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Application of electrical impedance tomography in an obese patient with ARDS

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Abstract

This clinical case report detailed a 60-year-old obese female (BMI 44 kg/m²) with severe ARDS. The patient underwent mechanical ventilation with PEEP 16 cmH_2O, but due to obesity and high PEEP, CT imaging was not feasible. Bedside Electrical Impedance Tomography (EIT) was employed for lung function monitoring.

Continuous EIT assessed regional lung ventilation, analyzing impedance changes to evaluate lung homogeneity and regional ventilation delay. Initial findings revealed significant inhomogeneity and regional ventilation delay. However, with EIT monitoring and adjustments to ventilator settings, coupled with physical therapy, the patient's regional ventilation gradually improved. After 7 days, the patient was successfully weaned off mechanical ventilation.

This case demonstrated the utility of bedside EIT in monitoring lung function in severe ARDS patients, especially those with obesity. Real-time, non-invasive assessment of regional lung ventilation facilitated optimized ventilator settings and improved outcomes.

Keywords: Acute Respiratory Distress Syndrome (ARDS); Electrical impedance tomography (EIT); positive end-expiratory pressure (PEEP); regional ventilation delay (RVD).

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1. INTRODUCTION

Acute Respiratory Distress Syndrome (ARDS) is an acute, diffuse, life-threatening lung injury occurring in critically ill patients. It is characterized by poor oxygenation, pulmonary infiltrates, and abrupt onset. At the microscopic level, ARDS involves capillary endothelial injury and diffuse alveolar damage. Typically, it develops within 7 days of a precipitating event, manifesting as bilateral pulmonary infiltrates and severe hypoxemia not attributable to cardiogenic pulmonary edema. According to the Berlin definition, ARDS is diagnosed based on acute onset, bilateral infiltrates on chest radiography or CT scan of non-cardiac origin, and a PaO_2/FiO_2 ratio below 300 mmHg. The incidence of ARDS in the United States ranges from 64.2 to 78.9 cases per 100,000 person-years, with 25% of cases initially classified as mild and 75% as moderate or severe, where one-third of mild cases progress to more severe forms. Approximately 10-15% of ICU patients and up to 23% of mechanically ventilated patients meet ARDS criteria. The overall mortality rate is 43%, correlating with disease severity: 27% (mild), 32% (moderate), and 45% (severe) [6, 12].

Obese patients with ARDS present significant challenges during mechanical ventilation due to altered respiratory physiology. Increased abdominal pressure

and chest wall mass in obese individuals lead to decreased lung volumes and an elevated risk of atelectasis. Therefore, higher levels of positive end-expiratory pressure (PEEP) are necessary compared to non-obese patients to maintain alveolar recruitment and improve oxygenation. Studies have shown that conventional PEEP levels may be insufficient for morbidly obese patients, and the implementation of alveolar recruitment maneuvers combined with PEEP titration can significantly enhance respiratory function. However, the use of high PEEP prolonged treatment time in the ICU.

Furthermore, driving pressure, may not accurately reflect the actual pressure applied to the lungs in obese patients. Due to the stiff chest wall and elevated baseline pleural pressure, a substantial portion of the pressure delivered by the ventilator may be utilized to distend the chest wall rather than the lungs [5].

Electrical impedance tomography (EIT) becomes indispensable for providing detailed and continuous information on regional lung ventilation. EIT enables direct and non-invasive assessment of ventilation changes across different lung regions, thereby assisting clinicians in making more precise treatment decisions. This is particularly crucial in selecting appropriate ventilator settings, such as optimal PEEP levels, to maintain alveolar expansion and improve oxygenation. Additionally, EIT aids in monitoring the effectiveness of interventions like respiratory physiotherapy and evaluating the impact of medications [1].

In obese patients, the transportation for CT imaging is often challenging and carries potential risks. EIT, with its capability for bedside monitoring, overcomes this limitation while providing continuous information on lung status without interrupting the treatment process. Thus, EIT plays a vital role in optimizing ventilation strategies and enhancing outcomes for obese patients with ARDS [9].

2. CASE PRESENTATION

We present the case of a 60-year-old female patient, weighing 90 kg, with a BMI of 35 kg/m², diagnosed with severe ARDS – sepsis shock – pneumonia/hypertension - diabetes mellitus – class II obesity, treated with volume-controlled mechanical ventilation with a PEEP of 15 - 16 cmH_2O, antibiotics, and vasopressors for 7 days. The patient exhibited progressive consolidation in the lungs. Oxygenation and respiratory mechanics indices were low on the admission day, specifically: a P/F ratio of 78/0.8, resulting in 97.5, with a short Ti of 0.8 seconds, lung elastance of 31 ml/cmH_2O, airway resistance of 16 cmH_2O/l/s, and mean airway pressure of 21 cmH_2O. Ventilator settings such as tidal volume and PEEP were implemented according to ARDS network. However, evaluating ventilation effectiveness was challenging due to the inability to transport the patient for daily chest CT scans. Challenges in transporting patients for pulmonary CT scans include: the lack of specialized transport ventilators with high-concentration oxygen and high PEEP, the risk of hypoxemia and PEEP loss during transport. Additionally, there was a shortage of personnel to transfer patients from the bed to the stretcher, from the stretcher into the narrow elevator, and then onto the CT table. Therefore, the patient underwent bedside non-invasive EIT for continuous lung injury assessment over 5 days at ICU department.

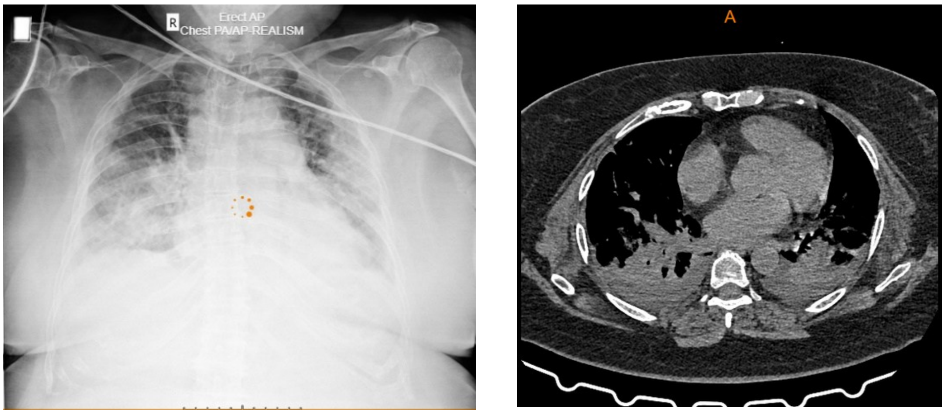

Figure 1. