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Case report

PHYSIOLOGICAL EFFECT OF HIGH FLOW OXYGEN THERAPY MEASURED BY ELECTRICAL IMPEDANCE TOMOGRAPHY IN SINGLE-LUNG TRANSPLANTATION

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Abstract

In patients with chronic obstructive pulmonary disease (COPD), single lung transplantation (SLT) is sometimes performed as an alternative to bilateral lung transplantation due to limited organ availability. However, the postoperative management of SLT presents challenges, including complications related to the distinct compliance of each lung. This case report presents the case of a 65-year-old male patient who underwent SLT and was in the weaning period from mechanical ventilation. High-flow oxygen therapy (HFOT) was administered, and the physiological effects were measured using electrical impedance tomography (EIT). The results demonstrated that the application of HFOT increased air trapping and overdistention in the native lung without benefiting the transplanted lung. HFOT through a tracheostomy tube or nasal cannula resulted in a more heterogeneous distribution of ventilation, with increased end expiratory lung impedance, prolonged expiratory time constants, and an increase in silent spaces. The drop in tidal impedance after applying HFOT did not indicate hypoventilation but rather overdistention and air trapping in the native lung, while the transplanted lung showed evidence of hypoventilation. These findings suggest that HFOT may not be beneficial for SLT patients and could potentially worsen outcomes. However, due to the limited scope of this case report, further prospective studies with larger patient cohorts are needed to confirm these results.

Key words: lung transplantation, noninvasive ventilation, oxygen inhalation therapy, chronic obstructive pulmonary disease, electrical impedance tomography

Resumen

Efectos fisiológicos del alto flujo de oxígeno medido por tomografía de impedancia eléctrica en trasplante unipulmonar

En pacientes con enfermedad pulmonar obstructiva crónica (EPOC), el trasplante pulmonar unilateral (SLT, por sus siglas en inglés) se realiza como alternativa a la disponibilidad limitada de donantes para el trasplante pulmonar bilateral. Sin embargo, el manejo postoperatorio del SLT presenta desafíos, incluyendo complicaciones relacionadas con la distinta complacencia de cada pulmón. Este reporte presenta el caso de un paciente varón de 65 años que fue sometido a un SLT y se encontraba en el proceso de destete de la ventilación mecánica. Se administró terapia de oxígeno de alto flujo (HFOT, por sus siglas en inglés) y se midieron los efectos fisiológicos utilizando la tomografía de impedancia eléctrica (EIT, por sus siglas en inglés). Los resultados demostraron que la aplicación de HFOT aumentó la retención de aire y la hiperinflación en el pulmón nativo sin beneficiar al pulmón trasplantado. Tanto la HFOT a través de un tubo de traqueostomía como a través de cánula nasal resultaron en una distribución más heterogénea de la ventilación, con un aumento en la impedancia pulmonar al final de la espiración, prolongación de las constantes de tiempo espiratorias y un aumento en los espacios silentes. La disminución de la impedancia *tidal* después de aplicar HFOT no indicó hipoventilación, sino más bien hiperinsuflación y retención de gas en el pulmón nativo, mientras que el pulmón trasplantado mostró evidencia de hipoventilación. Estos hallazgos sugieren que el HFOT puede no ser beneficioso para los pacientes con SLT y podría empeorar los resultados. Sin embargo, debido al alcance limitado de este informe de caso, se necesitan estudios prospectivos con cohortes de pacientes más amplias para confirmar estos resultados.

Palabras clave: trasplante pulmonar, ventilación no invasiva, terapia de inhalación de oxígeno, enfermedad pulmonar obstructiva crónica, tomografía de impedancia eléctrica

In the advanced stage of chronic obstructive pulmonary disease (COPD), bilateral lung transplantation has been shown to improve mortality rates[1]. In countries with limited availability of organ donations, single lung transplantation (SLT) has been found to be a valid alternative to enhance survival rates[2]. According to data reported by the *Instituto Nacional Central Único Coordinador de Ablación e Implante* (INCUCAI), during the last twenty years (from 2003 to 2023) in Argentina, a total of 613 lung transplants were performed, with 292 of them being SLT (47.6%) and 321 bilateral lung transplants (52.4%)[3].

However, the postoperative management of SLT poses an additional challenge due to the distinct compliance of each lung, leading to complications such as hyperinflation of the native lung and heterogeneous distribution of ventilation[4, 5]. During the weaning process from invasive mechanical ventilation (iMV), the use of high-flow oxygen therapy (HFOT) offers several advantages, including improved oxygenation, increased end-expiratory lung volume, and reduced work of breathing[6]. HFOT has also demonstrated lower intubation rates in patients with hypoxemic respiratory failure and comparable efficacy to non-invasive ventilation in preventing post-extubation respiratory failure[7]. However, the specific benefits of HFOT in SLT patients have not been clearly established.

To assess the impact of HFOT on each lung individually in these patients, electrical impedance tomography (EIT) proves to be a valuable tool by providing regional assessments of lung aeration[8, 9]. EIT is a non-invasive medical imaging technique used to generate real-time images, providing valuable insights into the distribution of electrical thoracic impedance and allowing inference of lung ventilation and aeration.

