Heliyon 10 (2024) e25159

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Case report

Bedside electrical impedance tomography to assist the management of pulmonary embolism: A case report

Chenling Ding [a,1], Yibo Zhu [a,1], Shuyi Zhang [a], Zhanqi Zhao [b,c,d], Yuan Gao [a,**], Zhe Li [a,*]

[a] Department of Critical Care Medicine, Renji Hospital, School of Medicine, Shanghai Jiao Tong University, China
[b] School of Biomedical Engineering, Guangzhou Medical University, Guangzhou, China
[c] Department of Critical Care Medicine, Peking Union Medical College Hospital, Beijing, China
[d] Institute of Technical Medicine, Furtwangen University, Villingen-Schwenningen, Germany

ARTICLE INFO

Keywords:
Electrical impedance tomography
Lung perfusion
Pulmonary embolism
Ventilation-perfusion
Asymmetry index
Intensive care unit

ABSTRACT

Background: Pulmonary embolism (PE) is a common worldwide disease with high mortality. Timely diagnosis and management of PE could significantly improve clinical outcomes. Electrical impedance tomography (EIT) is a novel noninvasive technique to monitor lung perfusion and help detect PE at the bedside. Here we present a case of clinical management of subsegmental PE with the help of the bilateral ventilation and perfusion(V/Q) asymmetry EIT image.

Case presentation: A 72-year-old cancer patient with respiratory failure and acute kidney injury in the intensive care unit was suspected of PE based on his clinical manifestation. The contraindication of computed tomography pulmonary angiography (CTPA) for PE diagnosis prevented escalating anticoagulation therapy. Besides EIT ventilation and perfusion monitoring showed an abnormal asymmetry V/Q match between the bilateral lungs which promoted our decision to start systemic continuous anticoagulation therapy and improved the patient clinically. The following CTPA which clarified the diagnosis of PE suggests that the patient has benefited from our decision.

Conclusion: For critically ill patients with suspected PE, the asymmetry of the EIT V/Q image may provide crucial objective information for clinical management.

1. Introduction

Pulmonary embolism (PE) is a common worldwide disease with an annual incidence of 1 in 1000 persons and a high mortality of 20 % [1,2]. Timely diagnosis and management of PE could significantly improve clinical outcomes [3]. Computed tomography pulmonary angiography (CTPA) is the most readily available clinical gold standard for diagnosing PE [4]. However, CTPA is limited in intensive care unit (ICU) patients due to complicated clinical situations such as high transfer risk of hemodynamic instability and contraindications to iodine contrast medium [4,5]. Real-time and effective monitoring tools at bedside for PE are critical for ICU patient.

* Corresponding author.
** Corresponding author.
E-mail addresses: rj_gaoyuan@163.com (Y. Gao), slamy1987@126.com (Z. Li).
[1] Chenling Ding and Yibo Zhu are co-first authors and have contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2024.e25159
Received 30 March 2023; Received in revised form 5 January 2024; Accepted 22 January 2024
Available online 26 January 2024

Electrical impedance tomography (EIT) is a noninvasive, bedside technique for ventilation monitoring, which is widely used for respiratory therapy [6–8]. More recently, lung perfusion image detected by EIT through a hypertonic saline bolus injection is gaining attention for its potential in the treatment of lung perfusion-related diseases [9–12]. Colleagues have demonstrated the efficacy of EIT ventilation and pulmonary blood flow distribution (ventilation-perfusion, V/Q match) in the diagnosis of massive pulmonary embolism [13]. However, to our knowledge so far, the EIT image features in subsegmental PE have not been reported.

Here we present a case of clinical management of a subsegmental PE in a cancer patient with unstable hemodynamics and acute kidney injury(AKI) under the bilateral ventilation and perfusion asymmetry detected by EIT. This is the first case to report using EIT to assist the management of subsegmental PE.

