Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Lesion site and outcomes of airway complications requiring bronchoscopic treatment after lung transplantation: a retrospective case series

Pengfei Li[1]
The First Affiliated Hospital of Zhengzhou University
Kai Zhao[1]
The First Affiliated Hospital of Zhengzhou University
Tian Gao[1]
The First Affiliated Hospital of Zhengzhou University
Zhi Qin[1]
The First Affiliated Hospital of Zhengzhou University
Zhenyuan Zhang[1]
The First Affiliated Hospital of Zhengzhou University
Zeyu Chang[1]
The First Affiliated Hospital of Zhengzhou University
Fengke Li[1]
The First Affiliated Hospital of Zhengzhou University
Xiaofei Liu[1]
The First Affiliated Hospital of Zhengzhou University
Jinrui Li[2]
First Affiliated Hospital of Hebei Medical University
Zhanyi Zhu[3]
The First Affiliated Hospital of Chongqing Medical University
Gaofeng Zhao
184371229110163.com

The First Affiliated Hospital of Chongqing Medical University
Zhidan Ding[1]
The First Affiliated Hospital of Zhengzhou University

Research Article

Keywords: lung transplantation, airway complications, therapeutic bronchoscopy, bronchial stenosis, bronchomalacia, airway stent, retransplantation

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11481613/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Lesion site and outcomes of airway complications requiring bronchoscopic treatment after lung transplantation: a retrospective case series

Authors: Pengfei Li[1]†; Kai Zhao[1]†; Tian Gao[1]†; Zhi Qin[1]; Zhenyuan Zhang[1]; Zeyu Chang[1]; Fengke Li[1]; Xiaofei Liu[1]; Jinrui Li[2]; Zhanyi Zhu[3]; Gaofeng Zhao[3]‡; Zhidan Ding[1]‡

† These authors contributed equally to this work.

‡ Co-corresponding authors.

Affiliations:

[1] The First Affiliated Hospital of Zhengzhou University, Zhengzhou 450000, Henan, China

[2] The First Hospital of Hebei Medical University, Shijiazhuang 050000, Hebei, China

[3] The First Affiliated Hospital of Chongqing Medical University, Chongqing 400010, China

Corresponding authors:

Gaofeng Zhao, MD, Professor/Chief Physician. Department of Thoracic Surgery, The First Affiliated Hospital of Chongqing Medical University, Chongqing 400010, China. Email: 18437122911@163.com. ORCID: 0009-0005-7376-5180.

Zhidan Ding, MM, Associate Professor/Associate Chief Physician. Department of Lung Transplantation, The First Affiliated Hospital of Zhengzhou University, Zhengzhou 450000, Henan, China. Email: 63229118@qq.com. ORCID: 0009-0007-0538-4428.

Email addresses: Pengfei Li, li1090110358@163.com; Kai Zhao, zhaokaizdyfy@163.com; Tian Gao, 3078034183@qq.com; Zhi Qin, zhiqin@gs.zzu.edu.cn; Zhenyuan Zhang, 15037133675@163.com; Zeyu Chang, ChangZeyu198@163.com; Fengke Li, lifk2021@126.com; Xiaofei Liu, 13633826120@139.com; Jinrui Li, 1793505803@qq.com; Zhanyi Zhu, 827501689@qq.com; Gaofeng Zhao,18437122911@163.com ; Zhidan Ding, 63229118@qq.com.

Abstract

Background. Airway complications after lung transplantation often require repeated bronchoscopic treatment, but the anatomical status that individual lesions reach during that treatment, and whether it differs between airway sites, is poorly described. We examined the timing, location, treatment burden and lesion-level outcomes of airway complications requiring intervention.

Methods. This single-centre retrospective case series included recipients transplanted between February 2021 and April 2024 who developed airway complications requiring bronchoscopic intervention. Clinical records were reviewed for lesion characteristics, therapeutic sessions and subsequent outcomes. Lesion outcomes at variable last documented airway assessments were summarised in recipients surviving beyond one year. Vital status was assessed through 30 July 2026, with descriptive Kaplan–Meier analysis from index transplantation.

Results. Seventeen recipients had 35 classified airway lesions. All first complications were detected within 142 days of transplantation (median 68 days), and 20 lesions (57.1%) were non-anastomotic, involving the lobar/distal bronchi or the bronchus intermedius. Bronchoscopy records documented 185 therapeutic sessions (median eight per recipient; range 2–21), including 21 after rescue retransplantation; four recipients received stents. Among 26 stenoses in the 15 recipients surviving beyond one year, 16 were stable or improved, six were completely or near-completely occluded and four had secondary malacia at the last documented assessment. All six occlusions were non-anastomotic, including three of five assessed right-upper-lobe stenoses, whereas all four secondary malacia lesions were anastomotic. None of the three primary bronchus-intermedius malacia lesions resolved. One dehiscence healed with stenosis; the other required rescue retransplantation. Nine recipients died; estimated survival was 88.2% (95% CI 60.6–96.9%) at one year, 76.5% (48.8–90.4%) at two years and 55.6% (28.1–76.2%) at three years.

Conclusions. First airway complications requiring intervention were detected within five months of transplantation, most classified lesions were non-anastomotic, and treatment was repeated and multimodal. At the last documented assessment, 10 of 26 stenoses in one-year survivors were occluded or had secondary malacia, with a site-related distribution: occlusion only outside the anastomosis, most often in the right upper lobe, and secondary malacia only at the anastomosis. Whether surveillance of the lobar bronchi and site-tailored follow-up improve outcomes warrants prospective evaluation.

Trial registration. Not applicable.

Keywords: lung transplantation; airway complications; therapeutic bronchoscopy; bronchial stenosis; bronchomalacia; airway stent; retransplantation.

Background

Airway complications remain a clinically important source of morbidity after lung transplantation (LTx). Stenosis, dehiscence and malacia may impair airway patency and require repeated bronchoscopic procedures, stenting or surgical rescue [1–7]. A meta-analysis of 38 studies estimated a pooled incidence of 12.4% [8], whereas contemporary single-centre estimates range from 12% of anastomoses to one-third of bilateral recipients [9–12]. This variation reflects case definitions, surveillance practices and whether the denominator comprises recipients, procedures or anastomoses.

The donor bronchus loses its systemic arterial supply during transplantation and initially depends on retrograde pulmonary perfusion until neovascularisation occurs, and impaired healing can manifest as early dehiscence or later fixed narrowing and dynamic collapse [1]. Anastomotic suture technique, severe reperfusion oedema and early rejection have been associated with complications requiring intervention [13,14], and clinically significant airway ischaemia remains common in contemporary practice [15]; central airway stenosis frequently follows extensive

73 airway necrosis, and hyperbaric oxygen did not reduce this risk in a randomised trial [16]. The
74 International Society for Heart and Lung Transplantation (ISHLT) consensus provides a common
75 framework for describing these abnormalities and their treatment [17]; a recent international
76 survey examined its adoption and the challenges of applying its grading system across centres
77 [18], and a Chinese expert consensus has proposed a standardised approach to diagnosis and
78 interventional management [19].

79 Large cohorts and a meta-analysis have characterised the frequency and prognostic implications
80 of airway complications [8,12,20], while treatment-focused studies document the substantial
81 procedural burden among affected recipients [21,22]. A recent cohort additionally examined
82 respiratory bacterial detections preceding intervention-requiring stenosis [23]. These studies
83 address who develops complications and their associations with subsequent outcomes. For
84 recipients already undergoing treatment, less is known about the anatomical status that individual
85 lesions reach during repeated intervention, and whether it differs between the anastomosis, the
86 lobar bronchi and the bronchus intermedius. Patient-level summaries can obscure different
87 outcomes at separate airway sites, and a technically satisfactory procedure does not by itself
88 establish sustained anatomical recovery.

89 We therefore examined the timing, anatomical distribution, bronchoscopic treatment burden and
90 lesion-level outcomes of airway complications requiring intervention at our institution, with
91 particular attention to whether local outcomes differed by airway site. Rescue retransplantation
92 and patient survival are reported separately from local airway outcomes. The study was
93 descriptive and did not aim to estimate treatment effects or identify risk factors.

Methods

Study design and setting

This retrospective, single-centre observational study was conducted at the First Affiliated Hospital of Zhengzhou University. The Medical Ethics Committee of the First Affiliated Hospital of Zhengzhou University approved the study (2025-KY-0954), which was conducted in accordance with the Declaration of Helsinki. Informed consent for the use of clinical data was obtained from the recipients or, for deceased recipients, from their next of kin.

Study population

Patients who underwent single or bilateral LTx between 1 February 2021 and 30 April 2024 and subsequently developed an airway complication requiring bronchoscopic intervention were eligible. Cases were identified from institutional transplant and bronchoscopy records and reviewed against the available clinical summaries and bronchoscopy reports. Complications treated outside the institution were included when documented in the institutional record. Airway abnormalities that did not prompt bronchoscopic intervention were outside the scope of this series. This was a record-based case series; complete ascertainment of all qualifying complications across the transplant population could not be established from the available materials.

The departmental registry recorded 109 transplant procedures between 1 February 2021 and 30 April 2024. Each single, bilateral, lobar or combined transplant counted as one procedure; retransplantations counted as additional procedures. The 17 affected recipients are reported relative to this procedure denominator for institutional context. This proportion is not a recipient-level cumulative incidence.

