trachea under bronchoscopic guidance while she received anti-tuberculosis treatment (Fig. 1A). Her respiratory condition improved, and a follow-up bronchoscopy two years later confirmed that the stent was well-tolerated and did not need to be removed. However, fifteen years ago, bronchoscopy indicated restenosis following the metal stent placement. Regular bronchoscopic balloon dilatation was conducted annually until five years ago, when re-examinations ceased due to COVID-19. Three weeks before admission, the patient experienced significant chest tightness, shortness of breath, and difficulty breathing during light activities, which gradually intensified. An outpatient bronchoscopy conducted the day before admission revealed a constriction of approximately 3–4 mm in the upper trachea that obstructed the bronchoscope. Consequently, she has been admitted to the hospital for further treatment. During the physical exam, the patient showed tachypnea at 25 breaths per minute, tachycardia at 106 beats per minute, a blood pressure of 122/76 mmHg, no fever, and a peripheral oxygen saturation of 87%. Cardiac auscultation was normal, but dry rales were observed in the large airways of both lungs. An arterial blood gas analysis indicated a pH of 7.463, a PO_2 of 58.9 mmHg, and a PCO_2 of 35.8 mmHg (F_IO_2 21%). In the complete blood count, white blood cells were at 7.30×10^9/L, neutrophils at 5.52×10^9/L, platelets at 212×10^9/L, and hemoglobin at 139 g/L. Liver and kidney functions, coagulation, and brain natriuretic peptide levels were normal. A chest computed tomography (CT) scan showed total tracheal stenosis with a visible metal stent, stenosis of the right main bronchus, and a strip shadow. The narrowest area measured about 3.88 mm in diameter (Fig. 1B-E). Based on Freitag's classification, the tracheal stenosis is rated as grade 4, indicating severe airway narrowing [10].

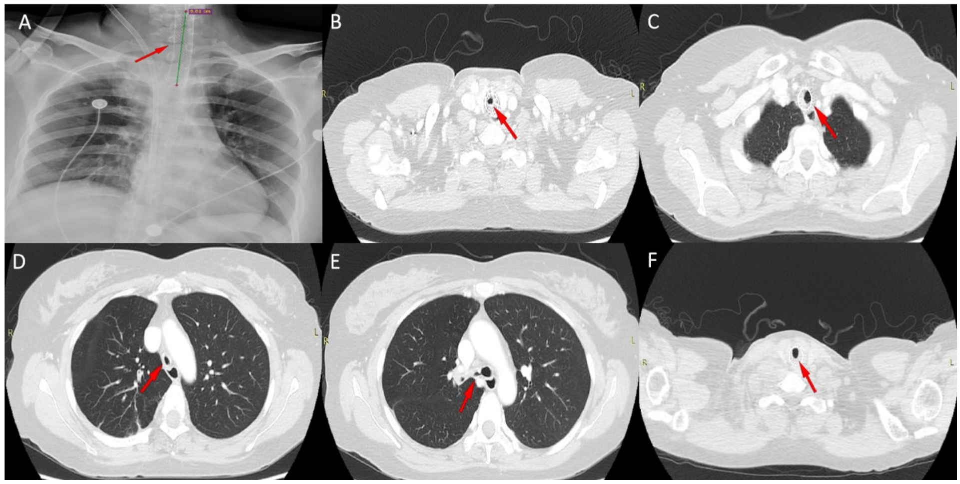

Fig. 1 Radiological examination before and after treatment. (**A**) chest X-ray showed an uncovered metallic stent (the green vertical line indicates a stent length of 9 cm) was implanted in the trachea (red arrow); (**B-D**) preoperative chest CT showed total tracheal stenosis (red arrow). The narrowest part of the upper trachea was approximately 3.88 mm (red arrow); (**E**) the stenosis of the right main bronchus (red arrow); (**F**) postoperative chest showed the stenosis of the upper tracheal segment was 9.58 mm (red arrow)