2. Case presentation

A 72-year-old man, with a history of ascending colectomy and postoperative chemotherapy, was transferred to our intensive care unit (ICU) from the local hospital due to respiratory failure. At the time of admission, his P/F ratio (the arterial PO_2 from the arterial blood gas divided by the FiO_2) was 111 mmHg and his $PaCO_2$ was 53 mmHg with mechanical ventilation (MV) through endotracheal intubation set to volume control ventilation model at a tidal volume of 460 mL, rate of 16, positive end-expiratory pressure (PEEP) of 5 cm H_2O, and FiO_2 of 70 %.

After a routine CT scan (showing infiltration and consolidation of the bilateral lower lung, Fig. S1), he had an acute drop in blood pressure (88/40 mmHg) and a significant increase of end-tidal CO_2 ($EtCO_2$, ~38 mmHg) and $PaCO_2$ (~66 mmHg) gap. The patient's contemporary examinations showed a normal EKG, a slightly dilated right ventricle (RV) of echocardiography (Fig. 1A), and a raised D-dimer level of 3.29 mg/L. Although deep vein thrombosis of lower extremity duplex scans was negative, considering the high revised Geneva Prediction Score of 10 (72 years old, heart rate ≥95 bpm, surgery, active cancer) and RV dilation, concern was raised for PE. The doctor on duty administered a vasoactive drug (norepinephrine 0.3 μg/kg/min), fluid therapy, empiric low-molecular-weight heparin (2050iu per day, adjusted to creatinine clearance ratio), and adjusted ventilator settings (PEEP of 10 cmH_2O, Minute Ventilation volume of 9 L). These interventions helped to maintain his Mean Arterial Pressure (MAP) above 65 mmHg and improve his P/F ratio to 170 mmHg. However, his $PaCO_2$ was still high at approximately 55 mmHg, and the $EtCO_2$-$PaCO_2$ gap remained at around 15 mmHg.

On the next day, a right-sided contrast transthoracic echocardiography was performed, and an intracardiac shunt was excluded (Fig. 1B). Additionally, right internal jugular vein thrombosis (the patient had a history of central venous catheterization) was further detected by vascular ultrasound (Fig. 1C), raising a high suspicion of PE. However, CTPA was rejected due to AKI (urine output < 0.3 mL/kg/h for 24 h with a history of renal replacement therapy before transfer) and hemodynamic instability (norepinephrine 0.23 μg/kg/min to maintain MAP over 65 mmHg).

Finally, we performed EIT monitoring (PulmoVista 500, Drager Medical, Lubeck, Germany), conducted the saline contrast (injecting 10 mL hypertonic saline bolus via a central venous catheter during the respiratory hold of MV), and reconstructed the V/Q match according to the procedure by the TRanslational EIT development stuDy (TREND) group and He et al. [9,14]. The global perfusion image showed a relatively normal distribution, however, an uncommon image feature of left-right asymmetric perfusion distribution and a dead space accounting for 14.71 % mainly in the right lung was noticed (Fig. 2A). Taking into account the fact that the right lower lung is the most common location for PE and the repeating EIT measurements showed the same result, we could not find a better clinical explanation for this patient other than right lung PE. Besides, it has been 24 h since the sudden change in the patient's condition, we surmised that there may be a process of jugular vein emboli dislodging into the main pulmonary artery and dispersing into the subsegment. The thrombolytic therapy was suggested but refused by his family members due to the risk of hemorrhagic complications. As a reference, anticoagulation was escalated to continuous infusion of unfractionated heparin with close monitoring of

