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CASE REPORT

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# Early bedside detection of pulmonary perfusion defect by electrical impedance tomography after pulmonary endarterectomy

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**Abstract**

Pulmonary endarterectomy (PEA) is the standard treatment for chronic thromboembolic pulmonary hypertension. However, it poses risks of perioperative vascular complications, which can lead to serious clinical outcomes. This study introduces a novel noninvasive and radiation-free clinical imaging tool, electrical impedance tomography (EIT), for real-time bedside assessment of lung perfusion after PEA. It identifies ventilation-perfusion mismatches arising from postoperative complications, particularly valuable for patients with hemodynamic instability, thus eliminating risks tied to CT room transfers. The article reports a case where EIT was used to identify an in-situ thrombosis post-PEA, marking the first such application. The emphasis is on early detection using EIT, which offers a promising approach for therapeutic interventions and improved postoperative evaluations.

**KEYWORDS**

critical care, electrical impedance tomography, pulmonary endarterectomy, pulmonary perfusion

## INTRODUCTION

Pulmonary endarterectomy (PEA) remains the gold standard treatment for chronic thromboembolic pulmonary hypertension (CTEPH). However, there is a potential risk of recurrent thrombotic events, such as in situ thrombosis, in the perioperative period, which can lead to devastating clinical outcomes. Timely assessment of pulmonary perfusion following PEA may improve surgical outcomes, guide treatment, and help assess prognosis.

Electrical impedance tomography (EIT) is a noninvasive and radiation-free imaging tool for monitoring the distribution of ventilation and lung perfusion in critically ill patients in a real-time manner and at the bedside. EIT examinations necessitate the placement of electrodes around the chest wall to deliver small alternating electrical currents. Electrical currents encounter varying levels of resistance as they pass through different tissues. When breathing, the resistivity within the lungs changes due to the thinning and stretching of the alveolar septa, which finally alters the voltages detected by the electrodes. Specialized reconstruction algorithms are used to process these data, generating functional images that map changes in resistivity. This enables real-time visualization of the ventilation process. EIT pulmonary ventilation monitoring plays an important role in the management of pulmonary critical care, as it helps assess regional tidal volume, detect heterogeneity in ventilation distribution, identify lung collapse and overdistension, monitor ventilatory dyssynchrony, and guide positive end-expiratory pressure settings. Additionally, EIT is accurate and effective in the assessment of pulmonary perfusion, bedside diagnosis of pulmonary embolism (PE), and monitoring therapeutic response. Employing a hypertonic saline solution guided by first-pass kinetics, contrast-enhanced imaging that produces dilution impedance waveforms is a reliable approach for assessing regional alterations in lung perfusion. Computed tomography pulmonary angiography (CTPA) indicated that normal ventilation distribution with massive perfusion defects of the affected regions in EIT imaging has strong diagnostic efficacy in studying multiple embolisms.[1,2] We report a rare case in which early bedside application of EIT for pulmonary perfusion assessment successfully identified a large in-situ thrombosis after PFA. This marks the first instance of EIT application in this clinical context.