Data collection and variables

Recipient, donor and operative characteristics, postoperative recovery, airway findings, microbiology, bronchoscopic treatment and vital status were extracted from the institutional records. Lesions were defined by anatomical unit: each bronchial anastomosis, the bronchus intermedius and each lobar bronchus (with the lingula included in the left upper lobe) counted as one lesion when the bronchoscopy reports documented dehiscence, stenosis or malacia there that was targeted by treatment. A change in type within the same unit, such as dehiscence followed by stenosis or primary malacia followed by fixed narrowing, was treated as the course of one lesion. One mildly narrowed right-middle-lobe orifice in P09, treated with cryotherapy in a single session, was not classified as a separate lesion. Lesion classification was restricted to the index grafts. Necrosis, suture exposure and granulation tissue were retained as descriptive findings rather than additional lesions. Small anastomotic defects that healed without specific intervention were not classified as lesions.

Treatment burden was measured as the number of therapeutic bronchoscopic sessions and the modalities used, counted from the longitudinal bronchoscopy records from the first qualifying lesion until death or the census date, including documented procedures at other centres. P02 underwent rescue retransplantation on postoperative day 31; all 21 counted sessions in this recipient followed it and treated the new graft, so they contribute to recipient-level treatment burden but not to the lesion classification. A session was counted as therapeutic when it included mechanical debridement, balloon dilatation, cryotherapy, argon plasma coagulation, high-frequency electrosurgery, laser or plasma ablation, or stent insertion, removal or repositioning; sessions limited to inspection, lavage, secretion clearance or biopsy were not counted.

Microbiological findings were reconciled with the longitudinal clinical records and counted once per patient for each organism or organism group. Explicitly suspected organism identifications

were excluded from organism-specific counts. Specimen types were heterogeneous and included respiratory and non-respiratory specimens; detections did not necessarily represent infection.

Airway categories were informed by the ISHLT consensus [17]. Dehiscence denotes full-thickness anastomotic separation, involving part or all of the circumference. Stenosis was based on documented fixed narrowing, with inability to pass the bronchoscope recorded when described. Malacia was based on documented dynamic expiratory collapse. Uniform quantitative measurements were unavailable, precluding consistent retrospective severity grading.

Local outcomes were taken from the most recent bronchoscopy or CT on or before the census date that described the lesion (the last documented assessment); documented malacia was regarded as persisting unless a later report described its resolution. Lesion outcomes were summarised for the 15 recipients surviving beyond one year as a conditional descriptive subset, not as outcomes of all 17 recipients. This threshold was set retrospectively so that every summarised recipient survived at least seven months after detection of the first lesion (the latest first detection was on day 142). The two recipients who died within one year (P13 and P14, on postoperative days 224 and 270) had received treatment until 12 and 87 days before death; their four lesions were excluded by this rule rather than for lack of assessment. The postoperative day and modality (bronchoscopy or CT) of the assessment used for each lesion are given in Additional file 1. Dates at which individual lesions first became occluded or malacic were not abstracted, so outcomes describe status at that assessment rather than the timing or sequence of change. The combined label “stable or improved” was retained from the qualitative clinical summaries; no common reference examination, quantitative change threshold or independent image adjudication could be established. It does not imply normalisation of the airway. Categories were stable or improved stenosis, complete occlusion (including near-complete occlusion), stenosis with secondary malacia, primary malacia that did not resolve, and dehiscence followed by stenosis or rescue retransplantation. Occlusion denoted a lumen described as closed

or nearly closed on bronchoscopy or CT, and secondary malacia denoted dynamic expiratory collapse documented at a previously treated stenosis. Assessment times varied, and lesions within a recipient were not independent. P17's first qualifying lesion was the clearly documented distal stenosis on postoperative day 142. Patient- and lesion-level classifications are provided in Additional file 1.

Bronchoscopic images

Representative bronchoscopic frames were assembled without retouching or image enhancement. Labels were placed outside the endoscopic field, and patient names and date overlays were excluded. Informed consent for publication of the de-identified images was obtained from the recipients or, for deceased recipients, from their next of kin.

Statistical analysis

Continuous variables are summarised as median with interquartile range (IQR) or range, and categorical variables as counts and percentages with stated denominators. Quartiles were the medians of the lower and upper halves, excluding the overall median for odd sample sizes. No hypothesis testing or adjusted modelling was undertaken. Overall survival from transplantation was estimated by the Kaplan–Meier method using day-level dates of transplantation, death or census, expressed in months (days/30.4375). Pointwise 95% confidence intervals used Greenwood variance with a log-log transformation. Descriptive summaries were calculated in Python 3; survival estimates and all plotted figures were produced in R 4.6.1 (survival, ggplot2 and patchwork packages).

Ascertainment of vital status and follow-up

Follow-up for vital status ended at death or the census date of 30 July 2026. Vital status at the census date was known for all 17 recipients, and none was lost to follow-up. Surviving recipients were censored at the census date; their censoring times therefore differed only because their

transplantation dates differed. The patient-level durations and vital status used in the analysis are provided in Additional file 1.

Results

Institutional context and study cohort

During the study period, 109 transplant procedures were performed: 36 in February–December 2021, 27 in 2022, 35 in 2023 and 11 in January–April 2024. Seventeen recipients developed complications requiring bronchoscopic intervention, corresponding to 15.6% relative to the procedure denominator. The total included two retransplantations, for anastomotic dehiscence and chronic lung allograft dysfunction, respectively.

Recipient, donor and operative characteristics

The cohort comprised 11 men and six women, with a median age of 55 years (IQR 39.5–65). Interstitial lung disease was the underlying diagnosis in 12 recipients. Twelve underwent bilateral and five single LTx, yielding 29 index bronchial anastomoses. The right lung was implanted first in nine bilateral recipients and the left lung first in three. Recipient, donor and perioperative characteristics are summarised in Table 1.

All 17 recipients received perioperative extracorporeal membrane oxygenation (ECMO). Four required postoperative reintubation or tracheostomy. Median intensive care unit (ICU) and hospital stays were eight and 23 days, respectively, among the 15 recipients with recorded durations. The treatment cohort was too small to assess associations between these characteristics and airway outcomes.

Timing and anatomical distribution of airway complications

The first airway complication was detected a median of 68 days after transplantation (IQR 40.5–95; range 17–142). Two recipients were diagnosed within 30 days, nine on days 31–90 and six on

days 91–180. First lesions were anastomotic in nine patients, lobar/distal in five and in the bronchus intermedius in three (Table 2; Figure 1).

The two dehiscences were detected on postoperative days 17 and 18. One was complicated by a bronchopleural fistula with subcutaneous emphysema and later healed with stenosis. The other caused severe airway disruption with tension pneumothorax and required rescue retransplantation.

Thirty-five lesions were recorded: 13 anastomotic stenoses, 12 lobar/distal stenoses, five bronchus-intermedius stenoses, three bronchus-intermedius malacia lesions and two dehiscences (Figure 2A). Twenty lesions (57.1%) were therefore non-anastomotic, involving the lobar/distal bronchi or the bronchus intermedius. These counts describe the classified lesions rather than every airway abnormality arising during subsequent treatment.

Right-sided involvement occurred in 11 of 12 bilateral recipients: six had right-only and five bilateral involvement. It was present in eight of nine recipients with right-first implantation and all three with left-first implantation. Six recipients had documented atelectasis, with complete or partial re-expansion after treatment in four.

Microbiology

Microbiological detections were common in the available records (Table 3). *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* were each reported in 12 recipients (70.6%); *Acinetobacter baumannii* and *Aspergillus* species were each reported in eight (47.1%). These descriptive findings combine culture and molecular detections across heterogeneous specimen types and sampling schedules and should not be interpreted as rates of clinical airway infection.

Bronchoscopic management

The bronchoscopy records documented 185 therapeutic sessions, with a median of eight per recipient (range 2–21); among the 15 recipients surviving beyond one year, the median was ten.

Twenty-one sessions, all in P02, followed rescue retransplantation and treated the new graft; the remaining 164 treated index grafts. The interval from the first to the last counted session had a median of 12.8 months (range 0.9–43.7). Mechanical debridement was used in all 17 recipients, balloon dilatation and cryotherapy in 16 each, argon plasma coagulation and high-frequency electrosurgery in 11 each and laser in four (Table 4). Figure 3 illustrates selected bronchoscopic appearances before and after individual treatment encounters; these frames document local findings rather than durable treatment success.

Four recipients received stents (P02, P08, P10 and P13). Their indications and subsequent courses differed, including treatment after rescue retransplantation and additional interventions after stent removal.

Lesion-specific outcomes and rescue treatment

Thirty-one lesions were assessed in the 15 recipients surviving beyond one year. Excluding the dehiscence treated by retransplantation, the assessment used for each lesion was made a median of 22.7 months (range 11.6–58.4) after detection of the recipient's first lesion, by bronchoscopy for 22 lesions and CT for eight. At the last documented assessment, 16 of 26 stenoses were stable or improved, six were occluded, including one near-complete occlusion, and four had secondary malacia (Table 4; Figure 2B). The distribution of these states differed by site. All six occlusions arose outside the anastomosis: five of 11 lobar/distal stenoses were occluded, including three of five right-upper-lobe stenoses, as was one of four bronchus-intermedius stenoses. By contrast, none of the 11 anastomotic stenoses was occluded; four had secondary malacia and seven were stable or improved, one of which remained supported by a silicone stent at the last documented assessment (P08). P10's anastomotic lesion improved while the separate left-upper-lobe lesion remained occluded. The pattern was unchanged when the near-complete occlusion (P09) and the stent-supported stenosis (P08) were set aside: the five remaining occlusions were all non-

anastomotic, and of the ten remaining anastomotic stenoses, six were stable or improved and four had secondary malacia.

None of the three primary bronchus-intermedius malacia lesions resolved, and fixed narrowing subsequently developed at the same site in two. All three affected recipients received non-invasive ventilation.

One dehiscence healed with stenosis. The other was treated with rescue retransplantation; the new graft subsequently developed right-sided airway stenosis that required 21 therapeutic sessions from day 112 after retransplantation, including repeated balloon dilatation and four stent insertions.

Survival

Nine recipients died and eight remained alive at the census date. Median observation was 32.2 months (range 7.4–62.6). Kaplan–Meier survival was 88.2% at one year, 76.5% at two years, 55.6% at three years and 37.1% at four years (Figure 4). The corresponding 95% confidence intervals were 60.6–96.9%, 48.8–90.4%, 28.1–76.2% and 12.7–62.0%. Only four recipients remained at risk immediately before 48 months. Individual onset and follow-up trajectories are shown in Figure 1.

Discussion

This series has three principal findings. First, the first airway complication requiring intervention was detected within five months of transplantation in every recipient, and more than half of the classified lesions involved the lobar/distal bronchi or the bronchus intermedius rather than the anastomosis. Second, despite repeated multimodal bronchoscopic treatment, with a median of eight therapeutic sessions per recipient, 10 of 26 stenoses were occluded or had secondary malacia at the last documented assessment. Third, these unfavourable states were distributed by site: occlusion was observed only in non-anastomotic stenoses, particularly of the right upper

lobe, whereas no anastomotic stenosis was occluded but four of 11 had secondary malacia, and primary malacia of the bronchus intermedius did not resolve. Treatment burden and lesion status are therefore complementary: procedure counts show what management involved, and lesion-level status shows the anatomical state reached at each site.

The repeated interventions are consistent with the treatment burden described in larger cohorts. In Gottlieb and colleagues' cohort, recipients with bilateral obstructive airway complications underwent a median of 26 bronchoscopies in the first postoperative year, compared with nine in controls [21]. In a ten-year balloon bronchoplasty series, primary patency was achieved in 18.5% of treated bronchi and secondary patency in 76.9% after repeated dilatation [22]. Our session counts cover variable observation periods and include only therapeutic procedures, so they are not directly comparable across centres, but they show that management usually extended well beyond a single recanalisation. More balloon procedures have been associated with lower one-year forced expiratory volume in 1 s (FEV1) [24], so a high procedure count is better regarded as a marker of refractory disease than of treatment success. For treatment-refractory stenosis, endobronchial brachytherapy has been reported to reduce the number of interventions required in the following six months [25].

The site-related distribution of unfavourable lesion states is the most clinically relevant observation. Every occlusion in this series arose outside the anastomosis, and three of five assessed right-upper-lobe stenoses were occluded at the last documented assessment despite repeated treatment. Non-anastomotic stenosis is not peculiar to our centre: in a contemporary series of 400 anastomoses, 11 of 25 stenoses were non-anastomotic [9]. Lobar orifices are smaller than the main bronchi and may offer less scope for repeated dilatation or stenting, so a recurrent lobar stenosis may progress to closure and loss of ventilation of the subtended lobe. This raises the hypothesis that early surveillance should include the lobar orifices, particularly the right upper lobe, and that recurrent lobar narrowing may warrant earlier consideration of alternative

treatment; because treatment strategies were not compared, the series cannot define when or how to escalate. At the anastomosis, by contrast, the lumen was preserved but four of 11 stenoses had secondary malacia, so the unfavourable state observed was dynamic collapse rather than closure, suggesting that dynamic expiratory assessment of treated anastomotic stenoses during follow-up may be informative. P10 shows that both states can coexist in one recipient: the anastomotic stenosis improved while the separate left-upper-lobe lesion remained occluded, a divergence that a patient-level success label would conceal.

The predominance of right-sided and non-anastomotic lesions is compatible with ischaemic injury extending beyond the anastomosis, although our data cannot identify its determinants. Donor-airway perfusion provides a biologically plausible context: human tissue oximetry and biopsy work found reduced donor-bronchial oxygen saturation, most clearly in the upper lobes, and linked hypoxia-responsive gene expression to airway complications [26], which is compatible with the vulnerability of the right upper lobe in this series. In clinical cohorts, bilateral and right-sided transplantation [8] and performing the left anastomosis first [15] have been associated with airway complications or clinically significant ischaemia, and stenosis of the bronchus intermedius is characteristic of vanishing bronchus syndrome [27]. After living-donor lobar transplantation, segmental perfusion defects on scintigraphy have also been associated with airway complications [28]. Our study measured neither perfusion nor molecular pathways, and the small left-first subgroup and absence of unaffected controls prevent inference about implantation order. The distribution nevertheless identifies where treatment was needed: the right lobar bronchi and bronchus intermedius as well as the anastomosis. The ISHLT framework provides a basis for reporting these sites consistently [17].

Microbiological findings require a distinction between organisms encountered during care and exposures that precede airway injury. Coppolino and colleagues analysed respiratory bacterial cultures occurring before stenosis and found an association with intervention-requiring bronchial

stenosis [23]. That temporal design is materially different from our aggregate record review, which combines respiratory and non-respiratory specimens collected at variable times. *Pseudomonas aeruginosa*, other gram-negative organisms and *Aspergillus* species are also the pathogens most frequently associated with bronchial anastomotic infection [29], and post-transplant *Aspergillus* isolation independently predicted airway complications in a contemporary series [9]. Conversely, in recipients with dehiscence, infection before healing was not associated with subsequent stenosis [30]. Airway stenosis has itself been associated with invasive aspergillosis after transplantation [31], and stented recipients are more often colonised with *Pseudomonas*, *Acinetobacter* and *Klebsiella* species [32], so organisms may also follow airway narrowing rather than precede it. Frequent *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* detections in this series therefore cannot establish whether infection preceded narrowing, followed impaired drainage or reflected colonisation. Their value here is clinical context, rather than evidence for pathogen-specific causation or a microbiology-based treatment algorithm.

Stenting and rescue surgery represent distinct management decisions. Published series describe stents for selected stenotic, malacic or dehiscent airways, together with complications and subsequent interventions [20,21,33]. A systematic review found consistent short-term symptomatic and functional benefit but no clear long-term functional benefit, and stent-related complications were common regardless of material [34]; biodegradable stents have been explored partly to reduce these complications [35]. Long-term series of self-expanding metal stents report sustained lung-function benefit without excess mortality but with stent fracture, in-stent stenosis and migration [36], and customised bifurcated or three-dimensionally designed silicone stents have been used when anastomotic anatomy is unsuitable for conventional devices [37,38]. Bronchoplasty or sleeve resection, including of the bronchus intermedius, has also been reported for stenoses refractory to endoscopic treatment [39]. Our four stented recipients differed in indications and clinical course, so neither their survival nor selected endoscopic appearances can

be attributed to stent efficacy. Rescue retransplantation likewise addressed severe airway disruption rather than preservation of the original graft. It remains a treatment option for selected severe cases [40], but the subsequent airway stenosis and repeated stenting in our rescue case show why receipt of a new graft should be reported separately from resolution of airway disease. This distinction retains the clinical importance of rescue treatment without subsuming it under bronchoscopic success.

Patient survival adds a further outcome level and should not be used as a surrogate for local airway recovery. Published findings vary with the complication definition and population: van Pel and colleagues [20], a meta-analysis [8] and recent cohorts [11,12] reported shorter survival in recipients with airway complications, whereas Coppolino and colleagues [23] and Kim and colleagues [10] did not detect a significant survival difference. These results do not establish a uniform mortality effect across stenosis, malacia and dehiscence. Our series cannot resolve that question because entry required a subsequently identified complication and there was no unaffected comparison group. The Kaplan–Meier curve describes survival from transplantation in the selected recipients, not survival from complication diagnosis or excess mortality caused by airway disease. The small late risk set further limits interpretation of the four-year estimate.

Limitations

The principal limitations define the scope of the clinical contribution. Selection was restricted to intervention-requiring complications at one centre, so the findings do not represent all post-transplant airway abnormalities. The institutional procedure denominator includes retransplantations and cannot support a recipient-level cumulative incidence. Multiple lesions within patients and the small sample also preclude reliable comparisons of risk factors or treatment strategies. For example, all recipients received perioperative ECMO, which has been associated with airway complications and dehiscence in other studies [8,10,41,42], although post-transplant veno-venous ECMO for severe primary graft dysfunction was associated with less

anastomotic ischaemic injury in another series [43]; its contribution could not be assessed. Similarly, most recipients had interstitial lung disease, and short-telomere interstitial lung disease has been associated with higher odds of dehiscence and stenosis [44]; telomere length was not assessed. The results are descriptive accounts of care in affected recipients, rather than comparative evidence supporting one intervention over another.

Ascertainment also differed across outcomes. The anatomical summary was restricted to 15 recipients surviving beyond one year, excluding two early deaths and four classified lesions from that outcome denominator. It therefore cannot be generalised to all 35 lesions or interpreted as a fixed one-year success rate. Available records did not support uniform retrospective ISHLT severity grading, standardised assessment intervals, or consistent linkage of anatomical findings to serial lung function. The site-specific pattern of outcomes rests on small numbers of lesions without formal statistical comparison and requires confirmation in larger cohorts. Assessment intervals differed between lesions, and the categories are anatomical states recorded in clinical reports rather than measures of symptoms or lung function. These constraints limit assessment of durable functional benefit.

Within these limits, the findings suggest three hypotheses for prospective testing. First, surveillance bronchoscopy and CT during the first months after transplantation may need to include the lobar bronchi and bronchus intermedius, not only the anastomosis. Second, recurrent lobar narrowing, particularly of the right upper lobe, might justify earlier consideration of options reported for refractory stenosis in other series, such as stenting, brachytherapy or surgical bronchoplasty [25,34,39], before complete occlusion develops; this series cannot define an escalation threshold or the preferable option. Third, treated anastomotic stenoses may warrant dynamic assessment for secondary malacia. Prospective multicentre studies with common assessment intervals and serial measures of patency and lung function are needed to test whether such site-directed strategies improve durable airway outcomes.

Conclusions

In this retrospective case series, the first airway complication requiring intervention was detected within five months of transplantation in every recipient, most classified lesions were non-anastomotic, and management involved repeated multimodal bronchoscopic treatment. At the last documented assessment, 10 of 26 stenoses in one-year survivors were occluded or had secondary malacia, with a site-related distribution: occlusion was observed only outside the anastomosis, most often in the right upper lobe, whereas secondary malacia was observed only at the anastomosis. Early surveillance that extends beyond the anastomosis and follow-up tailored to the lesion site merit evaluation in larger prospective studies.

Abbreviations

CI, confidence interval; CMV, cytomegalovirus; CT, computed tomography; CTD-ILD, connective-tissue-disease-associated interstitial lung disease; ECMO, extracorporeal membrane oxygenation; FEV1, forced expiratory volume in 1 s; ICU, intensive care unit; IQR, interquartile range; ISHLT, International Society for Heart and Lung Transplantation; LTx, lung transplantation; RSV, respiratory syncytial virus; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2

Declarations

Ethics approval and consent to participate

The Medical Ethics Committee of the First Affiliated Hospital of Zhengzhou University approved the study (2025-KY-0954). The study was conducted in accordance with the Declaration of Helsinki. Informed consent for the use of clinical data was obtained from the recipients or, for deceased recipients, from their next of kin.

Consent for publication

Informed consent for publication of the de-identified clinical information and bronchoscopic images was obtained from the recipients or, for deceased recipients, from their next of kin.

Availability of data and materials

Individual-level transplant records are not publicly available because they contain confidential patient information. Requests for de-identified study data may be addressed to the corresponding author and will be considered subject to institutional approval and applicable privacy requirements.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the Zhengzhou Collaborative Innovation Special Project (grant no. XTCX2023009) and the Lung Transplantation Department Special Fund of the First Affiliated Hospital of Chongqing Medical University (grant no. 04010503001). The funders had no role in the design of the study, the collection, analysis and interpretation of data, or the writing of the manuscript.

Authors' contributions

Pengfei Li: Conceptualization, Methodology, Formal analysis, Writing – original draft. Kai Zhao: Investigation, Data curation, Formal analysis, Writing – original draft. Tian Gao: Methodology, Validation, Visualization, Writing – original draft. Zhi Qin: Investigation, Data curation, Writing – review and editing. Zhenyuan Zhang: Investigation, Data curation, Writing – review and editing. Zeyu Chang: Investigation, Validation, Writing – review and editing. Fengke Li: Investigation, Resources, Writing – review and editing. Xiaofei Liu: Investigation, Resources, Writing – review and editing. Jinrui Li: Investigation, Writing – review and editing. Zhanyi Zhu: Investigation, Writing – review and editing. Gaofeng Zhao: Conceptualization, Supervision, Project administration, Writing – review and editing. Zhidan Ding: Methodology, Supervision, Project administration, Writing – review and editing. Pengfei Li, Kai Zhao and Tian Gao contributed equally. Gaofeng Zhao and Zhidan Ding are co-corresponding authors. All authors read and approved the final manuscript.

Acknowledgements

We thank Professor Jingyu Chen and his lung transplantation team for their technical support and guidance in lung transplantation and in the perioperative and bronchoscopic management of airway complications at our centre.

References

1. Santacruz JF, Mehta AC. Airway complications and management after lung transplantation: ischemia, dehiscence, and stenosis. Proc Am Thorac Soc. 2009;6(1):79-93. doi:10.1513/pats.200808-094GO.
2. Kshettry VR, Kroshus TJ, Hertz MI, Hunter DW, Shumway SJ, Bolman RM. Early and late airway complications after lung transplantation: incidence and management. Ann Thorac Surg. 1997;63(6):1576-1583. doi:10.1016/s0003-4975(97)83852-0.
3. Yserbyt J, Dooms C, Vos R, Dupont LJ, Van Raemdonck DE, Verleden GM. Anastomotic airway complications after lung transplantation: risk factors, treatment modalities and outcome-a single-centre experience. Eur J Cardiothorac Surg. 2016;49(1):e1-e8. doi:10.1093/ejcts/ezv363.
4. Herrera JM, McNeil KD, Higgins RS, Coulden RA, Flower CD, Nashef SA, et al. Airway complications after lung transplantation: treatment and long-term outcome. Ann Thorac Surg. 2001;71(3):989-993. doi:10.1016/s0003-4975(00)02127-5.
5. Yin M, Liang Y, Wei S, Zhang A. Comprehensive Review and Management Strategies of Airway Complications Post-lung Transplantation. J Surg Res. 2025;315:417-425. doi:10.1016/j.jss.2025.09.028.
6. Dhanani Z, Criner R, Criner GJ. Unraveling the spectrum of airway complications following lung transplantation: a comprehensive overview. Curr Opin Organ Transplant. 2024;29(5):323-331. doi:10.1097/MOT.0000000000001162.
7. Mondoni M, Rinaldo RF, Solidoro P, Di Marco F, Patrucco F, Pavesi S, et al. Interventional pulmonology techniques in lung transplantation. Respir Med. 2023;211:107212. doi:10.1016/j.rmed.2023.107212.

8. Huang J, Lin J, Zheng Z, Liu Y, Lian Q, Zang Q, et al. Risk factors and prognosis of airway complications in lung transplant recipients: A systematic review and meta-analysis. J Heart Lung Transplant. 2023;42(9):1251-1260. doi:10.1016/j.healun.2023.04.011.
9. Muñoz-Fos A, Moreno P, González FJ, Ruiz E, Vaquero JM, Baamonde C, et al. Airway Complications after Lung Transplantation-A Contemporary Series of 400 Bronchial Anastomoses from a Single Center. J Clin Med. 2023;12(9):3061. doi:10.3390/jcm12093061.
10. Kim HH, Jo KW, Shim TS, Ji W, Ahn JH, Oh DK, et al. Incidence, risk factors, and clinical characteristics of airway complications after lung transplantation. Sci Rep. 2023;13(1):667. doi:10.1038/s41598-023-27864-1.
11. Delbove A, Senage T, Gazengel P, Tissot A, Lacoste P, Cellerin L, et al. Incidence and risk factors of anastomotic complications after lung transplantation. Ther Adv Respir Dis. 2022;16:17534666221110354. doi:10.1177/17534666221110354.
12. Kapnadak SG, Ramos KJ, Flodin R, Mansoor S, Bilodeau K, Beidler P, et al. Airway complications after lung transplantation: Perioperative risk factors and clinical outcomes. JHLT Open. 2025;9:100315. doi:10.1016/j.jhlto.2025.100315.
13. Date H, Trulock EP, Arcidi JM, Sundaresan S, Cooper JD, Patterson GA. Improved airway healing after lung transplantation. An analysis of 348 bronchial anastomoses. J Thorac Cardiovasc Surg. 1995;110(5):1424-1432. doi:10.1016/S0022-5223(95)70065-X.
14. Ruttmann E, Ulmer H, Marchese M, Dunst K, Geltner C, Margreiter R, et al. Evaluation of factors damaging the bronchial wall in lung transplantation. J Heart Lung Transplant. 2005;24(3):275-281. doi:10.1016/j.healun.2004.01.008.
15. Li G, Liu Z, Salan-Gomez M, Keeney E, D'Silva E, Mankidy B, et al. Risk Factors, Incidence, and Outcomes Associated With Clinically Significant Airway Ischemia. Transpl Int. 2024;37:12751. doi:10.3389/ti.2024.12751.

16. Kraft BD, Mahmood K, Harlan NP, Hartwig MG, Snyder LD, Suliman HB, et al. Hyperbaric oxygen therapy to prevent central airway stenosis after lung transplantation. J Heart Lung Transplant. 2021;40(4):269-278. doi:10.1016/j.healun.2021.01.008.
17. Crespo MM, McCarthy DP, Hopkins PM, Clark SC, Budev M, Bermudez CA, et al. ISHLT Consensus Statement on adult and pediatric airway complications after lung transplantation: Definitions, grading system, and therapeutics. J Heart Lung Transplant. 2018;37(5):548-563. doi:10.1016/j.healun.2018.01.1309.
18. Crespo MM, Solé A, Bermudez CA, Richards TJ, Mazur Z, Budev M. Adoption and challenges of the 2018 International Society for Heart and Lung Transplantation consensus statement on adult and pediatric airway complications grading system in lung transplantation: A multicenter survey. JHLT Open. 2026;13:100602. doi:10.1016/j.jhlto.2026.100602.
19. Chinese Thoracic Society, Chinese Society of Organ Transplantation, Guangdong Association of Primary Medicine. [Expert consensus on airway complications after lung transplantation]. Zhonghua Jie He He Hu Xi Za Zhi. 2025;48(4):318-328. Chinese. doi:10.3760/cma.j.cn112147-20240814-00485. PMID: 40159050.
20. van Pel R, Gan CT, van der Bij W, Verschuuren EAM, van Gemert JPA, Van De Wauwer C, et al. Three Decades Single Center Experience of Airway Complications After Lung Transplantation. Transpl Int. 2023;36:11519. doi:10.3389/ti.2023.11519.
21. Gottlieb J, Fuehner T, Zardo P. Management and outcome of obstructive airway complications after lung transplantation – a 12-year retrospective cohort study. Ther Adv Respir Dis. 2023;17:17534666231181541. doi:10.1177/17534666231181541.
22. Kim DK, Kwon JH, Han K, Kim MD, Kim GM, Moon S, et al. Balloon Bronchoplasty for the Treatment of Bronchial Stenosis After Lung Transplantation: A Single-Center 10-Year Experience. Korean J Radiol. 2023;24(5):424-433. doi:10.3348/kjr.2022.0999.