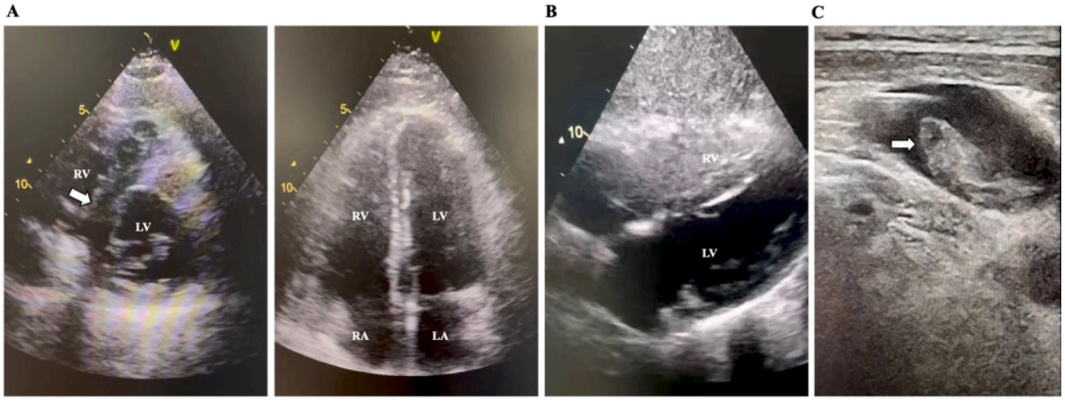

Fig. 1. Bedside echocardiography and venous ultrasound scan on day one and day two. (A) Flattened intraventricular septum (white arrow) in the diastole, and mildly dilated RV with an estimated ratio of 1:1 between the RV and the LV on day one. (B) Negative bubble test by transthoracic echocardiography on day two. RV: right ventricle; LV: left ventricle. (C) A vein thrombosis was found in the right internal jugular vein.