## CASE REPORT

A 25-year-old woman who was suffering from CTEPH for 6 months without a clear etiology, received comprehensive internal medicine care. Nevertheless, she still had progressive dyspnea with WHO functional class IV. The CTPA showed filling defects in the pulmonary trunk, the left main pulmonary artery, and the subsegmental arteries in the left upper lobe. No contrast filling was observed in the right main pulmonary artery and its branches. Single-photon emission computed tomography revealed reduced perfusion in the entire right lung and the apicoposterior segment of the upper lobe of the left lung. Transthoracic echocardiography showed pulmonary hypertension with a tricuspid systolic pressure gradient of 75 mmHg, and a significant right atrial and ventricular enlargement. Following a comprehensive assessment by a multidisciplinary team, PEA was recommended for the patient. During the surgical intervention, the patient experienced hemodynamic instability and respiratory failure induced by massive right airway hemorrhage and exacerbation of cardiac dysfunction. The cardiac surgeon claimed that the airway hemorrhage was the result of hyperperfusion and successfully removed most of the lesion before the incidence of hemorrhage. Consequently, the patient was emergently cannulated, and central veno-arterial extracorporeal membrane oxygenation (VA-ECMO) was used to provide respiratory and circulatory support, with an arterial cannula placed in the aorta and a venous cannula placed in the right atrium. The sternum was left open after central ECMO placement and the patient was transferred to our intensive care unit (ICU) immediately after the surgery. The patient gradually recovered and ECMO was discontinued on the third postoperative day, but his hemodynamics and oxygenation deteriorated on the fourth postoperative day. Postoperative clinical details are summarized in Table S1 in Supplement. EIT was utilized to evaluate regional ventilation and perfusion. EIT electrodes were placed on the 5th intercostal space, with continuous recordings at 20 Hz using PulmoVista 500 (Dräger Medical). The saline contrast-enhanced EIT procedure included the injection of 10 mL 10% NaCl bolus via a central venous catheter after a respiratory pause expiratory hold (minimum 8 s), as detailed in our previous studies.[3] EIT revealed a substantial perfusion defect in the right lung (Figure 1b), leading to a pronounced ventilation-perfusion mismatch (high dead space ratio; Figure 1a,c). Therefore, we became highly concerned about potential postoperative complications, including in-situ thrombosis. CTPA was conducted to re-evaluate the surgical intervention and provide the surgical team with more detailed information. This examination confirmed the complete occlusion of the right pulmonary arteries (Figure 1d–f). Based on these findings, a second surgical intervention was planned. However, regrettably, the patient's family declined further surgical management.

## DISCUSSION

PEA remains the primary surgical intervention for patients with CTEPH. However, the procedure imposes a high risk of perioperative vascular complications, which can significantly affect both respiratory and circulatory functions and potentially worsen the clinical outcome. CTPA poses a high risk in patients experiencing unexplained hypoxemia or shock, particularly in the presence of hemodynamic instability. The use of CTPA is also limited when contrast is contraindicated due to renal insufficiency. Therefore, alternative diagnostic methods are necessary. EIT offers a novel, repeatable, non-invasive, and radiation-free method for assessing lung

