Evaluating bronchial anastomotic stenosis dynamically by electrical impedance tomography in a lung transplant recipient: a case report

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Background: Lung transplantation has become the first-choice treatment method for end-stage pulmonary disease patients. However, various postoperative airway complications hinder the progress of lung transplantation, with the most frequently reported complication being bronchial stenosis. Pendelluft is an intrapulmonary air redistribution in areas with different time constants and this phenomenon is largely unobservable. Meanwhile, pendelluft is the movement of gas in the lung without a change in tidal volume and can contribute to injury by introducing regional overdistension and tidal recruitment. Electrical impedance tomography (EIT) is a radiation-free and noninvasive imaging tool that can be used to evaluate pulmonary ventilation and perfusion. EIT is also a novel imaging technique that allows real-time detection of pendelluft.

Case Description: A single lung transplant recipient had bronchial anastomotic stenosis caused by necrosis. The patient was admitted to the intensive care unit for the second time due to worsening oxygenation. We evaluated the patient's pulmonary ventilation and perfusion and pendelluft effect dynamically by EIT. The saline bolus injection method was used to evaluate pulmonary perfusion distribution. We removed the bronchial anastomosis necrosis using bronchoscopy biopsy forceps. The ventilation/perfusion (V/Q) matching in the transplanted lung improved compared to that before necrosis removal. After necrosis removal, the global pendelluft in the lung transplant recipient improved.

Conclusions: EIT can be used to quantitatively evaluate the pendelluft and V/Q matching due to bronchial stenosis in lung transplantation. This case also demonstrated the potential of EIT as a dynamic pulmonary functional imaging tool for lung transplantation.

Keywords: Lung transplantation; electrical impedance tomography (EIT); bronchial stenosis; pendelluft; case report

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Introduction

Lung transplantation has become the preferred treatment method for patients with end-stage pulmonary disease. The annual incidence of this surgery has been steadily increased (1). However, various postoperative airway complications impede the progress of lung transplantation (2), and the most frequently reported complication is bronchial stenosis (3). In the critical care of lung transplant recipients, monitoring the pulmonary function of the graft is one of the most concerning issues for physicians (4). Pendelluft, defined as asynchronous alveolar ventilation, refers to intrapulmonary air redistribution without a change in the tidal volume and this phenomenon is largely unobservable (5). Because pendelluft can contribute to injury by introducing regional overdistension and tidal recruitment, the detection pendelluft is essential to adjust the ventilation strategy accordingly. Electrical impedance tomography (EIT) is a functional imaging tool that can be used to evaluate pulmonary ventilation and perfusion. Due to its portable size, dynamic imaging ability, and the lack of need for radiation, EIT may be suitable for bedside monitoring in mechanically ventilated patients after lung transplantation (6). Moreover, it is a novel imaging technique that allows real-time detection of pendelluft (5). Here we report a case of bronchial anastomotic stenosis in single lung transplantation with EIT-based quantitative assessments of ventilation/perfusion (V/Q) matching and pendelluft. We present the following case report in accordance with the CARE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-4659/rc).

Case presentation

A 66-year-old man was admitted to the Department of Lung Transplant, The First Affiliated Hospital, Zhejiang University School of Medicine (Hangzhou, China), due to repeated coughing for more than 10 years and chest tightness for 1 year. He had a history of coronary atherosclerosis and cerebral infarction. Stenosis and stenting were found in both the carotid and vertebral arteries. Prehospital computed tomography (CT) examination revealed interstitial fibrosis changes and emphysema in both lungs, with local bullae. He received left single-lung allogeneic transplantation in our hospital on March 4, 2022 (day 1). After the operation, he was transferred to the intensive care unit (ICU) with the ventilator and extracorporeal membrane oxygenation (ECMO) operating status. On the first day in the ICU (day 1), ECMO was withdrawn successfully. Afterward, the routine treatment options after lung transplantation for him included administering piperacillin, tazobactam, voriconazole, and ganciclovir for anti-infection; tacrolimus for antirejection; and methylprednisolone for antiinflammation. Thereafter, he was transferred back to the general ward under the stable condition on day 7. The timeline illustrates the different events in the course of the patient's treatment and disease progression (*Figure 1*).