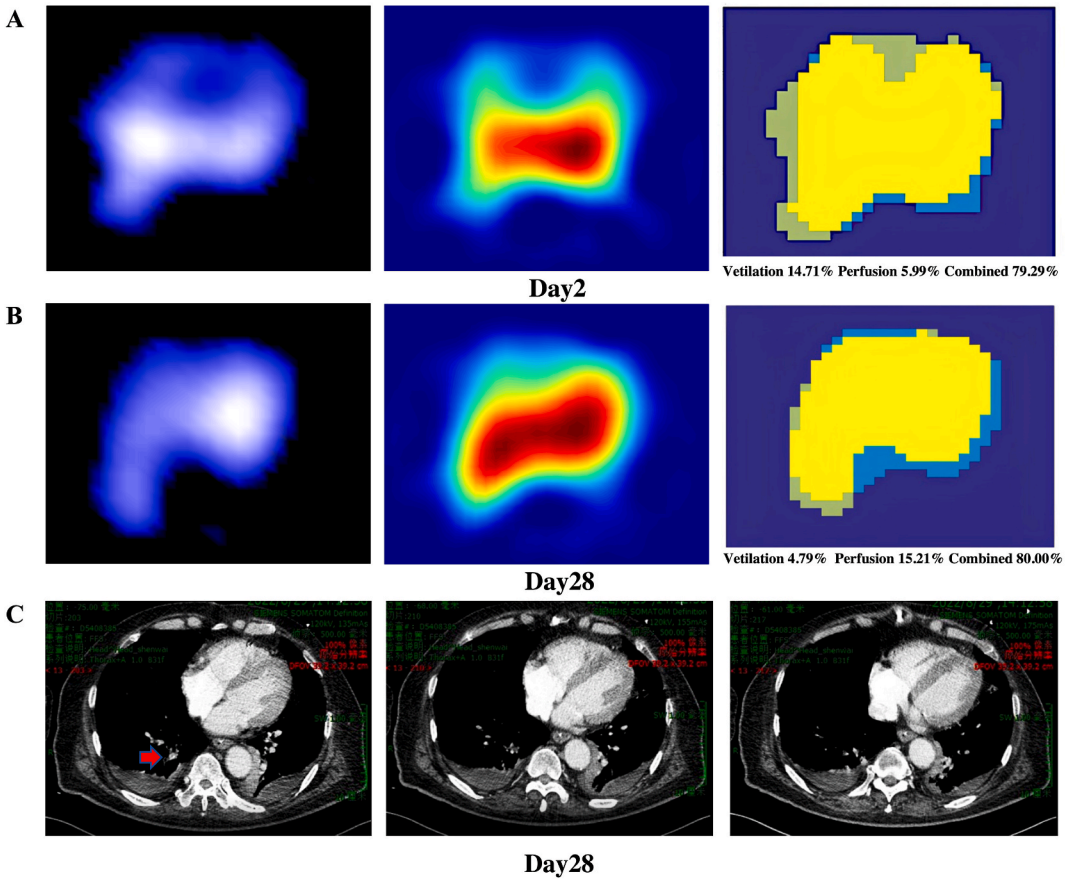

Fig. 2. EIT ventilation and perfusion (V/Q) change images and computed tomography pulmonary angiography (CTPA) images of the Patient. (A). The global V/Q match accounted for 79.29 % with a dead space asymmetry mainly in the right lung accounting for 14.71 % on day two. (B). The global V/Q match accounted for 80 % with a dead space asymmetry mainly in the right lung accounting for 4.79 % on day 28 after systemic anticoagulation therapy. Left: EIT image of the ventilation distribution. Regions with low-ventilated are shown in blue and high-ventilated in white. Middle: Image of the perfusion distribution. High-perfusion regions are shown in red and low-perfusion regions are shown in blue. Right: Image of the regional V/Q match. Regions with high ventilation and low perfusion are gray, low ventilation and high-perfusion regions are blue, and V/Q matches are yellow. High-ventilated regions: pixels with impedance changes higher than 20 % of the maximum tidal impedance variation in the ventilation image. Low-ventilated regions: pixels with changes lower than 20 %. (C). CTPA on Day 28 showed the embolism in the right lower pulmonary artery branch (red arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

activated partial thromboplastin time(around 65–75s) to ensure the therapeutic effect. A few hours later, the patient improved with a significant reduction in $EtCO_2$-$PaCO_2$ gap to about 8 mmHg, and stability in hemodynamics (norepinephrine 0.03 μg/kg/min to maintain MAP over 65 mmHg). 2 days later the doppler scan revealed that the previous thrombus had completely disappeared, indicating that the anticoagulation treatment had been effective.

The patient continued to undergo original medical treatment, and CTPA was performed after renal function recovery on day 28. Two experienced radiologists confirmed subsegmental pulmonary vascular thrombosis (Fig. 2C). Simultaneously, EIT images showed improved but still defective perfusion in the right lung (Fig. 2B). Finally, the patient was switched to oral anticoagulation and discharged for rehabilitation therapy.

3. Discussion

According to the guidelines, radiological imaging is the gold standard for the diagnosis of PE, which does not apply to patients with significant hemodynamic instability or contraindications in the ICU. Bedside echocardiography is currently recommended to detect PE-induced RV pressure overload, septal motility disorders, and acute pulmonary heart disease [4]. Nevertheless, echocardiography is not specifically “perfect”, as cardiac function in ICU patients can be impacted by a variety of conditions, including underlying cardiac insufficiency, infection, hypovolemic shock, and the use of analgesia and sedation drugs, as well as acid-base disorders. Therefore, the absence of abnormal RV signs on echocardiography may be more valuable for excluding hemodynamic instability due to PE. Unfortunately, bedside echocardiography can hardly serve as an objective basis for replacing CTPA to support further management [15].

In this case, we perform bedside EIT V/Q monitoring for a suspected PE patient in clinical situations where CTPA is not available. Our comprehensive clinical decision to systemic continuous anticoagulation therapy under the right lung perfusion asymmetric EIT image and other bedside available indicators such as D-dimer and ultrasound finally improved patients' outcomes. To our knowledge, this is the first attempt to describe the probable EIT image features in subsegmental PE.

Our patient experienced new-onset hemodynamic instability and an elevated $EtCO_2$ gap after transport. Although PE was suspected based on his clinical manifestation (history, ultrasound, laboratory tests), a lack of objective supporting evidence prevented more aggressive therapy. In critically ill ICU patients, this challenge is often faced due to the higher risk of bleeding. EIT perfusion images could provide some objective information in such a situation. Quite a few studies have reported the efficiency of a high dead space ratio in EIT V/Q match images in detecting massive PE [9,10]. Interestingly, our bedside EIT showed a dead space distribution (accounting for 14.71 %) only in the right lung, failing to meet the threshold of dead space accounting for 30.37 % to diagnose PE in the previous study [13]. However, the asymmetric EIT V/Q between the left and right lungs, indicating right lung PE, assisted us in escalating anticoagulation therapy and ultimately improving the patient's outcome. The subsequent CTPA, which clarified the diagnosis of PE, and the EIT images of improved perfusion suggested that the patient benefited from our clinical decision.

