



Application of 3D-Printed Tracheal External Stents Combined with Fasciocutaneous Flaps in the Treatment of Long-Segment Tracheal Defects

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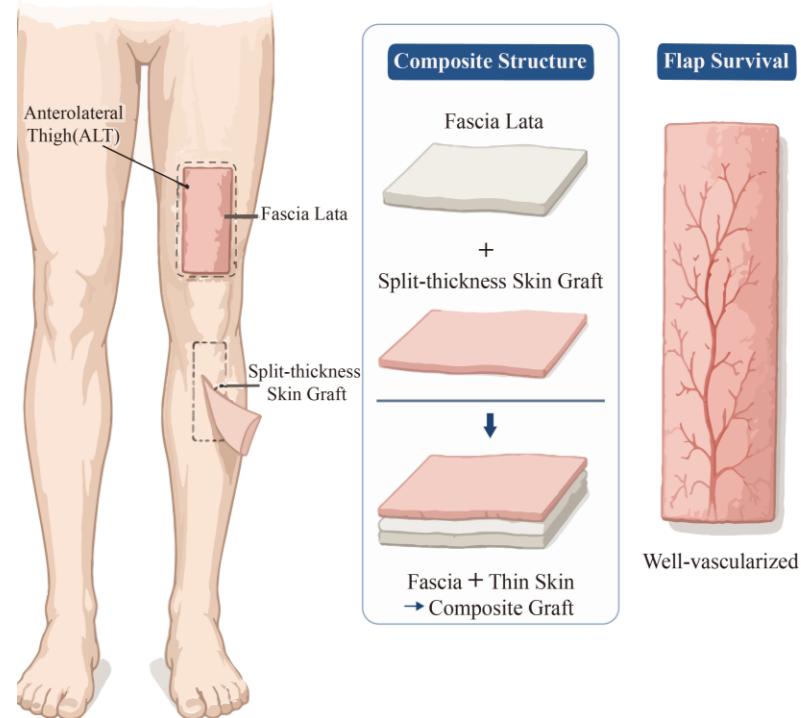


IASLC 2026 World
Conference on Lung Cancer
SEPTEMBER 12 - 15, 2026
SEOUL, REPUBLIC OF KOREA

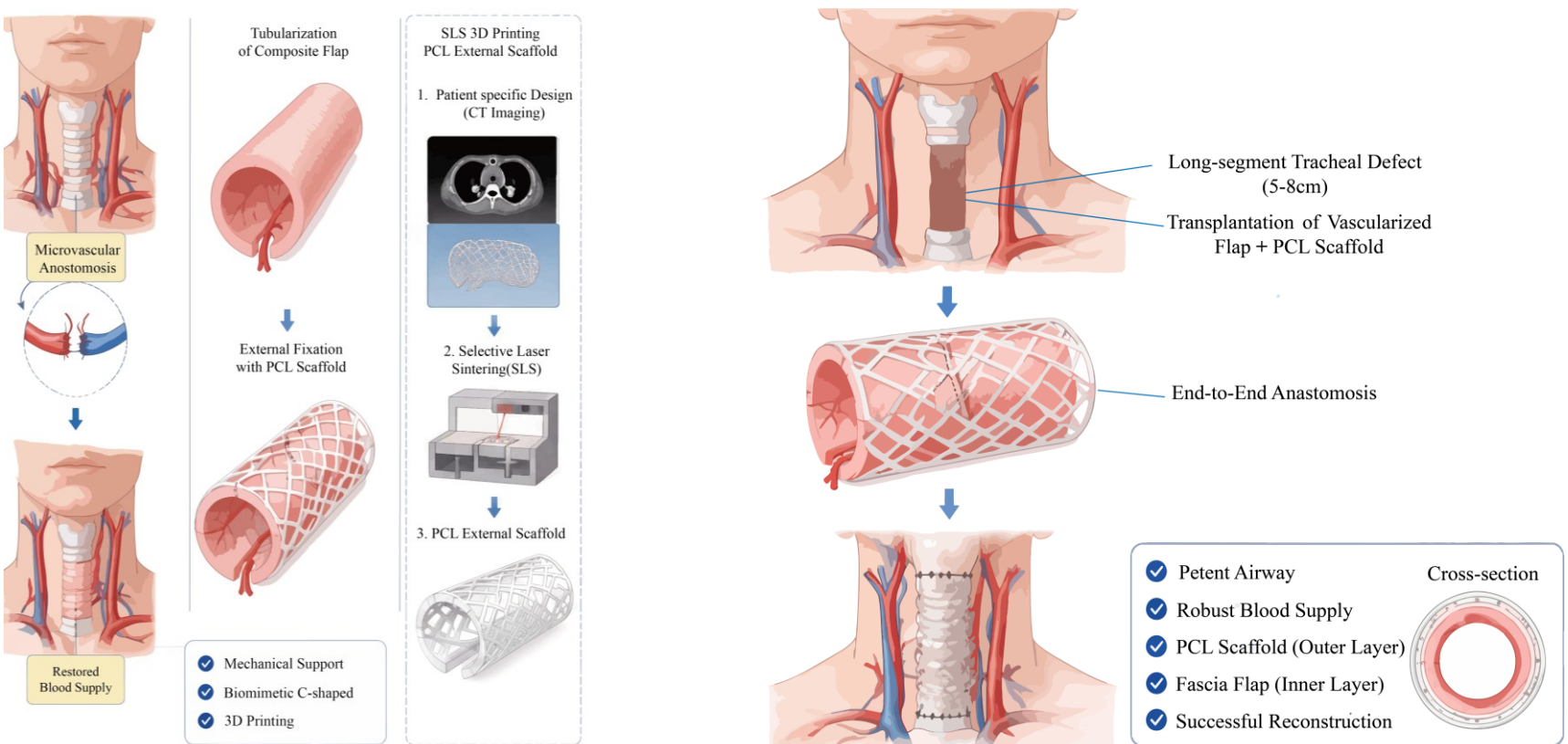
INTRODUCTION

Long-segment tracheal defects or stenosis may result from various causes, including burns, traumatic or combat-related injuries, intubation-associated damage, and tumor infiltration^[1, 2]. When the length of tracheal resection exceeds 50% in adults or 30% in children, tracheal replacement is required to achieve airway reconstruction^[3]. Clinically, reconstruction of tracheal defects or stenosis exceeding 6 cm in length remains one of the “holy grails” of reconstructive medicine, and no consensus has yet been reached regarding the optimal strategy for long-segment tracheal reconstruction. In this study, we developed an innovative approach for patients with complex long-segment tracheal defects or stenosis, which is based on findings from our previous animal experiments^[4]. To our knowledge, it is the first clinical application and validation of a reconstructive strategy combining a 3D-printed biodegradable external scaffold with an autologous free fascia lata flap. Subsequently, we established a standardized surgical treatment protocol for patients with complex long-segment tracheal defects or stenosis involving a 6-cm segment and reported the clinical outcomes of two patients treated with this approach. These findings provide valuable clinical evidence and a potential therapeutic reference for the management and reconstruction of complex long-segment tracheal defects or stenosis.

METHODS



Step 1. Preparation of a free anterolateral thigh (ALT) fascia flap: A rectangular donor site of appropriate dimensions was designed on one thigh, and a free anterolateral thigh fascia lata flap was harvested. A split-thickness skin graft of corresponding size was subsequently harvested from another region of the lower extremity and grafted onto the fascial flap to construct a skin-grafted composite ALT fascia flap.



Step 2. Construction of a vascularized tubular airway substitute: After flap maturation, the composite flap was transferred to the neck and revascularized. A patient-specific 3D-printed PCL external tracheal scaffold, fabricated by selective laser sintering (SLS) with a biomimetic C-shaped design, was sutured to the flap to create a mechanically supported tubular airway substitute.