We present a case report of a 65-year-old male patient who underwent SLT and was in the weaning period from iMV. In this case, we measured the physiological effect of HFOT using EIT.

Clinical case

We present the case of a 65-year-old male patient who was admitted to the intensive care unit for left SLT. The patient had a history of COPD and had been on the transplant waiting list for two years, with a BODE index of 8. Pulmonary function tests showed air entrapment and increased expiratory resistances. Postoperatively, the patient required prolonged iMV, and a tracheostomy was performed. During the weaning process, the attending team discussed whether the use of HFOT could prolong spontaneous ventilation periods in order to reduce the iMV time. To assess lung aeration in real time we used EIT.

The measurements were conducted with the patient in a semi-seated position, with the head elevated at 30°. A 16-electrode EIT belt (FluxMED, MBMed, Buenos Aires, Argentina) was positioned between the 4th and 5th intercostal space. The impedance units, referred to as Arbitrary Units (AU), represented volume. HFOT was administered using the Airvo2 system (Fisher & Paykel Healthcare, New Zealand) at a flow rate of 50 L/min and a temperature range of 34-37 °C. The fraction of inspired oxygen (FiO_2) level was titrated to maintain peripheral oxygen saturation (SpO_2) above 92%. Vital signs were also monitored. Informed consent from the patient was obtained.

We conducted evaluations of lung impedance in three different spontaneous breathing scenarios: through a tracheostomy tube without HFOT (scenario 1), applying transtracheal HFOT (scenario 2), and using HFOT through nasal cannula (scenario 3). The results of the EIT measurements are summarized in Table 1.

In scenario 1, we observed an inhomogeneous distribution of ventilation among lungs. Tidal impedance (TZ), which reflects the variations in lung aeration and ventilation during a tidal breath, demonstrated that the gas distribution was higher in the native lung. TZ in the native lung represented 61.5% of the global TZ . Also, the

Table 1 | Impedance variables over different modes of oxygen administration

	Scenario 1 Spontaneous breathing through tracheostomy without HFOT	Scenario 2 Transtracheal HFOT	Scenario 3 HFOT through nasal cannula
Tidal impedance (AU)			
Global	24 935	20 659	21 896
Native lung	15 720	12 915	14 522
Transplanted lung	9844	8321	7984
End-expiratory lung impedance (AU)			
Global	7795	8491	8321
Native lung	4163	5131	4793
Transplanted lung	3142	3009	3120
Silent spaces (%)			
Global	17.6	21.2	26.1
Native lung	15.6	17.7	22.4
Transplanted lung	20.3	26,1	31.2
Inhomogeneity Index			
Global	0.29	0.32	0.33
Native lung	0.39	0.41	0.45
Transplanted lung	0.34	0.35	0.39
Expiratory time constant (s)			
Global	0.49	0.62	1.77
Native lung	0.40	0.46	1.39
Transplanted lung	0.28	0.33	0.75
Respiratory rate (bpm)	23	26	13

HFOT: high flow oxygen therapy; AU: arbitrary units; s: seconds; rpm: breath per minute
Note: Values for tidal impedance and end-expiratory lung impedance are expressed in arbitrary units, which are measured using an electrical impedance tomography device. These arbitrary units are directly proportional to impedance and, consequently, volume. As a result, percentage changes are preserved

global inhomogeneity (GI) index was 0.29. The GI index is a parameter used to represent the spatial extent and dispersion in the distribution of tidal breath in each lung in comparison with global ventilation. It ranges from 0, which represents a perfect homogeneous distribution of ventilation, to 1, indicating a completely inhomogeneous distribution of ventilation. Finally, end expiratory lung impedance (EELI) was almost symmetrical. EELI is useful to assess changes in end-expiratory lung volume, for example after changing the positive end-expiratory pressure or after recruitment maneuvers for the reopening of dorsal atelectasis as well as for the detection of derecruitment of individual lung areas.

When comparing scenario 2 (applying transtracheal HFOT) vs. scenario 1 (breathing through a tracheostomy without HFOT), we observed a decrease native lung TZ and transplanted lung TZ (-17.8 and -15.5%, respectively), an increase in native lung EELI (+23.3%), without relevant changes in the transplanted lung EELI. The application of transtracheal HFOT exacerbated the inhomogeneity of air distribution (GI index +9.48%), extending regional expiratory time constant of the native lung (+15%) and increasing in silents spaces (17,6% in scenario 1 and 21,2% in scenario 2). Expiratory time constants represent the time required for the respiratory system to reach 63% of its equilibrium value and is an indication of the time required for the lungs to empty during exhalation. Therefore, a shorter time constant suggests a faster emptying process, while a longer time constant indicates a slower emptying process. Additionally, silent spaces refer to lung regions that exhibit an impedance change of less than 10%, indicating poor ventilation. Through silent spaces analysis, valuable information can be obtained regarding lung areas that experience limited airflow during tidal breathing, leading to hypoventilation. If these regions are situated at the lower portions of the lungs (dependent areas), there is a possibility that they may be collapsed, or be filled with fluid. Conversely, when these areas are located in the upper regions of the lungs, it is more probable that they are already distended, potentially even overdistended.

In scenario 3, the application of HFOT through nasal cannula produced a global and regional decrease in TZ in comparison with spontaneous breathing through a tracheostomy without HFOT (-12.2% for global TZ, -7.6% in native lung, and -18.9% in transplanted lung). Also an increase in global EELI, with greater expression in the native lung was observed (+6.75% in global EELI and +15.1% in native lung EELI), without major changes in the transplanted lung EELI. The GI index increased 11.5% as well as expiratory time constants. Finally, silent spaces increased when applying HFOT through the nasal cannula (21,2% in scenario 2 and 26,1% in scenario 3). In addition, applying HFOT had a relevant impact on decreasing the respiratory rate. Figure 1 shows the changes in EIT in different scenarios (these changes are also illustrated in Supplementary material: *Video*).

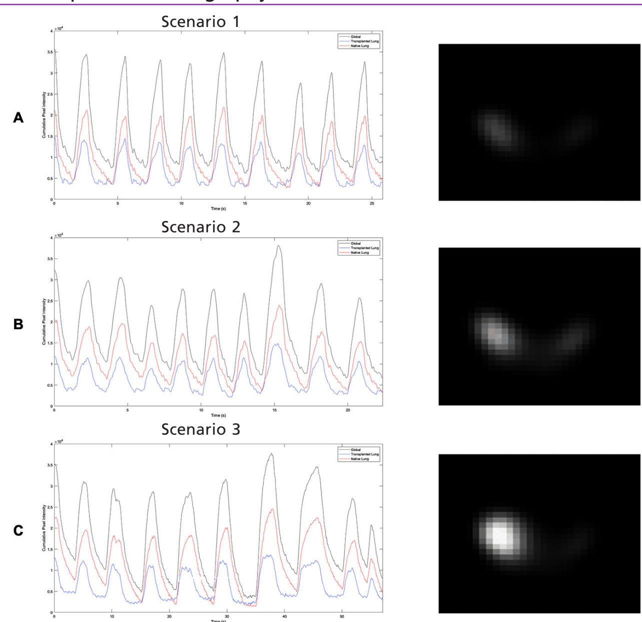
After conducting EIT measurements, we concluded that the application of HFOT resulted in increased air trapping and overdistention of the native lung, without yielding any benefits for the transplanted lung. As a result, we decided to proceed with the conventional iMV weaning strategy, which involved periodic intervals of spontaneous ventilation through tracheostomy without HFOT. The patient successfully completed the weaning process after 23 days of iMV and was subsequently discharged from the intensive care unit 42 days after being admitted to the hospital.

Discussion

Monitoring of pulmonary ventilation by EIT showed that the application of HFOT during the weaning period of iMV in this patient increased air trapping in the native lung with no benefit in the transplanted lung.

In scenario 1, during spontaneous breathing through a tracheostomy, the analysis of regional expiratory airflow in the native lung showed elevated expiratory time constants, which resulted in a heterogeneous air distribution due to gas trapping. However, the EELI remained symmetrical. This can be explained because the EELI

Figura 1 | Changes in electrical impedance tomography in different scenarios



A: Scenario 1: Spontaneous breathing through tracheostomy without HFOT
B: Scenario 2: Transtracheal HFOT
C: Scenario 3: HFOT through nasal cannula
Left graphs: Relative impedance changes (as surrogate for lung volume) over time in native lung (red line), transplanted lung (blue line), and global (black line)
Right graphs: Regional distribution of tidal ventilation.
The areas that receive a greater volume, and therefore present higher tidal impedance, are depicted with white pixels, while the areas that do not change their impedance are represented with black pixel.
HFOT: high flow oxygen therapy; s: seconds

represents a situation in which the expiratory flow is zero, so the pressure in both lungs are in a state of equilibrium. When HFOT was applied either through a tracheostomy (scenario 2) or nasally (scenario 3), the global distribution of ventilation became more heterogeneous, due to global and regional increase in EELI with greater expression in the native lung. After HFOT application in scenario 3, TZ decreased globally and regionally. Respiratory rate dropped abruptly, but gas trapping worsened, particularly in the native lung, evident by increased EELI, expiratory time constants, and silent spaces10. In the transplanted lung, TZ drop indicated hypoventilation with increased regional silent spaces, while EELI and expiratory time constants remained unchanged.

Measurements provided by EIT aimed to assess regional pulmonary aeration, and avoid hyperinflation in a thoracic-pulmonary system composed of lungs with different elastic and resistive properties due to a combination of a proportional increase in tidal volume (because of low lung elastance) and the phenomenon of expiratory flow limitation due to high airway resistance[11]. In extreme cases, air trapping in the native lung can produce a limitation of the expansion of the transplanted lung, called mediastinal shift, with the consequent decrease in the functional residual capacity, which can predispose to hypoxemia and increased iMV time[12-14].

Physiological effects reported were observed in only one patient, so we cannot extrapolate the results to all patients with SLT. Prospective studies with a large cohort of patients will be required to confirm this finding.

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Conflict of interest: None to declare

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