On day 109, the patient's partial pressure of arterial oxygen dropped from 95.0 to 61.0 mmHg with a fraction of inspired oxygen (FiO_2) of 21% and the physician conducted a bronchoscopy at his bedside. A gel-like attachment to the surface of the bronchial mucosa below the left main anastomosis was detected. The physician also took a biopsy of the attachment and sent it to the pathology laboratory. Hematoxylin-eosin (HE) staining of the sample revealed broken fiber and cartilage tissue or structureless inflammatory necrotic tissue under the microscope (*Figure 2A,2B*). The pathologist could not identify any basis for the graft rejection in the specimen. On day 111, the patient complained of chest tightness and felt difficulty breathing. His oxygen saturation decreased from 97% to 77% at 11:30 AM. Therefore, he was transferred again to the ICU. On day 112, the bronchoscopy showed that the left bronchial anastomosis was covered with necrosis, and the physician used biopsy forceps to remove a part of the necrosis.

On day 117, the patient was mechanically ventilated in the pressure control-assist/control mode (Evita Infinity V500, Dräger Medical, Lübeck, Germany), FiO_2 was 30%, the positive end-expiratory pressure was 8 cmH_2O, and the peak inspiratory pressure was 26 cmH_2O. A CT scan revealed local stenosis of the bronchial lumen in the lower lobe of the transplanted lung. Furthermore, the CT tracheal reconstruction images revealed multiple mesh-like changes with unclear boundaries in the native lung, with multiple circular translucent areas inside (*Figure 2C,2D*). In the afternoon, the patient's partial pressure of carbon dioxide ($PaCO_2$) increased to 66.0 mmHg, and the oxygen saturation decreased to 89%. We then performed EIT (PulmoVista

Highlight box

Key findings

- The global pendelluft in a single lung transplantation recipient improved compared to that before necrosis removal.

What is known and what is new?

- Pendelluft, defined as asynchronous alveolar ventilation, refers to intrapulmonary air redistribution without a change in the tidal volume and this phenomenon is largely unobservable.
- Electrical impedance tomography (EIT) can be used to quantitatively evaluate the pendelluft due to bronchial stenosis in lung transplantation.

What is the implication, and what should change now?

- The potential of EIT as a dynamic pulmonary functional imaging tool for lung transplantation to quantitatively evaluate the pendelluft and ventilation/perfusion matching.

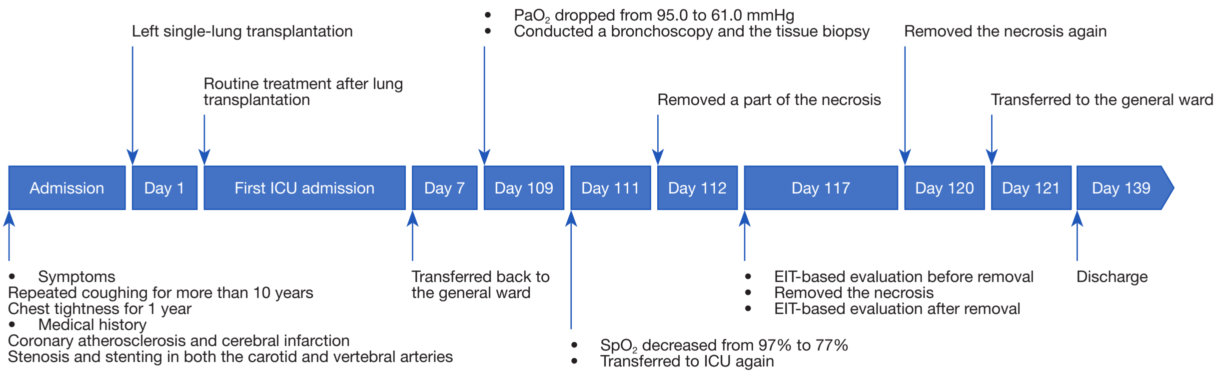


Figure 1 Timeline depicting the disease course of the patient. The timeline illustrates the different events in the course of the patient's treatment and disease progression. ICU, intensive care unit; PaO_2, partial pressure of arterial oxygen; SpO_2, oxygen saturation; EIT, electrical impedance tomography.