23. Coppolino A, Maurer R, Woehl E, Connolly EM, Chamberlin E, Goldberg HJ, et al. Bronchial stenosis after lung transplant: Risk factors and clinical outcomes. JHLT Open. 2026;11:100392. doi:10.1016/j.jhlto.2025.100392.
24. Nęcki M, Latos M, Urlik M, Antończyk R, Gawęda M, Pandel A, et al. Number of Bronchoscopic Interventions in Lung Transplant Recipients Correlates with Respiratory Function Assessed by Pulmonary Function Tests. Ann Transplant. 2021;26:e927025. doi:10.12659/AOT.927025.
25. Schaar DA, Yohannes A, Groszkiewicz A, Iheagwara U, Johnson BA, Schuchert M, et al. Endobronchial High-Dose-Rate Brachytherapy for Posttransplant-Associated Bronchial Stenosis: Extended Follow-up of Pulmonary Function and Subsequent Procedures. Adv Radiat Oncol. 2026;11(9):102159. doi:10.1016/j.adro.2026.102159.
26. Kraft BD, Suliman HB, Colman EC, Mahmood K, Hartwig MG, Piantadosi CA, et al. Hypoxic gene expression of donor bronchi linked to airway complications after lung transplantation. Am J Respir Crit Care Med. 2016;193(5):552-560. doi:10.1164/rccm.201508-1634OC.
27. Notsuda H, Kumata S, Onodera K, Watanabe T, Watanabe Y, Hirama T, et al. Vanishing Bronchus Syndrome After Lung Transplantation: Clinical Characteristics, Airway Colonization, and Stent Outcomes. Clin Transplant. 2026;40(10):e70707. doi:10.1111/ctr.70707.
28. Imanishi K, Sugimoto S, Ryuko T, Tomioka Y, Tanaka S, Suzawa K, et al. Lung Segmental Perfusion Defect Is Associated With Airway Complications After Living-Donor Lobar Lung Transplantation. Interdiscip Cardiovasc Thorac Surg. 2026;41(5):ivag139. doi:10.1093/icvts/ivag139.
29. Abdelnour-Berchtold E, Gijs PJ, Koutsokera A, Walti LN. Bronchial anastomotic infection after lung transplantation - An interdisciplinary review. JHLT Open. 2026;11:100417. doi:10.1016/j.jhlto.2025.100417.

30. Courtwright AM, Doyon JB, Blumberg EA, Cevasco M, Cantu E, Bermudez CA, et al. Infectious complications associated with bronchial anastomotic dehiscence in lung transplant recipients. Clin Transplant. 2023;37(10):e15040. doi:10.1111/ctr.15040.
31. van Gemert JPA, Fleurke GJ, Akkerman OW, Gan CT, Steenhuis WN, Kerstjens HAM, et al. *Aspergillus* After Lung Transplantation: Prophylaxis, Risk Factors, and the Impact on Chronic Lung Allograft Dysfunction. Transpl Infect Dis. 2025;27(4):e70020. doi:10.1111/tid.70020.
32. Izhakian S, Wasser WG, Vainshelboim B, Pertzov B, Gorelik O, Kramer MR. Long-term outcomes of metallic endobronchial stents in lung transplant recipients are not affected by bacterial colonization. Interact Cardiovasc Thorac Surg. 2021;32(1):47-54. doi:10.1093/icvts/ivaa221.
33. Uğur Chousein EG, Turan D, Vayvada M, Tanriverdi E, Taşçi AE, Özgül MA, et al. Management of airway complications following lung transplantation: first interventional bronchoscopy report from Türkiye. Turk J Med Sci. 2024;54(4):615-622. doi:10.55730/1300-0144.5830.
34. Wang Z, Zhao B, Deng M, Tong R, Bian Y, Zhang Q, et al. Utility and safety of airway stenting in airway stenosis after lung transplant: A systematic review. Front Med (Lausanne). 2023;10:1061447. doi:10.3389/fmed.2023.1061447.
35. van Pel R, Gan T, Daniels JMA, Ruigrok D, Hellemons ME, Klooster K, et al. Lung transplant airway complications treated with biodegradable airway stents: The Dutch multi-center experience. Clin Transplant. 2024;38(3):e15289. doi:10.1111/ctr.15289.
36. Izhakian S, Wasser W, Unterman A, Fruchter O, Gorelik O, Kramer M. Long-Term Success of Metal Endobronchial Stents in Lung Transplant Recipients. Thorac Cardiovasc Surg. 2022;70(6):520-526. doi:10.1055/s-0040-1721461.

37. Guinde J, Bismuth J, Laroumagne S, Coiffard B, Astoul P, Thomas PA, et al. Bifurcated Silicone Stents for the Management of Anastomotic Complications in Lung Transplanted Patients: Ten Years' Experience. Respiration. 2022;101(7):675-682. doi:10.1159/000523755.
38. Sawal N, Pennington KM, Petrossian R, Reisenauer J, Mullon J, Midthun D, et al. Custom silicone Y-stents for the management of anastomotic stenosis in lung transplant recipients. Respir Med. 2024;231:107737. doi:10.1016/j.rmed.2024.107737.
39. Faccioli E, Dell'Amore A, Ferrigno P, Schiavon M, Mammana M, Terzi S, et al. Surgical management of post-transplant bronchial stenoses: a single-center experience. Surg Today. 2022;52(3):449-457. doi:10.1007/s00595-021-02360-z.
40. Michel E, Galen Hartwig M, Sommer W. Lung Retransplantation. Thorac Surg Clin. 2022;32(2):259-268. doi:10.1016/j.thorsurg.2021.12.001.
41. Atchade E, Ren M, Jean-Baptiste S, Tran Dinh A, Tanaka S, Tashk P, et al. ECMO support as a bridge to lung transplantation is an independent risk factor for bronchial anastomotic dehiscence. BMC Pulm Med. 2022;22(1):482. doi:10.1186/s12890-022-02280-9.
42. Subasi M, Duger M. Preoperative risk factors of airway complications in adult lung transplant recipients: A systematic review and meta-analysis. Turk Gogus Kalp Damar Cerrahisi Derg. 2023;31(4):517-529. doi:10.5606/tgkdc.dergisi.2023.25399.
43. Noda K, Jawad-Makki MH, Chan EG, Ryan J, Furukawa M, Hage CA, et al. Veno-Venous Extracorporeal Membrane Oxygenation Support for Severe Primary Graft Dysfunction Is Associated With Reduced Airway Complications After Lung Transplantation. Clin Transplant. 2024;38(11):e70029. doi:10.1111/ctr.70029.
44. Choi B, Messika J, Courtwright A, Mornex JF, Hirschi S, Roux A, et al. Airway complications in lung transplant recipients with telomere-related interstitial lung disease. Clin Transplant. 2022;36(3):e14552. doi:10.1111/ctr.14552.

Figure titles and legends

Figure 1. Onset of the first qualifying airway complication and follow-up in all 17 recipients. Each line begins at index transplantation and ends at death (cross) or the census date of 30 July 2026 (plus sign). The symbol on each line marks detection of the first qualifying complication and its site: circles denote anastomotic lesions other than dehiscence, squares lobar/distal lesions, diamonds bronchus-intermedius lesions and triangles the two anastomotic dehiscences. Days were divided by 30.4375 solely for placement on the month axis. The right-hand columns give the postoperative day of detection, follow-up in months and whether a stent was ever recorded; the stent column does not indicate insertion dates, removal dates or continuous dwell time. The median detection day was 68 (IQR 40.5–95; range 17–142). These are detection times, not necessarily the biological onset of disease, and line length is observation time, not the duration of active airway disease or treatment. Identifiers correspond to Additional file 1.

Figure 2. Lesion site and outcome. (A) All 35 classified lesions by recipient (rows) and site (columns). Each filled cell is one lesion, coloured by its outcome at the last documented airway assessment. Outcomes were assessed only in the 15 recipients surviving beyond one year; lesions of the two recipients who died within one year (P13 and P14) are shown as excluded from the outcome summary. Primary malacia denotes the three bronchus-intermedius malacia lesions; secondary malacia developed in a treated stenosis. F marks fixed narrowing that later developed at a primary malacia site, S a silicone stent in place at the last assessment (P08) and the asterisk a near-complete occlusion (P09). BI, bronchus intermedius; RUL/RML, right upper/middle lobe; LUL/LLL, left upper/lower lobe; the LUL column includes the lingula. (B) Outcomes of the 26 assessed stenoses by site. Right-upper-lobe stenoses are a subset of the lobar/distal row and are not counted twice; occlusion includes the near-complete occlusion. Counts are descriptive, lesions within a recipient are not independent, and no between-site comparison was tested. Identifiers correspond to Additional file 1.