The EIT image features for subsegmental PE have not been studied. Since EIT is a functional imaging technique, it is challenging to employ it to identify embolisms that only mildly affect pulmonary perfusion (such as embolisms that are anatomically localized distally or that do not completely obstruct the pulmonary arteries). Our post hoc image reconstruction analysis of the bilateral asymmetry index (AI) revealed that the right lung was more ventilated than the left lung (Fig. 3A). This finding aligns with the anatomical understanding of lung volume, with the right lung having a larger lung volume area than the left lung (Fig. 3C) [16] as also observed in our case with visually more severe basal pleural effusion and consolidation on the left than on the right. A left-dominated asymmetry perfusion distribution should be expected based on this anatomy and pulmonary vasculature adaptations such as hypoxic pulmonary vasoconstriction [17,18]. However, our EIT analysis showed that the perfusion volume of the right lung is the same as that of the left lung (Fig. 3B), which may suggest a decrease in symmetry due to defective perfusion in the right lung. Based on the EIT-assisted embolism treatment in our case, we believe that this is an interesting topic deserving more clinical investigation and pathophysiological validation. AI may hold the potential to be another novel approach that interprets EIT images from an anatomical perspective compared to conventional EIT indices. In line with our suspicions, a recent study reported that pneumothorax can be detected by the