Step 3. Reconstruction of long-segment tracheal defects: The vascularized tubular construct was subsequently implanted for reconstruction of the long-segment tracheal defect by end-to-end anastomosis with the native trachea, thereby restoring airway continuity.

DISCUSSION AND CONCLUSION

Airway injury is one of the leading causes of preventable mortality in combat-related trauma, second only to massive hemorrhage^[5]. Explosions, shrapnel injuries, and blast trauma frequently result in complex long-segment tracheal defects characterized by extensive tissue loss and irregular morphology. Conventional reconstructive approaches are often unable to simultaneously restore structural integrity and airway function. Therefore, developing a rapid, accurate, and effective strategy for the reconstruction of complex long-segment tracheal defects is of substantial clinical importance.

In this study, we developed a novel reconstructive strategy that combines a patient-specific 3D-printed biodegradable external tracheal scaffold with a free autologous fascia lata flap for the repair of long-segment tracheal defects. The scaffold was individually designed based on CT imaging to achieve precise anatomical conformity. The biodegradable scaffold provides stable mechanical support during the early healing phase, while the vascularized autologous fascia lata flap establishes a reliable blood supply, promotes neovascularization and epithelialization, and ultimately enables functional airway reconstruction.

Compared with conventional end-to-end anastomosis, allogeneic transplantation, and artificial tracheal substitutes, this approach integrates the advantages of personalized scaffold design and autologous vascularized tissue reconstruction. It addresses several key challenges associated with long-segment tracheal repair, including inadequate mechanical support, limited vascularization, and an increased risk of infection^[6]. These findings suggest that this technique represents a promising alternative for the reconstruction of complex airway defects following combat-related trauma, with considerable potential for future clinical application.

This study is limited by the small sample size and relatively short follow-up period. Further studies involving larger cohorts and long-term follow-up are required to validate the long-term safety and efficacy of this technique in combat-related airway reconstruction and to provide higher-quality clinical evidence for its broader application.

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RESULTS

Patient 1: A 57-year-old woman was diagnosed with papillary thyroid carcinoma invading the trachea. Preoperative computed tomography (CT) and bronchoscopy demonstrated tumor invasion of the tracheal wall with intraluminal extension (Figure 1A-C). Following multidisciplinary team (MDT) discussion, the patient underwent surgical reconstruction.

In the first stage, a prefabricated composite flap was created using an anterolateral thigh fascia lata flap combined with a skin graft (Figure 2A). Three weeks later, the second-stage procedure consisted of total thyroidectomy and tumor resection, including removal of an approximately 6-cm-long segment involving two-thirds of the tracheal circumference, part of the cricoid cartilage, and eight tracheal rings. The resulting tracheal defect was reconstructed using the prefabricated free fascia lata flap. A patient-specific, three-dimensional (3D)-printed biodegradable polycaprolactone (PCL) external tracheal scaffold was placed around the flap to provide mechanical support (Figure 2B-C). Bronchoscopy performed 1 month postoperatively showed a patent airway and satisfactory flap viability (Figure 3A-C). At more than 10 months after surgery, CT demonstrated that the reconstructed trachea remained morphologically stable, with no definite evidence of stenosis (Figure 3D).

Patient 2: A 22-year-old woman developed severe tracheal injury following surgery for papillary thyroid carcinoma. After thyroid surgery at an outside hospital, she experienced a tracheal fistula, respiratory failure, and infection. Despite multiple debridement procedures, atresia of the upper trachea developed, resulting in long-term dependence on a tracheostomy tube for breathing and loss of phonation. Preoperative bronchoscopy and CT confirmed a long-segment tracheal defect and stenosis (Figure 4A-E).

In the first stage, a free fascia lata flap combined with a skin graft was prefabricated (Figure 5A). Two weeks later, tracheal scar resection and airway reconstruction were performed. Intraoperatively, an approximately 5-cm, 360° circumferential tracheal defect was identified. The airway was reconstructed by anastomosing the prefabricated free fascia lata flap to the proximal and distal tracheal remnants. Four 3D-printed PCL external scaffold modules were then assembled and secured around the outer surface of the flap (Figure 5B). Bronchoscopy at 2 weeks postoperatively demonstrated a patent reconstructed airway (Figure 6A-B).