Following admission, the patient was evaluated for bronchoscopic thermal ablation to enlarge the airway diameter from top to bottom gradually. Severe total tracheal stenosis rendered respiratory support techniques, including conventional oxygen therapy (COT), high-flow nasal cannula (HFNC), and noninvasive ventilation (NIV), inadequate for the patient's oxygenation during assessment. Increasing the oxygen concentration during laser and high-frequency electrocoagulation procedures poses risks of combustion and explosion. If endotracheal intubation is necessary, a tube with an outer diameter of less than 5 mm must be chosen, which is incompatible with bronchoscopy. Furthermore, an uncovered metal stent (9 cm long) was placed in the trachea, preventing tracheotomy for ventilation. As a result, following a comprehensive multidisciplinary assessment, bronchoscopic interventional therapy was performed with the assistance of ECMO support. On the sixth day of admission, intravenous anesthesia was administered while preserving the patient's breathing. A 21Fr cannulation was placed in the right femoral vein to a depth of 40 cm, and a 17Fr cannulation was placed in the right internal jugular vein to a depth of 15 cm. ECMO treatment commenced with a blood flow of 3.84 L/min and an airflow of 3 L/min, ensuring SpO_2 remained above 95%. A bronchoscopy was performed using a laryngeal mask. During the procedure, a narrow scar with a twisted lumen was identified in the trachea, rendering it impassable (Fig. 2A, B). Laser treatment (10–20 W) and high-frequency electrocoagulation (40 W) were applied multiple times to cauterize the stenosis. Post-treatment, the lumen expanded to 9 mm, allowing successful passage of the bronchoscope to the distal end (Fig. 2C-F). The right main bronchus exhibited a narrowed lumen; however, the right middle and lower lobe bronchial tubes had smooth lumens through the constricted segment, while the right upper lobe displayed needle-like stenosis at its opening (Fig. 2G, H). Following the procedure, a 7 mm nasotracheal tube was inserted and connected to a ventilator. The bronchoscopy examination lasted 58 min, after which the patient was transferred to the respiratory intensive care unit (RICU) for ongoing symptomatic treatment with ECMO support. During the procedure, we consistently track the patient's hemodynamic status and oxygen levels, adjusting the ECMO's oxygen concentration based on the patient's needs. On the first day post-examination, the arterial blood gas results were: pH 7.381, PO_2 81.7 mmHg, PCO_2 41.0 mmHg (F_IO_2 40%). Bedside bronchoscopy was performed to remove necrotic tissue and aspirate sputum. As per the standard ECMO weaning protocol, we adjusted the gas flow to 0 and blood flow to 1.5 L/min. After 1 h, the patient's blood gas analysis showed no significant changes, meeting the weaning criteria. ECMO was halted after clearance, totaling 30 h of use. The arterial blood gas on the second day following the bronchoscopy showed: pH 7.490, PO_2 159 mmHg, PCO_2 31.3 mmHg (F_IO_2 40%). During the bronchoscopy, no necrotic tissue was detected. Sputum aspiration was conducted, and the tracheal tube was later removed. The patient was then started on HFNC therapy at a flow rate of 30 L/min with an F_IO_2 of 35%. Her vital signs remained stable, and by the third day, she was transferred to a regular ward on COT.

After the follow-up bronchoscopy and cleaning of necrotic tissue (Fig. 2I-L), a postoperative chest CT scan showed a significant increase in the diameter of the tracheal lumen to approximately 9 mm (Fig. 1F). This resulted in reduced chest tightness and shortness