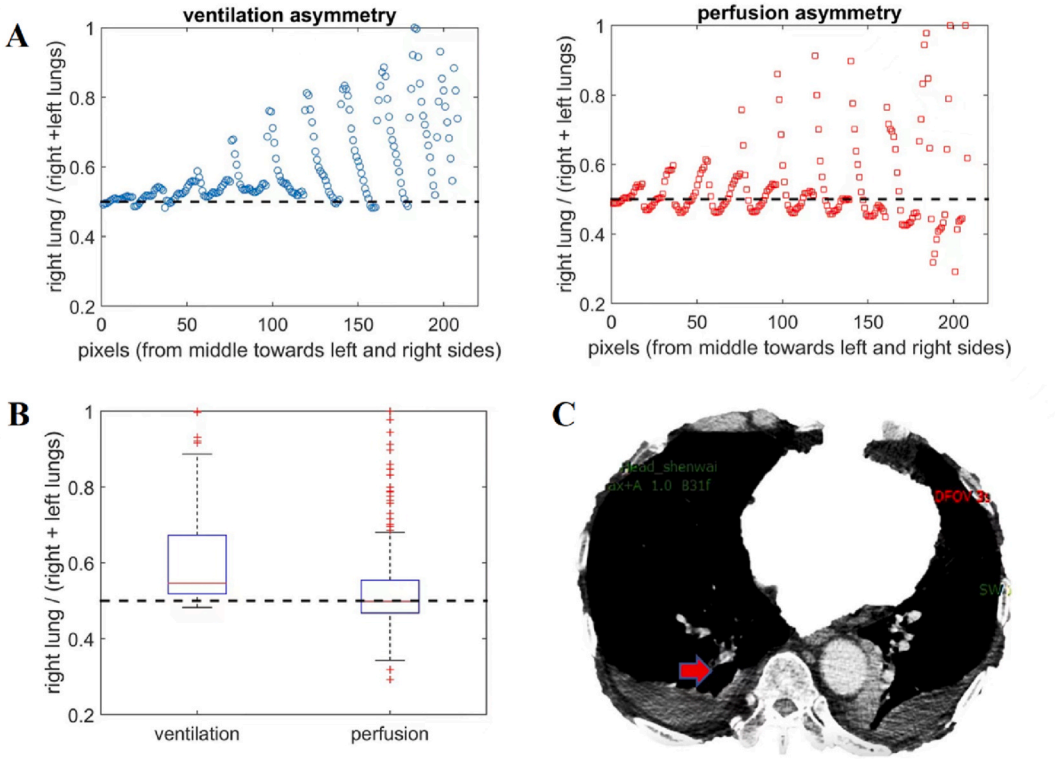

Fig. 3. Post hoc asymmetric analysis of EIT images. (A) asymmetry index (AI) of ventilation and perfusion. The X-axis represents right lung pixels horizontally distributed from the middle (0) to the side (200). The Y-axis represents the bilateral asymmetry index (AI) value of ventilation (Left) and perfusion (Right) calculated by dividing the impedance of the right lung pixel by the sum of the modified impedance of the right lung pixel plus the left symmetrical lung pixel. AI ranges from 0 to 1, and ventilation or perfusion distribution was considered symmetrical if AI = 0.5. (B) Boxplots of ventilation and perfusion AI value. Boxplot center line, median; box limits, upper and lower quartiles; whiskers, 1.5 × interquartile range. (C) Lung images intercepted from computed tomography pulmonary angiography (CTPA).

asymmetry in ventilation between the left and right anterior chest [19]. Nevertheless, its range and diagnostic value do require further clinical verification.

Since this is a single-center clinical case, there are certain limitations. First, from a clinical perspective, it is unlikely that the subsegmental PE detected by CTPA could cause hemodynamic instability. Considering his negative EKG and routine CT scan that excluded arrhythmia and pneumothorax, we surmise there may be a process of jugular vein emboli dislodging into the main pulmonary artery and dispersing into the subsegment. Due to the constraints of the clinical scenario (renal function, etc.), we regrettably were unable to confirm the diagnosis of PE at an early stage. Second, we believe that to compare the EIT and CTPA images in supporting the clinical diagnosis of PE, both tests should be performed simultaneously. However, since this case occurred with a real clinical challenge, the comparison of both methods simultaneously could not be done at the onset of the course. For such cases, which are common in ICU patients, the clinical outcome of our patient may somewhat represent the value of asymmetrical V/Q match by EIT for the management of PE. Third, other conditions that may affect the asymmetry of left and right lung ventilation or perfusion cannot be ignored, such as pleural effusion, consolidation, atelectasis, etc. Clinical screening based on these considerations needs to be performed before promoting the AI index, and we believe that it is worth being deeply studied in the future.

4. Conclusions

In summary, this case demonstrated for the first time the potential of the bedside EIT asymmetrical V/Q match in combination with other clinical indicators to assist the management of PE for ICU patients when the CTPA is not available.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Informed consent statement

Written informed consent has been obtained from the patient to publish this paper.

Data availability statement

Data will be made available on reasonable request.

CRediT authorship contribution statement

Chenling Ding: Writing – original draft, Formal analysis. **Yibo Zhu:** Writing – original draft, Data curation. **Shuyi Zhang:** Data curation. **Zhanqi Zhao:** Software, Formal analysis. **Yuan Gao:** Writing – review & editing, Conceptualization. **Zhe Li:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:ZZ receives a consulting fee from Dräger Medical. Other authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25159.

References

[1] S.R. Kahn, K. de Wit, Pulmonary embolism, N. Engl. J. Med. 387 (1) (2022) 45–57.
[2] P. Lehnert, T. Lange, C.H. Moller, P.S. Olsen, J. Carlsen, Acute pulmonary embolism in a National Danish cohort: increasing incidence and decreasing mortality, Thromb. Haemostasis 118 (3) (2018) 539–546.
[3] C. Minet, L. Potton, A. Bonadona, R. Hamidfar-Roy, C.A. Somohano, M. Lugosi, J.C. Cartier, G. Ferretti, C. Schwebel, J.F. Timsit, Venous thromboembolism in the ICU: main characteristics, diagnosis and thromboprophylaxis, Crit. Care 19 (1) (2015) 287.
[4] S.V. Konstantinides, G. Meyer, C. Becattini, H. Bueno, G.J. Geersing, V.P. Harjola, M.V. Huisman, M. Humbert, C.S. Jennings, D. Jimenez, et al., 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS), Eur. Heart J. 41 (4) (2020) 543–603.
[5] M. Murata, N. Nakagawa, T. Kawasaki, S. Yasuo, T. Yoshida, K. Ando, S. Okamori, Y. Okada, Adverse events during intrahospital transport of critically ill patients: a systematic review and meta-analysis, Am. J. Emerg. Med. 52 (2022) 13–19.
[6] M.C. Bachmann, C. Morais, G. Bugedo, A. Bruhn, A. Morales, J.B. Borges, E. Costa, J. Retamal, Electrical impedance tomography in acute respiratory distress syndrome, Crit. Care 22 (1) (2018) 263.
[7] Z. Li, S. Qin, C. Chen, S. Mei, Y. Yao, Z. Zhao, W. Li, Y. Deng, Y. Gao, Emerging trends and hot spots of electrical impedance tomography applications in clinical lung monitoring, Front Med (Lausanne) 8 (2021) 813640.