Figure 1. Preoperative examinations of Patient 1

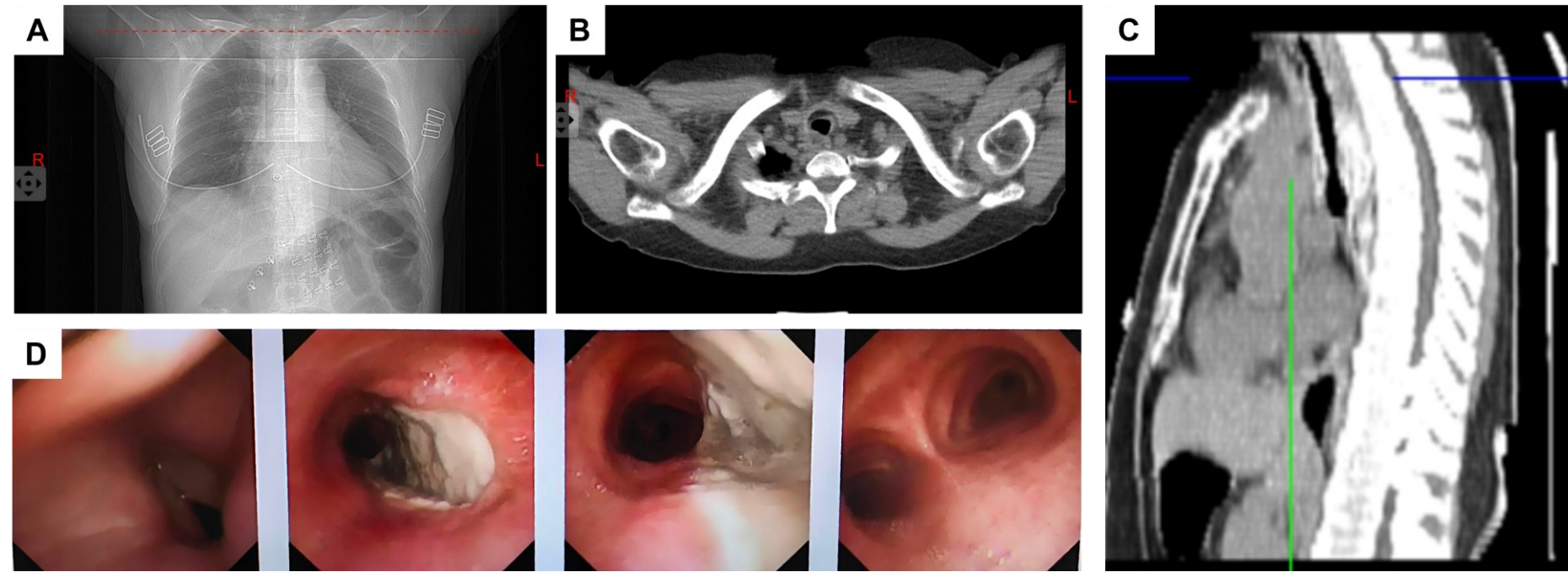


Figure 3. Postoperative follow-up results of Patient 1

