DOI: 10.1002/pul2.12302

CASE REPORT

Pulmonary Circulation Open Access | PVRI | WILEY

Whole-process respiratory management strategies based on electrical impedance tomography in a pregnant woman with diffuse alveolar hemorrhage induced by systemic lupus erythematosus under veno-venous extracorporeal membrane oxygenation

Yu Zhao | **Longxiang Su** | **Huaiwu He** | **Dawei Liu** | **Yun Long**

State Key Laboratory of Complex Severe and Rare Diseases, Department of Critical Care Medicine, Peking Union Medical College, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences, Beijing, China

Correspondence
Huaiwu He and Dawei Liu
Email: tjmuhhw@126.com and dwliu98@163.com

Funding information
National High-Level Hospital Clinical Research Funding, Grant/Award Number: 2022-PUMCH-D-005; National Natural Science Foundation of China, Grant/Award Number: 82272249; National Key Research and Development Program of China, Grant/Award Number: 2022YFC2404805

Abstract

Electrical impedance tomography (EIT) as a bedside, noninvasive, radiation-free technology, could quantify alveolar collapse and over-distension and provide real-time ventilation images of lungs. Clinical studies have shown potential benefit in reducing lung injury by EIT to guide mechanical ventilation setting in acute respiratory distress syndrome (ARDS). The respiratory management of ARDS with venous–venous extracorporeal membrane oxygenation (VV ECMO) remains a challenge for ICU doctors. Moreover, EIT has gained great interests in the respiratory management in VV ECMO therapy. Here, EIT was used for respiratory management in the presented case of a 36-year-old gravida with systemic lupus erythematosus, who developed severe hypoxia caused by diffuse alveolar hemorrhage. Although the patient received mechanical ventilation, VV ECMO was further used for the refractory respiratory failure. EIT was applied to titrate positive end-expiratory pressure (PEEP), guide prone position and early mobilization, dynamic evaluating lung development during ECMO therapy. She was successfully rescued after comprehensive therapy. In summary, an EIT-guided whole-process respiratory management strategy that included PEEP titration, prone position, early mobilization, and dynamic lung ventilation monitoring was proposed. This case demonstrated that EIT-guided whole-process respiratory management strategy was feasible in the respiratory failure patient with VV ECMO therapy.

KEYWORDS

diffuse alveolar hemorrhage, electrical impedance tomography, extracorporeal membrane oxygenation, gravida, systemic lupus erythematosus

CASE DESCRIPTION

A 36-year-old woman (gravida 2, para 1) at 25 weeks gestation, who was diagnosed with systemic lupus erythematosus (SLE), was presented to the emergency department with progressively exacerbated dyspnea for 10 days. Upon arrival, the vital signs were as follows: heart rate 103/min, blood pressure 90/50 mmHg, respiratory rate 42/min, oxygen saturation 80% on noninvasive positive-pressure ventilation (IPAP 15 cmH_2O, EPAP 5 cm H_20, FiO_2 95%). Physical examination showed butterfly-shaped malar rash over the cheeks and bridge of the nose and erythematous lesions involved hands and fingers. Laboratory tests indicated antinuclear antibody (+) 1:1000, anti-dsDNA antibody (+) 1:320. Chest radiograph displayed diffuse homogeneous opacities (Figure 1a). Computed tomography of the chest showed bilateral diffuse reticular and ground-glass opacity (Figure 1b). Intubation was performed since noninvasive ventilation cannot maintain the oxygenation. Bronchoalveolar lavage showed bloody secretion, revealing diffuse alveolar hemorrhage (DAH).

MECHANICAL VENTILATION AND EXTRACORPOREAL MEMBRANE OXYGENATION

Mechanical ventilation (VC mode, VT 350 mL, f 18/min, positive end-expiratory pressure [PEEP] 8 cmH_2O, FiO_2 100%) was administered but the oxygen saturation was 85%. The arterial blood gas showed PaO_2 less than 80 mmHg <6 h, which indicate the requirement of venous–venous extracorporeal membrane oxygenation (VV-ECMO) therapy for the patient. Veno-venous (vv) ECMO cannulation (right femoral-jugular) was performed under guidance of ultrasound. The speed of ECMO was 4000 rpm with blood flow 3.8 L/min and gas flow 3.0 L/min. With the assistance of ECMO, the oxygen saturation could maintain 100% and PaO_2 rose to 80–100 mmHg.

ElECTRICAL IMPEDANCE TOMOGRAPHY (EIT)-BASED PEEP TITRATION

The patient's lung condition and potential for recruitment might be various over time and position. Dynamic monitoring might be beneficial for individual lung protection. EIT was used to titrate the optimal PEEP in supine and prone position daily (Figure 1c,d). The procedures of PEEP titration were the same as previous study.[1] The best PEEP is defined as the crossover point of the reversible atelectasis and lung overdistension. For this patient, the best PEEP is 12 cmH_2O in supine position and 16 cmH_2O in prone position on Day 1 (Figure 1c,d). In the next few days, we used EIT to titrate PEEP daily in supine and prone position (Supporting Information: Table S1). With the improvement of the lung condition, the best PEEP titrated by EIT decreased during the therapeutic period.

EIT-GUIDED EARLY PRONE POSITIONING UNDER ECMO

EIT measurement found a poor ventilation in dependent regions, especially in lower right lobe at supine position. Therefore, we started early PP during ECMO once after cesarean section and kept this patient in prone position for 16 h daily (Figure 1o,p) even the oxygenation was normal. The PP ventilation obviously alleviated inhomogeneous ventilation distribution and improved dependent regions ventilation (Figure 1e,f). Since the dependent regions ventilation has been obviously improved, the PP was terminated on eigth day.

DYNAMIC ASSESSMENT OF LUNG VENTILATION FUNCTION

EIT was used daily and we could find obvious amelioration of ventilation function as time went by (Figure 1g–l). The ventilation distribution in four regions was notably improved (Supporting Information: Table S1), which was consistent with patient's condition. Especially the lower right region, the percentage of ventilation raised from 2% to 16% on Day 7 (Supporting Information: Table S1).

EIT-GUIDED EARLY MOBILIZATION

The ventilation area monitored by EIT on orthostatic position was largest and the ventilation distribution was most homogeneous (Figure 1m,n). Thus, the patient received early mobilization through sitting on a wheelchair from eigth day on (Figure 1q), and EIT showed the percentages of ventilation in four regions were closest equal on Day 8–9 (Supporting Information: Table S1).

TREATMENT OF SLE

The cesarean section was performed to terminate pregnancy under the VV ECMO therapy. Methylprednisolone 1 g/day was used for 3 days and the dose was