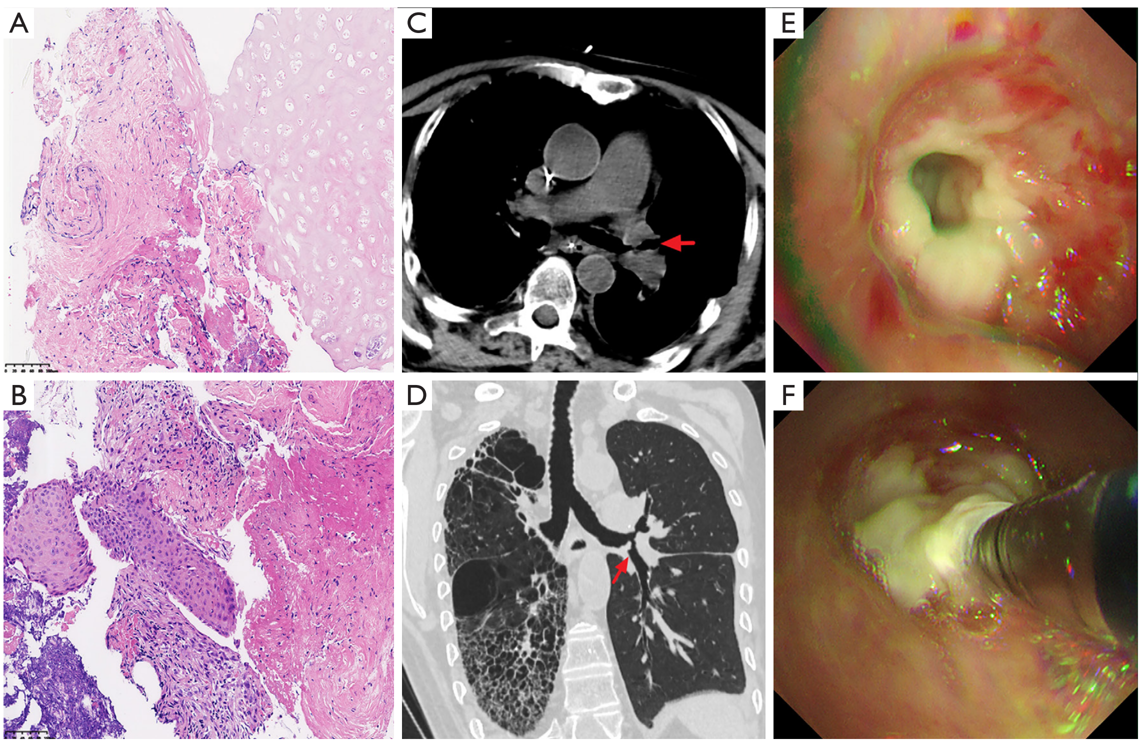


Figure 2 Pathological, radiographic, and bronchoscopy images of the patient. (A,B) Photomicrographs of HE-stained sections from the left main bronchial anastomosis specimen obtained on day 109. Magnification: ×200. (C,D) CT image of the lungs and CT tracheal reconstruction image before the stenosis removal on day 117. The red arrow indicates the left bronchial anastomosis stenosis. (E,F) Bronchoscopy biopsy forceps were used to remove the necrosis on day 117. HE, hematoxylin-eosin; CT, computed tomography.