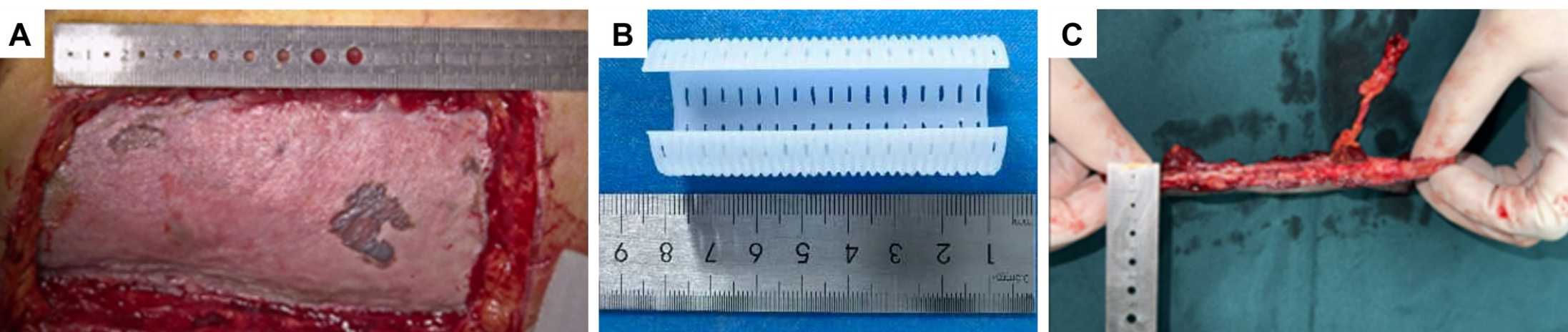


Figure 2. Intraoperative photographs of Patient 1

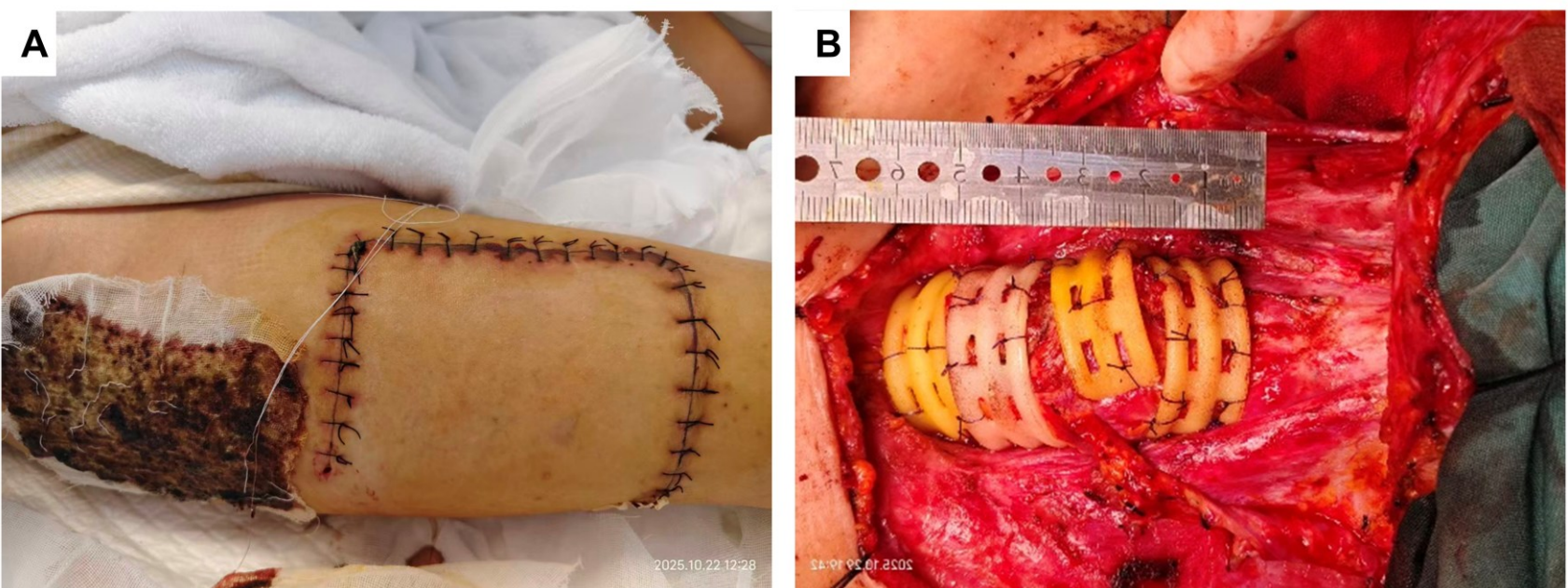