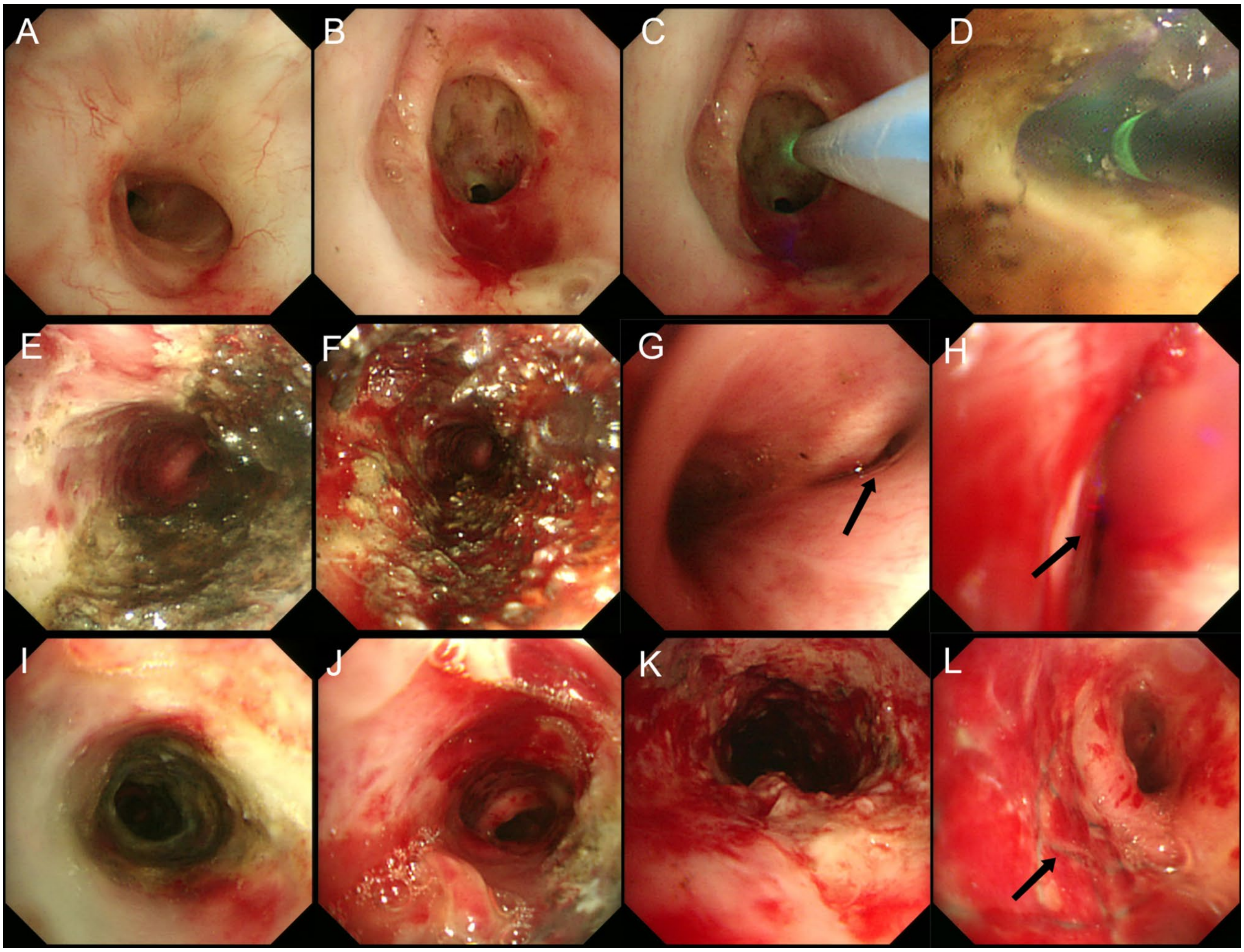

Fig. 2 Bronchoscopic images during the examination. (**A**, **B**) intraoperative bronchoscopy showed severe distortion and cicatricial stenosis of the upper tracheal segment on the sixth day of admission; (**C**) the laser was to cauterize lesions; (**D**) high-frequency electrocoagulation was used to cauterize lesions; (**E**, **F**) the trachea lumen was enlarged after thermal ablation (laser and high-frequency electrocoagulation); (**G**) the opening of the right main bronchus softens and shows lip-like stenosis (black arrow); (**H**) the opening of the right upper lobe was needle-like stenosis (black arrow); (**I-K**) bronchoscopy showed that necrotic tissue and granulation tissue were attached to the trachea wall, and the tracheal lumen was obviously enlarged after cleaning on the eleventh day of admission; (**L**) metal stent could be seen on the left wall of the lower end of the trachea (black arrow)

of breath. The treatment timeline for this patient is presented in Table 1. The patient received bronchoscopic balloon dilation every 2–3 months, maintaining stable airway diameter. We instructed the patient to return to the clinic as scheduled and engage in concurrent pulmonary rehabilitation. At present, the patient does not need oxygen and feels only slight chest tightness following physical exertion. She is capable of handling self-care on her own.

Discussion and conclusion

We presented a case of a patient with tuberculosis who subsequently developed total tracheal stenosis after receiving a metal tracheal stent. Using VV-ECMO, we successfully performed bronchoscopic thermal ablation, alleviating the patient's clinical symptoms without any complications.