500, Dräger Medical) for the evaluation of both ventilation and perfusion. An EIT belt with 16 surface electrodes was placed at the 4^{th} intercostal space level around the patient's chest wall. EIT measurements were recorded continuously at 20 Hz. During an expiratory hold for at least 8 seconds, a bolus of 10 mL of 10% NaCl was injected through the central venous catheter. EIT data were digitally filtered using a low-pass filter with a cut-off frequency of 0.67 Hz

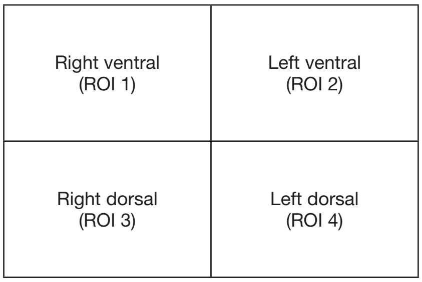


Figure 3 Diagram of ROIs in EIT images. Ventilation or perfusion distribution in the left lung = ROI 2 + ROI 4. Ventilation or perfusion distribution in the right lung = ROI 1 + ROI 3. The same is true for of quantitative evaluation of pendelluft. ROIs, regions of interest; EIT, electrical impedance tomography.

to eliminate cardiac-related periodic impedance changes (used to evaluate ventilation and perfusion). In addition, the data were analyzed offline using the custom software programming in MATLAB R2015 (MathWorks Inc., Natick, MA, USA). In the EIT images, EIT-based ventilated and perfused regions were determined with 20% of the maximum pixel value as the threshold. Dead space was defined as the percentage of the area that was only EIT-based ventilated globally. Shunt was defined as the percentage of the area that was only EIT-based perfused globally. V/Q matching is the percentage of the area that was both EIT-based ventilated and perfused globally (7).

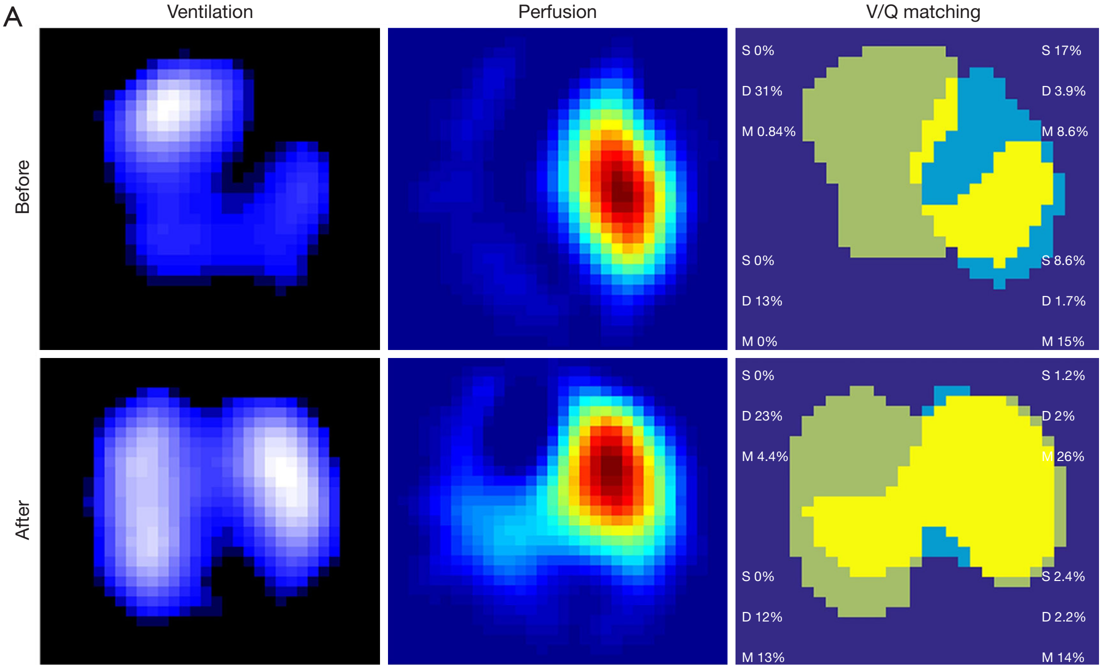
According to the EIT-based images, the left lung (transplanted lung) fell into hypoventilation, and its ventilation was poorly matched with the perfusion. The bronchoscopy revealed that gray-white necrosis was still present. Meanwhile, the physician removed the bronchial anastomosis necrosis using biopsy forceps (*Figure 2E,2F*). The patient's $PaCO_2$ decreased from 66.0 to 37.0 mmHg after the removal. On the same day (day 117), EIT was performed again to evaluate the ventilation and perfusion. The EIT images can be divided into four regions of interest (ROIs). We adopted a quadrant arrangement with the image center as the origin and equally divided it into four ROIs, viz., upper left, upper right, lower left, and lower right, corresponding to left ventral, right ventral, left dorsal, and right dorsal, respectively (*Figure 3*). After necrosis removal, the V/Q matching increased with improved ventilation, with almost constant perfusion in bilateral lungs. In addition, the global shunt decreased compared to that before necrosis removal (*Figure 4*). The image revealed that the mismatch of V/Q occurred in the left lung due to hypoventilation rather than hypoperfusion before necrosis removal. However, the perfusion of the right lung (native lung) was deficient compared to that of the transplanted lung, irrespective of the removal of necrosis. This situation may be associated with increased pulmonary vascular resistance in interstitial lung disease (8).