Figure 3. Bronchoscopic appearances before and after individual treatment encounters. (A, B) P03, postoperative day 65: debridement and cryotherapy for left anastomotic stenosis with necrotic tissue and exposed sutures. (C, D) P17, postoperative day 142: electrosurgery, argon plasma coagulation and cryotherapy for membranous stenoses of the left upper and left lower lobe orifices. (E, F) P16, postoperative day 157: electrosurgical resection, debridement and cryotherapy for obstructing tissue in the bronchus intermedius. (G, H) P02, day 255 after index transplantation (day 224 after rescue retransplantation): balloon dilatation and cryotherapy for right-sided airway stenosis of the new graft. Encounter-level treatments were reconciled with clinical notes; source frames were labelled before/after treatment. Different viewing positions preclude quantitative lumen comparisons. The frames show immediate appearances and do not establish durable patency or comparative efficacy. Full frames retain their aspect ratios with black padding; image content and colours were unaltered.

Figure 4. Kaplan–Meier overall survival from index transplantation in the 17 recipients. Recipients were selected for airway complications requiring intervention. The shaded area shows pointwise 95% confidence intervals calculated using Greenwood variance with a log-log transformation; plus signs indicate censoring. All-cause deaths are events; the eight recipients alive at the census date of 30 July 2026 are censored on that date, so their censoring times differ only because transplantation dates differed. No recipient was lost to follow-up. Times were calculated from day-level dates and expressed in months. The risk table gives the number at risk immediately before each time point, with deaths and censorings accumulated strictly before that time. At 48 months only four recipients remained at risk. The curve describes a retrospectively selected complication cohort and does not estimate survival for all transplant recipients or survival from complication diagnosis.

Tables

Table 1. Recipient, donor and perioperative characteristics (n = 17)

Characteristic	Value
Recipient male sex	11 (64.7)
Recipient age, years	55 (39.5–65); range 30–69
Body mass index, kg/m² (n = 17)	21.8 (19.6–25.4); range 17.4–28.8
Body mass index < 20 kg/m²	5/17 (29.4)
Blood group (A / B / O / AB)	5 / 7 / 3 / 2
Underlying disease	
Interstitial lung disease (incl. paraquat, CTD-ILD)	12 (70.6)
Bronchiolitis obliterans (incl. BOS after HSCT)	2 (11.8)
Pulmonary alveolar proteinosis	1 (5.9)
Bronchiectasis	1 (5.9)
Alveolar cell carcinoma	1 (5.9)
Pretransplant respiratory support	
Nasal cannula oxygen	14 (82.4)
Invasive mechanical ventilation	3 (17.6)
Extracorporeal membrane oxygenation	1 (5.9)
Pretransplant microbiological finding	7 (41.2)
Donor male sex	16 (94.1)
Donor age, years	42 (30.5–45); range 13–57
Type of transplant	
Bilateral	12 (70.6)
Left single	3 (17.6)
Right single	2 (11.8)
Index bronchial anastomoses	29
Implantation sequence, bilateral recipients (n = 12): right first / left first	9 / 3
Bronchial calibre mismatch	1 (5.9)
Cold ischaemic time, hours, median (range)	
Single transplant (n = 5)	4.0 (2.7–6.0)
Bilateral, first side (n = 12)	6.1 (2.9–8.5)
Bilateral, second side (n = 11)	10.3 (7.0–12.4)
Intraoperative ECMO	
Veno-venous	12 (70.6)
Veno-arterial	3 (17.6)
Veno-arterio-venous	1 (5.9)
Preoperative veno-arterial ECMO with an additional venous cannula	1 (5.9)
Operative time, hours, median (range) (n = 10)	6.1 (3.0–8.8)
Intraoperative blood loss, mL, median (range) (n = 14)	600 (300–2500)
ICU length of stay, days, median (range) (n = 15)	8 (5–28)
Postoperative hospital stay, days, median (range) (n = 15)	23 (15–49)
Reintubation or tracheostomy	4 (23.5)

Data are n (%), median (IQR; range) or median (range) as indicated, with available-case denominators shown. ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit; CTD-ILD, connective-tissue-disease-associated interstitial lung disease. Anastomoses refer to index transplantation. Operative time excludes the ambiguous “3 + 6 h” entry; blood-loss statistics exclude the unquantified “200+ mL” entry. Pretransplant microbiological findings include one microscopy-suspected fungal finding, but exclude T-SPOT alone. Bilateral includes one right lung plus left upper lobe transplantation (P01). BOS, bronchiolitis obliterans syndrome; HSCT, haematopoietic stem cell transplantation.

Table 2. Characteristics of airway complications

Variable	Value
Lung transplant procedures during the study period	109
Affected recipients relative to transplant procedures	17/109 (15.6%)
Interval from transplantation to first complication, days	68 (40.5–95); range 17–142
≤30 days / 31–90 days / 91–180 days	2 (11.8) / 9 (52.9) / 6 (35.3)
Site of the first lesion	
Anastomosis	9 (52.9)
Lobar or distal bronchi	5 (29.4)
Bronchus intermedius	3 (17.6)
Median interval to first lesion by site, days (anastomosis / lobar-distal / bronchus intermedius)	64 / 77 / 92
Anastomotic dehiscence	2 (11.8); postoperative days 17 and 18
Total classified lesions	35
Anastomotic stenosis	13
Anastomotic dehiscence	2
Lobar/distal bronchial stenosis	12
Bronchus intermedius stenosis	5
Bronchus intermedius malacia	3
Laterality in bilateral recipients (n = 12)	
Right side only	6 (50.0)
Both sides	5 (41.7)
Left side only	1 (8.3)
Right-sided involvement	11/12 (91.7)
Left-sided involvement	6/12 (50.0)
Right-sided involvement when right lung implanted first	8/9 (88.9)
Right-sided involvement when left lung implanted first	3/3 (100)
Atelectasis attributable to the airway lesion	6 (35.3)
Documented complete or partial re-expansion after treatment	4/6

Data are n (%) or median (IQR/range). The frequency uses 109 procedures as the denominator and 17 affected recipients as the numerator. Lesions were classified by anatomical unit and type as defined in the Methods. Bilateral side-specific counts overlap.

Table 3. Selected microorganisms reported in the clinical microbiology records (n = 17)

Organism	Patients, n (%)
Pseudomonas aeruginosa	12 (70.6)
Klebsiella pneumoniae	12 (70.6)
Acinetobacter baumannii	8 (47.1)
Aspergillus species	8 (47.1)
Stenotrophomonas maltophilia	5 (29.4)
Candida species	5 (29.4)
Other Enterobacterales	7 (41.2)
Burkholderia cepacia complex	5 (29.4)
Corynebacterium striatum	5 (29.4)
Viruses (including CMV, SARS-CoV-2, RSV, influenza A and torque teno virus)	9 (52.9)
Gram-positive cocci (Staphylococcus, Enterococcus or Streptococcus)	6 (35.3)

Each recipient is counted once per organism/group; groups overlap. Detections include culture and molecular findings from available clinical records, including respiratory and non-respiratory specimens. Other Enterobacterales include *Klebsiella aerogenes*. The viral category includes a blood CMV detection and is not a respiratory-infection rate. Suspected *Aspergillus* identifications in P02/P14 and suspected *Candida* in P13 were excluded from the respective organism counts. CMV, cytomegalovirus; RSV, respiratory syncytial virus. Patient-level mappings are provided in Additional file 1.

Table 4. Bronchoscopic management and outcomes

Variable	Value
Therapeutic bronchoscopic sessions	185
Sessions per patient, all patients	8 (2–21)
Sessions per patient, survivors > 1 year (n = 15)	10 (2–21)
Modalities	
Mechanical debridement (forceps/clamping)	17 (100)
Balloon dilatation	16 (94.1)
Cryotherapy	16 (94.1)
Argon plasma coagulation	11 (64.7)
High-frequency electrosurgery	11 (64.7)
Laser	4 (23.5)
Airway stent	4 (23.5)
Lesion status at last documented assessment (31 lesions; 15 survivors > 1 year)	
Stenotic lesions	26
- complete occlusion	6 (23.1)
- stable or improved	16 (61.5)
- stenosis with secondary malacia	4 (15.4)
By site: occluded / stable or improved / secondary malacia	
- anastomotic stenoses (n = 11)	0 / 7 / 4
- lobar/distal stenoses (n = 11)	5 / 6 / 0
- bronchus-intermedius stenoses (n = 4)	1 / 3 / 0
Primary bronchus-intermedius malacia	3; none resolved (later fixed narrowing in 2)
Anastomotic dehiscence	2; 1 followed by stenosis; 1 treated with rescue retransplantation
Survival	
Deaths	9 (52.9)
Median observation, months	32.2 (7.4–62.6)
Kaplan–Meier survival, 1 / 2 / 3 / 4 years	88.2% / 76.5% / 55.6% / 37.1%

Data are n (%) or median (range). Therapeutic sessions and modalities were counted from the bronchoscopy records from the first qualifying lesion until death or the census date; sessions limited to inspection, lavage, secretion clearance or biopsy were not counted. The 185 sessions include 21 in P02, all after rescue retransplantation and directed at the new graft. Lesion outcomes apply to the 15 recipients surviving beyond one year, with variable assessment times; percentages for stenosis outcomes use 26 as the denominator; by-site counts are occluded / stable or improved / secondary malacia. Complete occlusion includes one near-complete occlusion. Stable/improved is a qualitative category without a uniform quantitative threshold; one improved stenosis remained stented. Observation was calculated from day-level dates.

Supplementary Information

Additional file 1 (.xlsx). Table S1. Individual patient data. Worksheet S1a gives patient-level characteristics, treatment counts, observation time and vital status; S1b gives lesion-level sites,

types and outcomes at the last documented assessment; S1c gives the patient-level microbiological detections underlying Table 3.