Case reports and retrospective studies have highlighted the role of ECMO in treating tracheal stenosis. Zhang et al. described a case involving airway stenosis due to recurrent polychondritis, where ECMO aided in the implantation of an endotracheal stent [11]. In 2018, Malpas et al. analyzed 45 patients with central airway obstruction who underwent rigid bronchoscopy with ECMO support, finding that ECMO effectively maintains adequate oxygenation during central airway obstruction procedures [6]. Meyer et al. caution that challenging broncho tracheal stent placements may result in significant complications, even potentially fatal ones [12]. For cases involving the removal or replacement of metal stents, ECMO consideration is vital. This patient had a longstanding metal stent due to airway tuberculosis, which had completely epithelialized and was impossible to remove. Bronchoscopic thermal ablation could

Table 1 The treatment timeline of this patient

Date and time	Event
The day before admission	The upper trachea was found to have a narrowing of approximately 3–4 mm during bronchoscopy, which prevented the bronchoscope from passing through.
The first day of admission	Admitted to the respiratory medical ward. The Preoperative chest CT examination revealed that the narrowest point of the tracheal lumen measured approximately 3.88 mm in diameter.
The sixth day of admission at 09:40 AM	Femoral-internal jugular vein catheterization, VV-ECMO initiated, performed bronchoscopic laser and high-frequency electrocoagulation under ECMO support.
The sixth day of admission at 10:42 AM	After the procedure, 7 mm nasotracheal intubation was replaced and connected to a ventilator. With the assistance of ECMO, transferred to RICU.
The seventh day of admission at 3:10 PM	Performed endotracheal necrotic tissue removal and sputum aspiration by bronchoscopy.
The seventh day of admission at 3:50 PM	Weaning off VV-ECMO.
The eighth day of admission at 11:45 AM	Performed endotracheal and sputum aspiration by bronchoscopy.
The eighth day of admission at 12:20 PM	Removal of the endotracheal tube, high-flow oxygen provided.
The ninth day of admission	Nasal cannula for oxygen and transferred to a regular ward.
The eleventh day of admission	Performed endotracheal necrotic tissue removal and sputum aspiration by bronchoscopy. The postoperative chest CT examination revealed that the diameter of the tracheal lumen had increased to approximately 9 mm.
The twelfth day of admission	Discharged from the hospital.

Abbreviations: CT: computed tomography; ECMO: extracorporeal membrane oxygenation; VV-ECMO: veno-venous extracorporeal membrane oxygenation; RICU: respiratory intensive care unit

be the most effective approach for severe airway stenosis across all segments. Nonetheless, reducing inhaled oxygen concentration during thermal ablation is crucial, as airway resistance will rise during tracheoscopy, posing a major challenge to the patient's oxygenation during surgery [13]. Therefore, in this scenario, ECMO represents this patient's safest option for sustaining intraoperative oxygenation.

ECMO will require some time to initiate smoothly. Maxwell et al. categorized ECMO support in airway procedures into three types: standby, elective, and rescue. Standby or elective ECMO support is advisable for patients with severe lower airway obstruction requiring general anesthesia, given their elevated risk of intraoperative cardiorespiratory failure, which can result in a high mortality rate if rescue ECMO is needed. In five instances of attempted rescue ECMO, four patients did not survive [14]. VV-ECMO is preferable to Veno-Arterial (VA)-ECMO, as it guarantees sufficient oxygen delivery to the upper body during procedures, prevents differential hypoxia, and results in fewer bleeding issues. Extended use of VA ECMO can also lead to ischemic necrosis in the distal limb [7, 8]. Evidence suggests that low-dose heparin anticoagulant protocols may help mitigate bleeding risks [15]. Considering the patient's condition, we chose elective ECMO and utilized a low-dose anticoagulation strategy to keep whole blood coagulation time at 160–220 s, avoiding bleeding or other complications.

Stauffer et al. highlight that in Europe and America, tracheal intubation and tracheostomy are the main contributors to benign cicatricial airway stenosis (BCAS), accounting for 19% and 65% of cases, respectively [16]. In contrast, tracheobronchial tuberculosis is the primary cause of BCAS in China, with local studies indicating it constitutes 64.25% of cases of benign airway stenosis in the region [17]. One treatment approach for BCAS is surgery, which can involve tracheal resection with end-to-end anastomosis, tracheal transplantation, tracheoplasty, and other surgical methods [18]. Although airway reconstruction surgery is regarded as the gold standard for symptomatic BCAS, a contraindication arises when tracheal stenosis is 50% or more of the normal tracheal length. In this particular circumstance, a chest CT revealed that the extent of tracheal stenosis exceeded 50% of the total tracheal length, indicating elevated surgical risks and the possibility of trauma. As a result, surgical reconstruction of the airway was deemed unfeasible. An alternative treatment is bronchoscopic interventional therapy, which encompasses techniques like thermal ablation, cryotherapy, and mechanical dilation therapy. Thermal ablation includes technologies such as laser therapy, high-frequency electrocoagulation, and argon plasma coagulation (APC). Of these, laser therapy is considered the most effective due to its deep tissue penetration, establishing it as the gold standard for treating tracheal stenosis [19].