In the present case, a simple EIT-based method was used to quantitatively evaluate pendelluft by regional time phase shift and amplitude (9). According to Otis *et al.* (10), when pendelluft occurs, the sum of regional tidal volumes is larger than the overall tidal volume, and their difference indicates the pendelluft volume. Therefore, EIT-based pendelluft amplitude was defined as the impedance difference between the sum of all regional tidal impedance variations (TIVs) and global TIVs. The regional phase shift was defined as the time difference between global and regional impedance-time curves. The regional time difference for inspiration begins was defined as the average difference between the time points of global inspiration-begin and pixel inspiration-begin, and a similar rule was applied for the regional time difference for expiration begins. Similar to the mathematical harmonic curve, the EIT-based pendelluft amplitude reflects the magnitude of the pendelluft. The left ventral region and the global lung amplitude decreased from 16.53 to 3.78 pendelluft amplitude to tidal variation ratio in percentage (/TV%) and 22.00 to 7.83 /TV% after necrosis removal, respectively. These results suggested that the pendelluft improved after necrosis removal (*Figure 5*).

On day 120, the patient again underwent bronchoscopy at the bedside, which revealed the regrowth of some bronchial anastomosis necrosis. The necrosis was again removed by biopsy forceps. After the last necrosis removal, the patient's $PaCO_2$ decreased to 30 mmHg (*Figure 6*). Finally, the patient was transferred to the general ward on day 121 and discharged from the hospital on day 139. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal. This case study was approved by the clinical research ethics committee of The First Affiliated Hospital, Zhejiang University School of Medicine (No. IIT2022017B-R1).