Figures

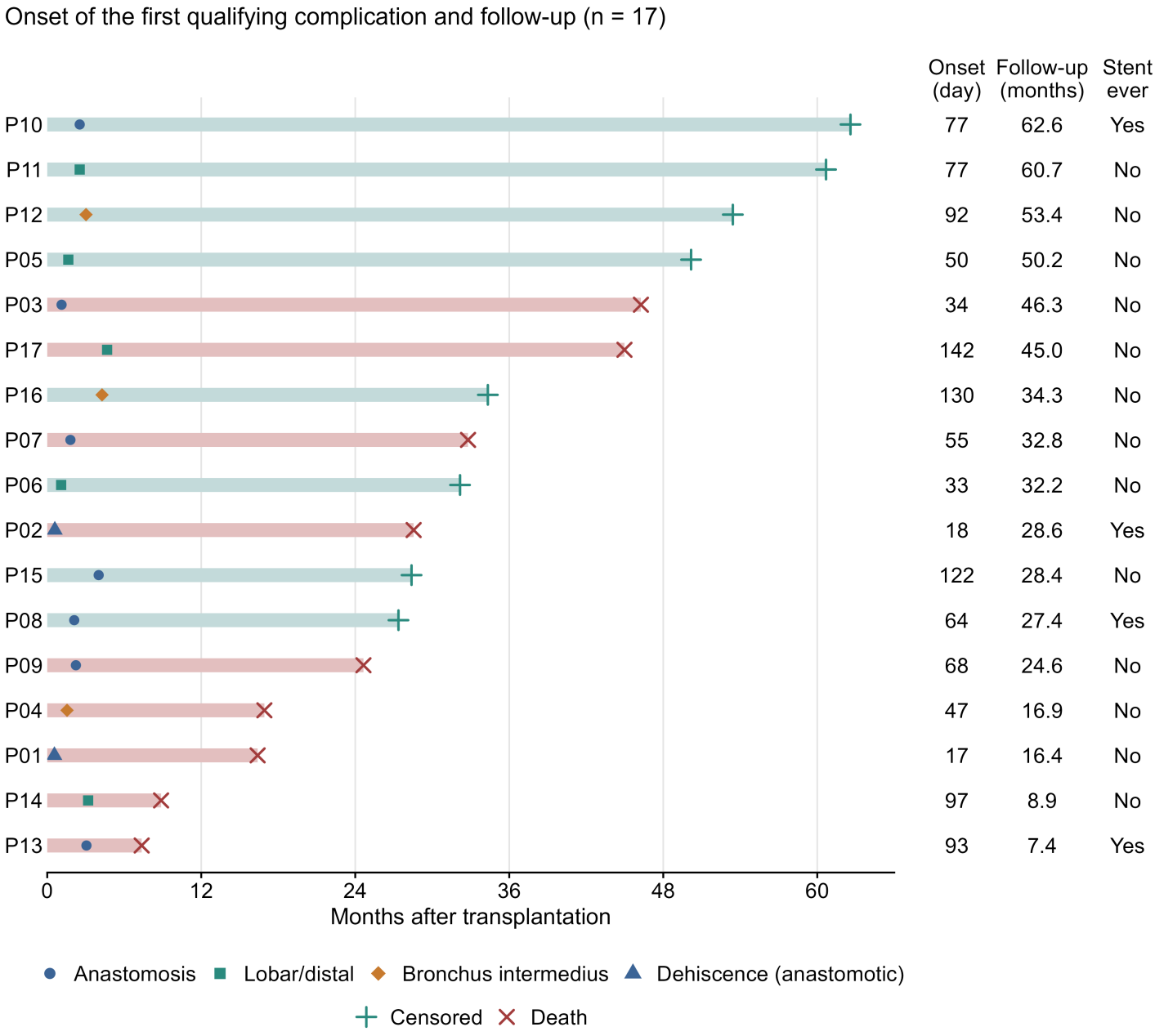
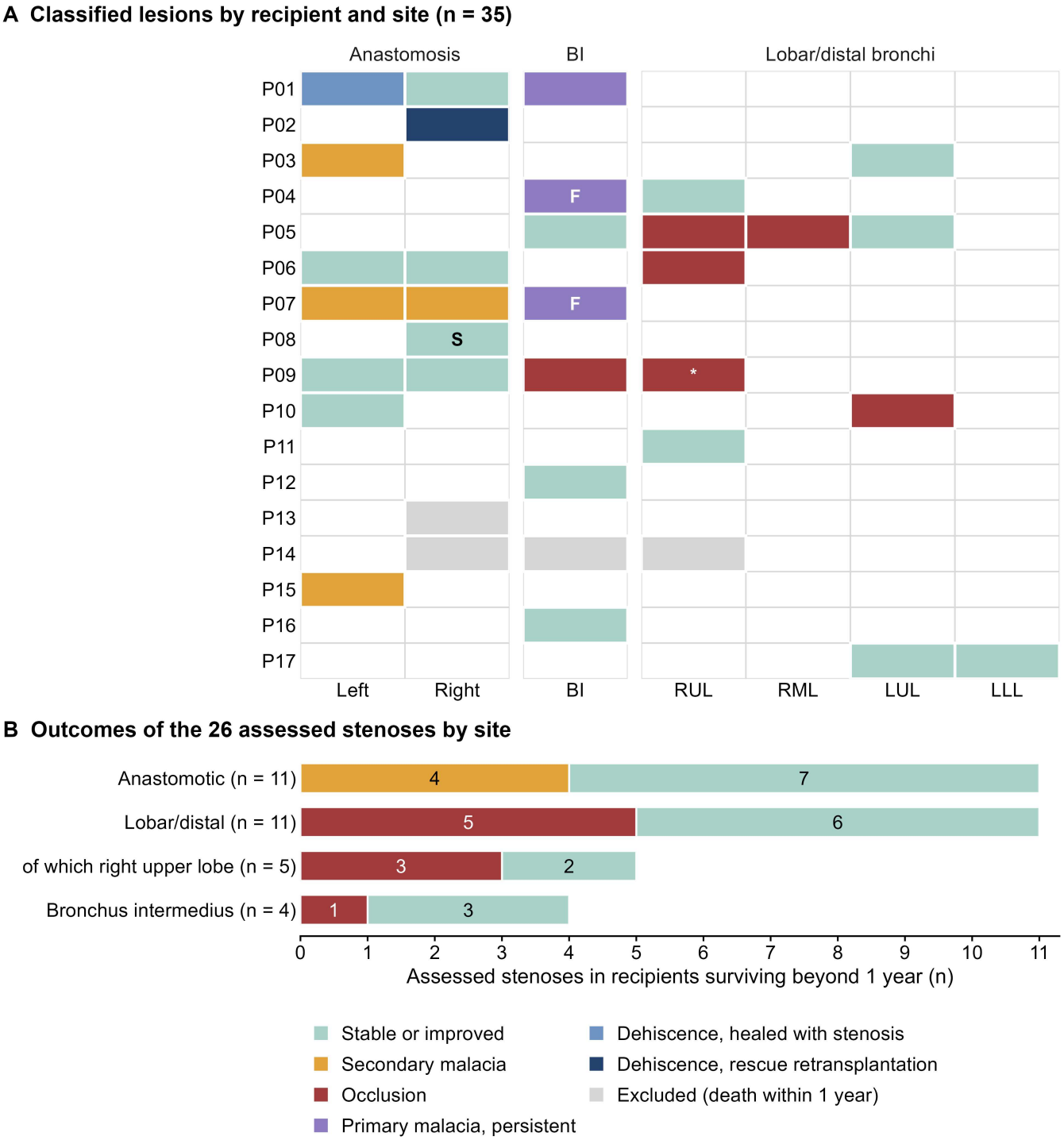


Figure 1

Onset of the first qualifying airway complication and follow-up in all 17 recipients. Each line begins at index transplantation and ends at death (cross) or the census date of 30 July 2026 (plus sign). The symbol on each line marks detection of the first qualifying complication and its site: circles denote anastomotic lesions other than dehiscence, squares lobar/distal lesions, diamonds bronchus-intermedius lesions and triangles the two anastomotic dehiscences. Days were divided by 30.4375 solely for placement on the month axis. The right-hand columns give the postoperative day of detection, follow-up in months and whether a stent was ever recorded; the stent column does not indicate insertion dates, removal dates or continuous dwell time. The median detection day was 68 (IQR 40.5–95; range

17–142). These are detection times, not necessarily the biological onset of disease, and line length is observation time, not the duration of active airway disease or treatment. Identifiers correspond to Additional file 1.



BI, bronchus intermedius; RUL/RML, right upper/middle lobe; LUL/LLL, left upper/lower lobe.
F, fixed narrowing later developed at the site; S, silicone stent in place; *, near-complete occlusion.

Figure 2

Lesion site and outcome. (A) All 35 classified lesions by recipient (rows) and site (columns). Each filled cell is one lesion, coloured by its outcome at the last documented airway assessment. Outcomes were assessed only in the 15 recipients surviving beyond one year; lesions of the two recipients who died within one year (P13 and P14) are shown as excluded from the outcome summary. Primary malacia denotes the three bronchus-intermedius malacia lesions; secondary malacia developed in a treated stenosis. F marks fixed narrowing that later developed at a primary malacia site, S a silicone stent in place at the last assessment (P08) and the asterisk a near-complete occlusion (P09). BI, bronchus intermedius; RUL/RML, right upper/middle lobe; LUL/LLL, left upper/lower lobe; the LUL column includes the lingula. (B) Outcomes of the 26 assessed stenoses by site. Right-upper-lobe stenoses are a subset of the lobar/distal row and are not counted twice; occlusion includes the near-complete occlusion. Counts are descriptive, lesions within a recipient are not independent, and no between-site comparison was tested. Identifiers correspond to Additional file 1.