Figure 5. Operative details of Patient 2

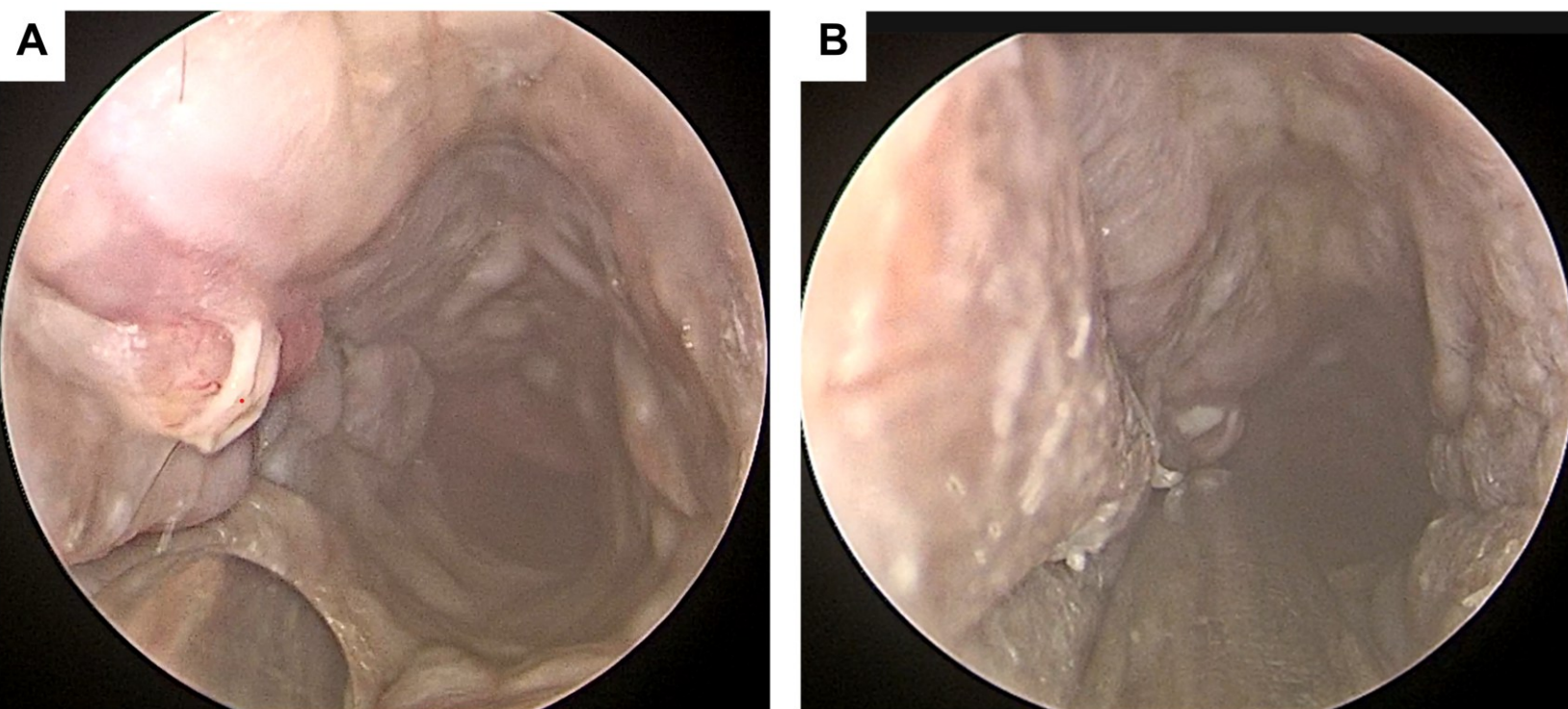


Figure 6. Postoperative bronchoscopic