Discussion

The novelty in this case is the EIT-based visualization



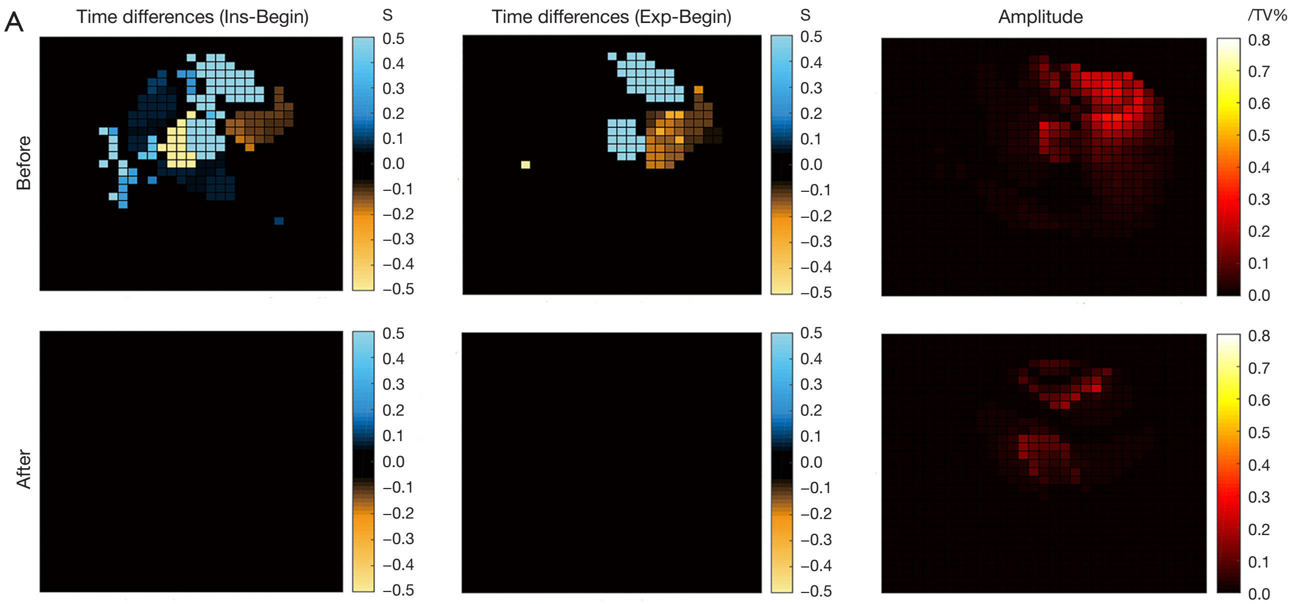
B

ROIs	Left lung ventral		Left lung dorsal		Right lung ventral		Right lung dorsal		Global	
Sequence	Before	After	Before	After	Before	After	Before	After	Before	After
Shunt (%)	17.0	1.2	8.6	2.4	0	0	0	0	25.6	3.6
Dead space (%)	3.9	2.0	1.7	2.2	31.0	23.0	13.0	12.0	49.6	39.2
V/Q matching (%)	8.6	26.0	15.0	14.0	0.8	4.4	0	13.0	24.4	57.4

Figure 4 Ventilation, perfusion, and V/Q matching images before and after necrosis removal on day 117. (A) Global ventilation images are shown in the first column. Low- and high-ventilated regions are marked in dark and light blue, respectively. Global perfusion images are shown in the second column. Regions with high perfusion are marked in red, and low perfusion is marked in green. Global V/Q matching images are shown in the third column. The dead space fraction area is marked in light green, the intrapulmonary shunt area is marked in light blue, and the V/Q matching region is marked in yellow. (B) The percentage of shunt, dead space, and V/Q matching areas in different ROIs before and after removal on day 117. ROIs, regions of interest; V/Q matching, ventilation/perfusion matching.

and quantitative assessment of pendelluft in the lung transplant recipient. Moreover, EIT was used to monitor the V/Q matching due to bronchial stenosis in this patient. After stenosis removal, the V/Q matching and pendelluft improved.

Pendelluft is the movement of gas in the lung without a change in tidal volume. This effect can also be conceptualized as the redistribution of air in areas with different time constants (5,11). The time constant reflects of both the resistance and compliance of the lungs. The compliance of the transplanted lung is well understood to be naturally different from that of the native lung (12). Therefore, pendelluft in single lung transplantation is an issue that several researchers have often suspected but rarely confirmed (13). In this case, EIT was used to detect quantitatively and dynamically the improvement of pendelluft in the lung transplant recipient after bronchial anastomotic removal. Furthermore, bronchial stenosis is well-known as an obstructive lesion. Based on the experience of this case, we assume that dynamic images of EIT combined with $PaCO_2$ can play a valuable role in evaluating obstructive airway complications in lung transplantation. Therefore, the elevation of $PaCO_2$ after lung transplantation with hypoventilation indicated by EIT