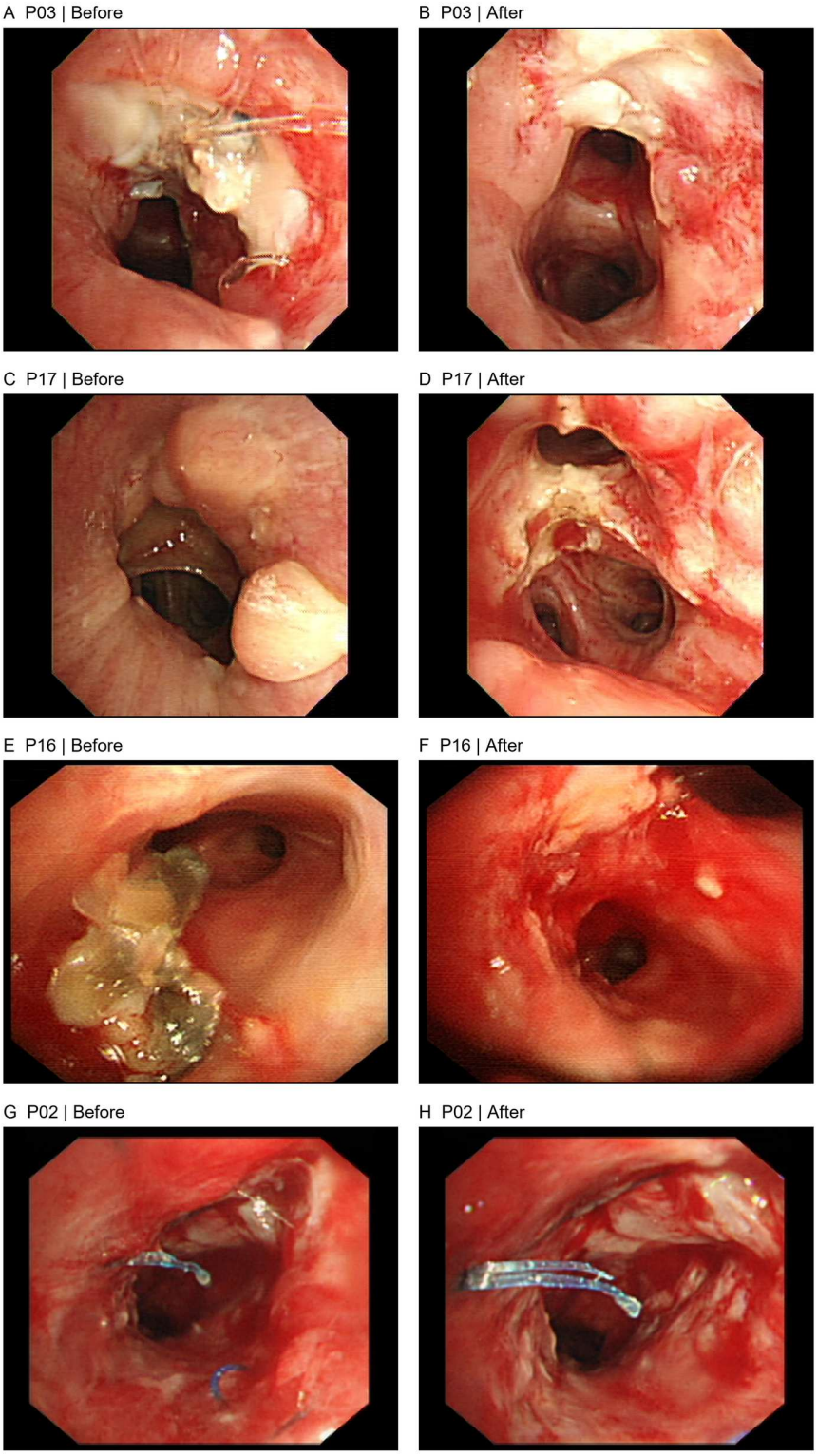


Figure 3

Bronchoscopic appearances before and after individual treatment encounters. (A, B) P03, postoperative day 65: debridement and cryotherapy for left anastomotic stenosis with necrotic tissue and exposed sutures. (C, D) P17, postoperative day 142: electrosurgery, argon plasma coagulation and cryotherapy for membranous stenoses of the left upper and left lower lobe orifices. (E, F) P16, postoperative day 157: electrosurgical resection, debridement and cryotherapy for obstructing tissue in the bronchus

intermedius. (G, H) P02, day 255 after index transplantation (day 224 after rescue retransplantation): balloon dilatation and cryotherapy for right-sided airway stenosis of the new graft. Encounter-level treatments were reconciled with clinical notes; source frames were labelled before/after treatment. Different viewing positions preclude quantitative lumen comparisons. The frames show immediate appearances and do not establish durable patency or comparative efficacy. Full frames retain their aspect ratios with black padding; image content and colours were unaltered.

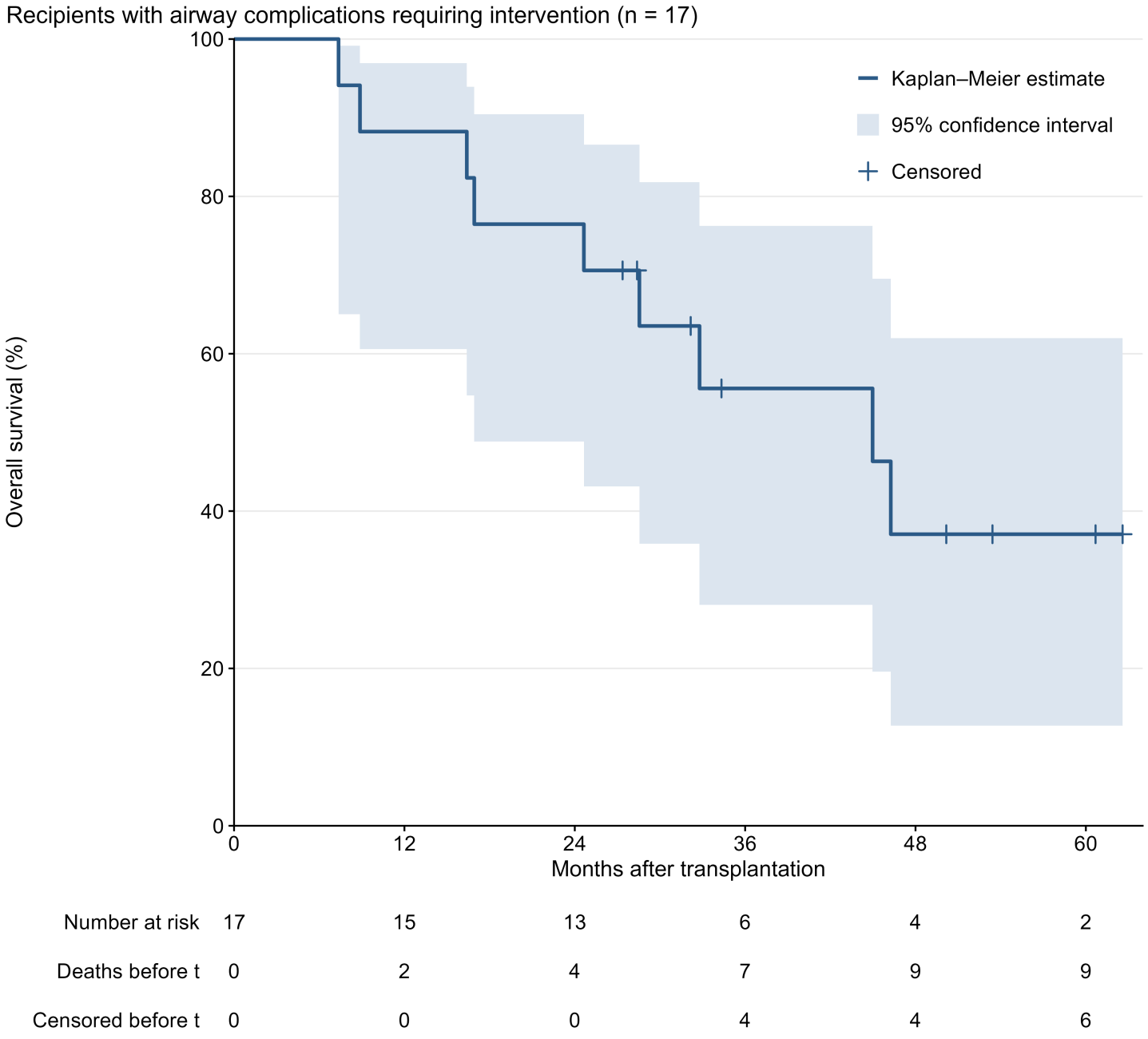


Figure 4

Kaplan–Meier overall survival from index transplantation in the 17 recipients. Recipients were selected for airway complications requiring intervention. The shaded area shows pointwise 95% confidence

intervals calculated using Greenwood variance with a log-log transformation; plus signs indicate censoring. All-cause deaths are events; the eight recipients alive at the census date of 30 July 2026 are censored on that date, so their censoring times differ only because transplantation dates differed. No recipient was lost to follow-up. Times were calculated from day-level dates and expressed in months. The risk table gives the number at risk immediately before each time point, with deaths and censorings accumulated strictly before that time. At 48 months only four recipients remained at risk. The curve describes a retrospectively selected complication cohort and does not estimate survival for all transplant recipients or survival from complication diagnosis.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.xlsx