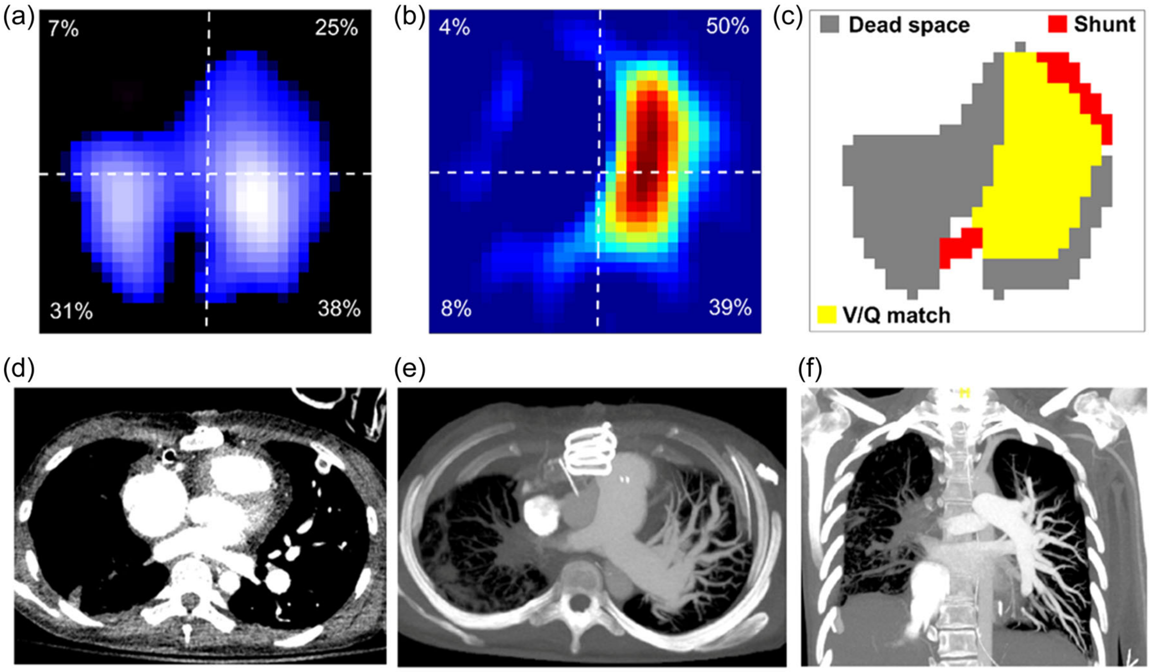


**FIGURE 1** . The results of electrical impedance tomography (EIT) and CT pulmonary angiography (CTPA) showing perfusion defects of the patient. (a) Functional EIT image of ventilation distribution. Regions with low ventilation are marked in the dark blue, and regions with high ventilation are marked in white. (b) Functional EIT image of perfusion distribution measured by injecting 10 mL of 10% saline bolus during respiratory hold. Regions with high perfusion are marked in red and regions with low perfusion are marked in blue. (c) Functional EIT image showing the distribution of regional ventilation/perfusion ratios. Ventilated regions were defined as pixels with impedance changes of more than 20% of the maximum tidal impedance variation in the functional ventilation image. Perfused regions were defined as pixels with more than 20% of the maximum bolus-related impedance change in the functional perfusion image. Regions with high ventilation and low perfusion are marked in gray (corresponding pixels show the ventilated but not perfused regions). Low ventilation and high perfusion regions are marked in red (corresponding pixels show the perfused but not ventilated regions). Good ventilation-perfusion matching is marked in yellow (pixels belong to both regions and exhibit both ventilation and perfusion). (d–f) CTPA revealed that right pulmonary arteries were occluded. (d) CTPA scan; (e, f) 3-Dimensional reconstruction of pulmonary arteries at the horizontal and coronal planes.

perfusion at the bedside. This technique is especially useful in the intensive care setting as it can serve as a rapid bedside diagnostic method. It can rule out central PE or identify ventilation-perfusion mismatches caused by postoperative vascular complications, particularly in patients with hemodynamic instability subsequent to high-risk PE. Zarantonello et al. reported EIT-based detection and follow-up of pulmonary artery stenosis in patient undergoing lung transplantation.[4]

In-situ thrombosis after PEA is a rare complication with a poor prognosis. Early detection may improve the response to treatment. Accumulating clinical evidence supports the use of EIT to diagnose PE at the bedside and to help classify the broad etiology of acute respiratory failure.[1–5] Previous studies have predominantly concentrated on validating the strong concordance between the results of saline-contrast EIT and CTPA in diagnosing PE. However, saline-contrast EIT as an initial diagnostic modality for PE remains debatable. This study represents the first reported case for whom EIT initially diagnosed pulmonary artery embolism after PEA, highlighting the potential of EIT in accelerating the diagnosis of pulmonary artery embolism.

Although EIT is valuable in clinical scenarios, it has certain limitations. Firstly, EIT has lower spatial resolution and cannot provide precise anatomical localization. It is more effective in detecting larger or more central pulmonary PE rather than smaller emboli in the pulmonary artery. In contrast, CTPA, with its higher spatial resolution, can identify smaller emboli. Furthermore, postoperative changes in lung perfusion, including increased perfusion in newly perfused areas and decreased perfusion in normal areas, may persist for several months. These variations in perfusion patterns can affect the accuracy and interpretation of ventilation-perfusion ratio assessment using EIT.

In summary, this report introduces the novel application of EIT for comprehensive bedside assessment of lung perfusion after PEA, presenting a novel approach for measuring surgical outcomes.

## AUTHOR CONTRIBUTIONS

Qianlin Wang and Huaiwu He prepared the final copy of the manuscript and EIT images. Jing Jiang and Yi Chi performed the EIT examination. Siyi Yuan obtained patient's consent. Yun Long and Zhanqi Zhao edited and revised the manuscript. All authors contributed to the article and approved the submitted version.

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## CONFLICT OF INTEREST STATEMENT

Zhanqi Zhao receives a consulting fee from Dräger Medical. The remaining authors declare no conflict of interest.

## ETHICS STATEMENT

The Institutional Research and Ethics Committee of the Peking Union Medical College Hospital approved this study on human subjects. Written informed consent was obtained from the patients' next of kin.

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## SUPPORTING INFORMATION

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

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