B

Sequence	Tins (s)	Texp (s)	Left lung ventral amplitude (/TV%)	Left lung dorsal amplitude (/TV%)	Right lung ventral amplitude (/TV%)	Right lung dorsal amplitude (/TV%)	Global amplitude (/TV%)
Before	0	0	16.53	1.78	2.70	0.99	22.0
After	0	0	3.78	0.82	2.30	0.93	7.83

Figure 5 Visualization images and quantitative assessment of pendelluft by EIT before and after necrosis removal on day 117. (A) The time difference images for inspiration and expiration begin are shown in first and second column, respectively. Orange and blue mark the early and delayed ventilation, respectively, compared with the global curve. The images of EIT-based pendelluft amplitude are shown in the third column. Red to yellow shows the increase in pendelluft amplitude. (B) The quantitative assessment of pendelluft before and after necrosis removal on day 117. S, the time difference in seconds; /TV%, pendelluft amplitude to tidal variation ratio in percentage; EIT, electrical impedance tomography.

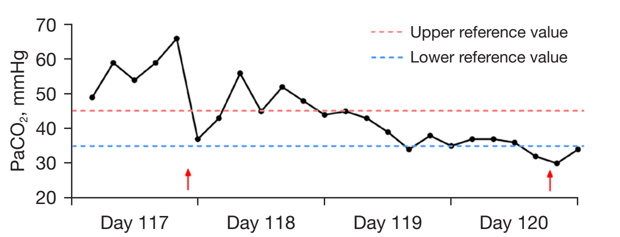


Figure 6 Trend chart of $PaCO_2$ of the patient from day 117 to day 120. The upper and lower reference values of $PaCO_2$ in our hospital's clinical laboratory are 45 and 35 mmHg, respectively. The red arrow indicates the timing of necrosis removal. $PaCO_2$, partial pressure of carbon dioxide.

suggests the need to focus on airway stenosis.

Bedside evaluation of lung perfusion by EIT has recently been an emerging field (14). Saline bolus injection for perfusion imaging is often used to evaluate the V/Q matching (15). In addition, an increasing amount of attention has been given to the V/Q matching evaluated by EIT as a novel characteristic in respiratory disorders. A study demonstrated that EIT-derived parameters, including dead space, V/Q matching, and intrapulmonary shunt percentage, could discriminate patients with acute pulmonary embolism from other patients with acute respiratory failure (16). Moreover, EIT has been considered to have the potential to provide additional physiological data in cases of lung transplantation complications. In 2021, Zarantonello *et al.* reported the application of EIT in the detection and follow-up of pulmonary artery stenosis in a lung transplant recipient (17). EIT demonstrated a V/Q mismatch in the left graft due to potential vessel stenosis, which was subsequently confirmed by CT pulmonary angiography. During the follow-up in the latter few days, EIT revealed an improvement in V/Q matching with a resolution of the anastomotic stricture. Similarly, our study is a case report using EIT to monitor V/Q mismatch caused by bronchial stenosis at the bedside in a lung transplant recipient.

Nonetheless, we could not cure bronchial stenosis completely and did not investigate the pathogenesis, which is a limitation of this case report. The use of biopsy forceps to remove necrosis regularly may be a treatment rather than a cure, but it is effective in improving the hypoventilation caused by bronchial stenosis.

Conclusions

To summarize, EIT can be used to quantitatively evaluate pendelluft and V/Q matching due to bronchial stenosis in lung transplantation. This case also demonstrated the potential of EIT as a dynamic pulmonary functional imaging tool for lung transplantation.

Acknowledgments

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Footnote

Reporting Checklist: The authors have completed the CARE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-4659/rc

Peer Review File: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-4659/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-4659/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal. This case study was approved by the clinical research ethics committee of The First Affiliated Hospital, Zhejiang University School of Medicine (No. IIT2022017B-R1).

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