findings of Patient 2

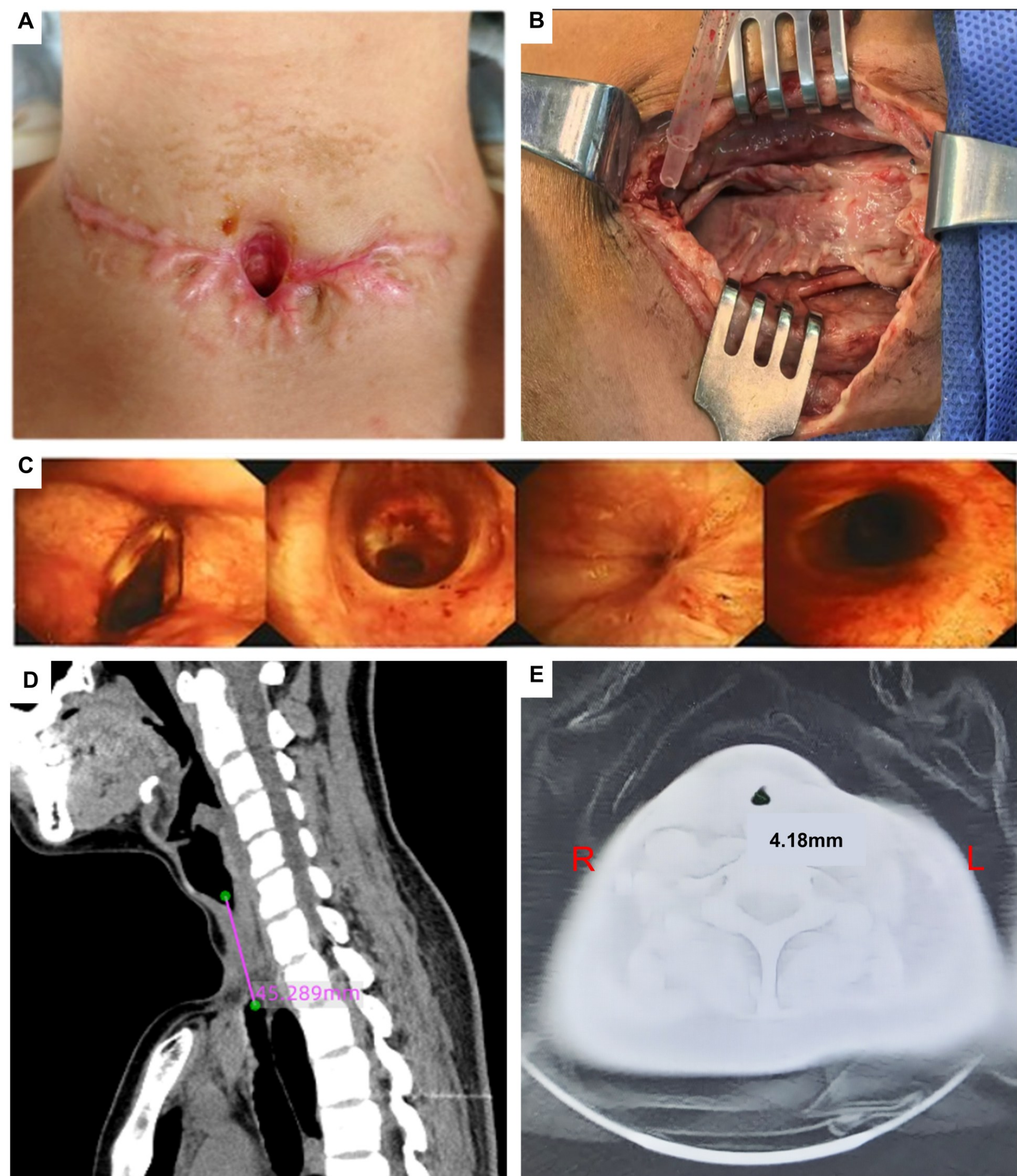


Figure 4. Preoperative physical signs and imaging findings of Patient 2