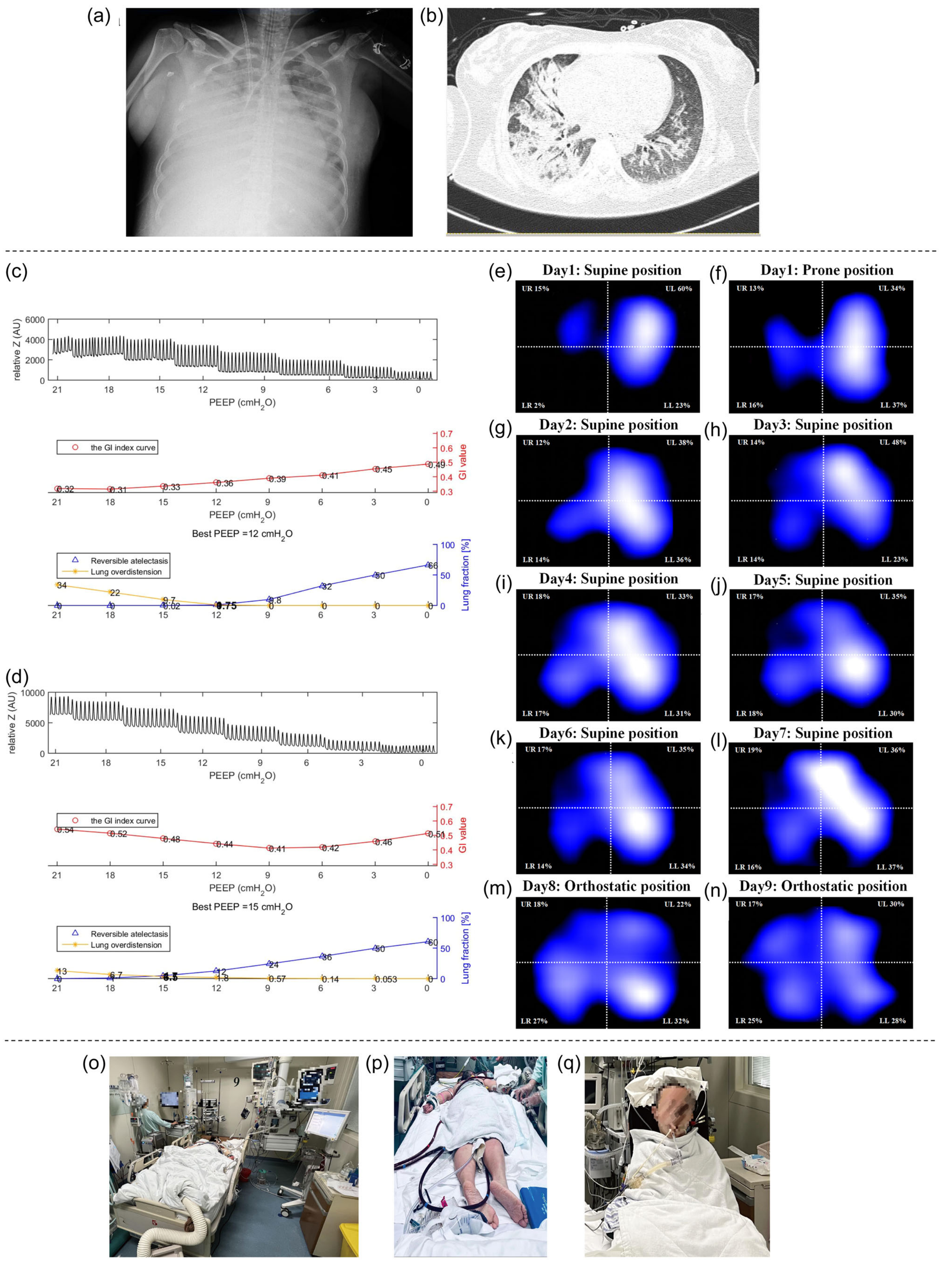

FIGURE 1 (See caption on next page).

adjusted to 40 mg/day in the next 14 days. Human immunoglobulin 20 g/day was used for 5 days. Five days later after the corticosteroid therapy, the aspiration from endotracheal intubation presented as normal sputum without bloody manifestation.

She weaned from ECMO on the fourth day and mechanical ventilation on the 11th day separately. Moreover, the patient developed acute kidney injury caused by SLE. Continuous renal replacement therapy was continued for 9 days and urine volume of 24 h increased to more than 1000 mL on 10th day. The patient was discharged from ICU on the 14th day.

DISCUSSION

We describe a gravida ECMO case diagnosed with SLE-induced DAH, adopting EIT-based whole-process respiratory management strategies, and withdrew from ECMO rapidly.

Patients with acute respiratory distress syndrome (ARDS) are susceptible to ventilator-associated lung injury (VALI). The advantages of ECMO includes maintaining better oxygenation, lowering ventilators parameters, and decreasing the VALI. The protective ventilation strategies such as using minimal tidal volume 4 mL/kg predicted body weight and keeping low plateau pressure (≤25 cmH_2O) are recommended under VV-ECMO.[2] EIT is a besides, imaging tool which can quantify alveolar collapse, recruitment, and overdistension. It has been widely used in monitoring of ventilation and lung perfusion and guide therapy for respiratory failure at beside,[3] such as guiding mechanical ventilation setting, assessing lung perfusion for pulmonary embolism,[4] identification of the right-to-left intracardiac shunt,[5] and early recognition of pneumothorax.[6]

EIT has superiorities in dynamic monitoring for lung ventilation at the bedside. In this case, there are many restrictions of gravida with ECMO to receive radiological examinations, thus the application of the bedside, noninvasive, and radiation-free EIT effectively avoided going out, enormously reduce the risks of transportation and radiation. However, some limitations of EIT image should be stressed, such as only one cross-sectional lung tomography, lack of consensus on the normal reference range of EIT-targeted parameters and poor spatial resolution.

In the present case, we applied EIT to whole-process respiratory management strategy, which consists of the following components: (1) PEEP titration in supine or prone position daily to achieve lung protection. Our previous study showed that EIT-based PEEP titration reduced mortality in patients with ARDS.[1] (2) Detection of poor ventilation in dependent regions contributed to early prone positioning under ECMO. Monitoring ventilation daily assessed the moment to terminate PP. (3) Estimating effects of early mobilization. Recent study demonstrated early mobilization is efficacious in accelerating recovery of critically ill patients.[7] (4) Lung ventilation by EIT daily could be used to assess the state of the illness and effects of respiratory therapy.

The application of EIT might accelerate recovery of this patient who withdrew from ECMO, which was compared to similar patients with SLE-induced DAH whose period of ECMO running was 6–10 days.[8,9] This case demonstrated that whole-process respiratory management strategy by EIT was safe and feasible. The improvement of EIT images was consistent with the ascending of oxygen index and patient's condition. Moreover, EIT monitoring could reduce risks of transport. However, the threshold values of EIT applied to different respiratory therapies need to be further investigated by large-scale studies.

CONCLUSIONS

EIT is a beside, real-time tool can be applied to all aspects in whole-process respiratory management strategy, including PEEP titration, prone position ventilation, dynamic monitoring recovery process, and early mobilization. Consequently, EIT can substitute for CT to some extent, thereby reduce risks of transport and going out. In conclusion, EIT-based whole-process respiratory management strategies were safe, beneficial, and practicable. Further study is required to validate the effect of proposed strategy on patient's outcome.