Hypoxemia is one of the most common complications of bronchoscopy, particularly with sedation [20, 21]. The incidence of hypoxemia in recent randomized controlled trials ranged from 29.2 to 69.2% during bronchoscopy examination [22–25]. Common causes of hypoxemia include inadequate ventilation and upper airway obstruction due to the insertion of the bronchoscope, bronchoalveolar lavage, excessive or insufficient sedation, laryngospasm, and bleeding and pneumothorax secondary to bronchopulmonary biopsy or bronchoscopic interventional surgery [26–28]. During bronchoscopy, the PaO_2 level in healthy individuals may decrease by

20–30 mmHg, whereas the PaO_2 level in critical patients may decrease by 30–60 mmHg [29]. Moreover, bronchoscopy in patients with hypoxemia respiratory failure carries increased risks compared to non-hypoxemia patients [30]. Hypoxemia can result in serious adverse effects, such as cardiovascular events, neurological complications, acute respiratory failure, and even death. For patients with severe tracheal stenosis, any intratracheal operation may cause serious complications, and blind induction of anesthesia and forced tracheal intubation may further aggravate the degree of tracheal stenosis and even lead to asphyxia. Therefore, establishing safe and efficient respiratory support is crucial for treating severe tracheal stenosis.

Based on this case and the review of existing literature, we advise that all tuberculosis patients undergo regular screening for tracheobronchial tuberculosis. If airway stenosis is detected, immediate treatment is essential to prevent it from worsening into severe airway stenosis. For patients with an intra-airway stent, it is important to remove it promptly when conditions permit, thereby avoiding complications from prolonged use. Additionally, patients with airway stenosis should be provided with appropriate education and should regularly have bronchoscopy performed to track any changes in their condition.

Our study presents several strengths. Firstly, it marks the first instance of ECMO-assisted bronchoscopy for total airway tuberculosis stenosis, which holds significant implications for treating patients with severe airway stenosis. Additionally, given the patient's critically ill state, the absence of ECMO would leave no alternative rescue measures available once hypoxia arises during the procedure. This underscores the vital role of preoperative planning for high-risk bronchoscopy. However, there are some limitations to consider. As this is merely a case report, the findings are not generalizable. Moreover, ECMO treatment carries various complications, making it difficult to specify the appropriate indications for ECMO in patients with airway stenosis in this instance.

In conclusion, ECMO offers reliable and efficient cardiopulmonary support during bronchoscopic intervention for severe airway stenosis. Nonetheless, questions about the timing, mode, and management of ECMO require clarification through randomized controlled trials (RCTs), and the supplemental indicators for ECMO use in bronchoscopy ought to be fine-tuned to enhance regulatory practices in clinical application.

Abbreviations

CT	Computed tomography
ECMO	Extracorporeal membrane oxygenation
VV-ECMO	Veno-venous extracorporeal membrane oxygenation
VA-ECMO	Veno-Arterial extracorporeal membrane oxygenation
RICU	Respiratory intensive care unit
COT	Conventional oxygen therapy
HFNC	High-flow nasal cannula
NIV	Noninvasive ventilation
BCAS	Benign cicatricial airway stenosis
APC	Argon plasma coagulation
RCTs	Randomized controlled trials

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Author contributions
HZ, YW and HQ performed the literature review and drafted the manuscript. HZ designed the research study. JZ, XN and QW collected the clinical data. WZ and CB revised the manuscript. All authors read and approved the final version of the manuscript.HZ, YW and HQ have contributed equally to this work and share first authorship.WZ and CB are the corresponding author.

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Data availability
Availability of data and materialsAll the data generated or analyzed during this study are included in the manuscript.

Declarations

Ethics approval and consent to participate
Ethical approval to report this case was not required due to its retrospective nature.

Consent for publication
Written informed consent was obtained from the patient for publication of this case presentation and any accompanying images.

Competing interests
The authors declare no competing interests.

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