[8] Z. Li, Z. Zhang, Q. Xia, D. Xu, S. Qin, M. Dai, F. Fu, Y. Gao, Z. Zhao, First attempt at using electrical impedance tomography to predict high flow nasal cannula therapy outcomes at an early phase, Front. Med. (Lausanne) 8 (2021) 737810.
[9] H. He, Y. Long, I. Frerichs, Z. Zhao, Detection of acute pulmonary embolism by electrical impedance tomography and saline bolus injection, Am. J. Respir. Crit. Care Med. 202 (6) (2020) 881–882.
[10] S.A. Prins, D. Weller, J.A.M. Labout, C.A. den Uil, Electrical impedance tomography as a bedside diagnostic tool for pulmonary embolism, Crit. Care Explor. 5 (1) (2023) e0843.
[11] H. He, J. Jiang, M. Xu, S. Yuan, Y. Long, Y. Chi, I. Frerichs, Z. Zhao, Saline bolus-based electrical impedance tomography method for rapid bedside assessment of regional lung perfusion during ECMO therapy, Crit. Care 26 (1) (2022) 266.
[12] F.A.K. Foronda, L.R. Fernandes, A.L.C. Lahoz, C. Johnston, W.B. de Carvalho, Electrical impedance tomography clues to detect pulmonary thrombosis in a teenager with COVID-19, Pediatr. Radiol. 52 (1) (2022) 144–147.
[13] H. He, Y. Chi, Y. Long, S. Yuan, R. Zhang, I. Frerichs, K. Moller, F. Fu, Z. Zhao, Bedside evaluation of pulmonary embolism by saline contrast electrical impedance tomography method: a prospective observational study, Am. J. Respir. Crit. Care Med. 202 (10) (2020) 1464–1468.
[14] I. Frerichs, M.B. Amato, A.H. van Kaam, D.G. Tingay, Z. Zhao, B. Grychtol, M. Bodenstein, H. Gagnon, S.H. Bohm, E. Teschner, et al., Chest electrical impedance tomography examination, data analysis, terminology, clinical use and recommendations: consensus statement of the TRanslational EIT developmeNt stuDy group, Thorax 72 (1) (2017) 83–93.
[15] J. Helms, M. Carrier, F.A. Klok, High-risk pulmonary embolism in the intensive care unit, Intensive Care Med. 49 (5) (2023) 579–582.
[16] L.M. Malbouisson, C.J. Busch, L. Puybasset, Q. Lu, P. Cluzel, J.J. Rouby, Role of the heart in the loss of aeration characterizing lower lobes in acute respiratory distress syndrome. CT Scan ARDS Study Group, Am. J. Respir. Crit. Care Med. 161 (6) (2000) 2005–2012.
[17] K.J. Dunham-Snary, D. Wu, E.A. Sykes, A. Thakrar, L.R.G. Parlow, J.D. Mewburn, J.L. Parlow, S.L. Archer, Hypoxic pulmonary vasoconstriction, Chest 151 (1) (2017) 181–192.
[18] U.M. Weinreich, L.P. Thomsen, S.E. Rees, B.S. Rasmussen, The effects of oxygen induced pulmonary vasoconstriction on bedside measurement of pulmonary gas exchange, J. Clin. Monit. Comput. 30 (2) (2015) 207–214.
[19] Y. Yang, H. He, Y. Long, Y. Chi, S. Yuan, Z. Shen, I. Frerichs, Z. Zhao, Bedside electrical impedance tomography in early diagnosis of pneumothorax in mechanically ventilated ICU patients - a single-center retrospective cohort study, J. Clin. Monit. Comput. 37 (2) (2022) 629–637.