FIGURE 1 (a, b) Chest radiograph and computed tomography of the chest. (c) Using EIT to titrate positive end-expiratory airway pressure in supine position. (d) Using EIT to titrate positive end-expiratory airway pressure in prone position. (e, f) EIT assessment of ventilation function in supine and prone position on Day 1. (g–l) Continuous monitoring of ventilation distribution by EIT on Days 2 to 7. (m, n) EIT assessment of ventilation function in orthostatic position on Days 8 to 9. (o–q) Photographs of this patient in prone positioning assessed by EIT under ECMO and photograph of early mobilization of through sitting on a wheelchair. EIT, electrical impedance tomography; LL, lower left lung; LR, lower right lung; PEEP, positive end-expiratory pressure; UL, upper left lung; UR, upper right lung.

AUTHOR CONTRIBUTIONS

Yu Zhao and Longxiang Su contributed to the collection and analysis of data. Yu Zhao drafted the manuscript. Huaiwu He, Dawei Liu, and Yun Long revised the manuscript and approved the submitted version. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

The study was partially supported by the National High-Level Hospital Clinical Research Funding (2022-PUMCH-D-005), National Natural Science Foundation of China (82272249), and National Key Research and Development Program (2022YFC2404805).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All the original data presented in this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The Institutional Research and Ethics Committee of the Peking Union Medical College Hospital approved this study. Written informed consent was obtained once the patients transferred to intensive care unit.

ORCID

Yu Zhao http://orcid.org/0000-0001-5282-7817
Huaiwu He http://orcid.org/0000-0003-3422-3109

REFERENCES

1. He H, Chi Y, Yang Y, Yuan S, Long Y, Zhao P, Frerichs I, Fu F, Möller K, Zhao Z. Early individualized positive end-expiratory pressure guided by electrical impedance tomography in acute respiratory distress syndrome: a randomized controlled clinical trial. Crit Care. 2021;25(1):230.
2. Schmidt M, Pellegrino V, Combes A, Scheinkestel C, Cooper D, Hodgson C. Mechanical ventilation during extracorporeal membrane oxygenation. Crit Care. 2014;18(1):203.
3. Frerichs I, Amato MBP, van Kaam AH, Tingay DG, Zhao Z, Grychtol B, Bodenstein M, Gagnon H, Böhm SH, Teschner E, Stenqvist O, Mauri T, Torsani V, Camporota L, Schibler A, Wolf GK, Gommers D, Leonhardt S, Adler A. Chest electrical impedance tomography examination, data analysis, terminology, clinical use and recommendations: consensus statement of the TRanslational EIT developmeNt stuDy group. Thorax. 2017;72(1):83–93.
4. He H, Chi Y, Long Y, Yuan S, Zhang R, Frerichs I, Möller K, Fu F, Zhao Z. Bedside evaluation of pulmonary embolism by saline contrast electrical impedance tomography method: a prospective observational study. Am J Respir Crit Care Med. 2020;202(10):1464–8.
5. He H, Wang N, Zhang M, Jiang J, Cui N, Frerichs I, Long Y, Zhao Z. New application of saline contrast-enhanced electrical impedance tomography method for right ventriculography besides lung perfusion: detection of right-to-left intracardiac shunt. QJM. 2023:1–7.
6. Rahtu M, Frerichs I, Waldmann AD, Strodthoff C, Becher T, Bayford R, Kallio M. Early recognition of pneumothorax in neonatal respiratory distress syndrome with electrical impedance tomography. Am J Respir Crit Care Med. 2019;200(8):1060–1.
7. Wang J, Ren D, Liu Y, Wang Y, Zhang B, Xiao Q. Effects of early mobilization on the prognosis of critically ill patients: a systematic review and meta-analysis. Int J Nurs Stud. 2020;110:103708.
8. Kimura D, Shah S, Briceno-Medina M, Sathanandam S, Haberman B, Zhang J, Myers L, Kumar TS, Knott-Craig C. Management of massive diffuse alveolar hemorrhage in a child with systemic lupus erythematosus. J Intensive Care. 2015;3:10.
9. Pacheco Claudio C, Charbonney E, Durand M, Kolan C, Laskine M. Extracorporeal membrane oxygenation in diffuse alveolar hemorrhage secondary to systemic lupus erythematosus. J Clin Med Res. 2014;6(2):145–8.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Zhao Y, Su L, He H, Liu D, Long Y. Whole-process respiratory management strategies based on electrical impedance tomography in a pregnant woman with diffuse alveolar hemorrhage induced by systemic lupus erythematosus under veno-venous extracorporeal membrane oxygenation. Pulm Circ. 2023;13:e12302. https://doi.org/10.1002/pul2.12302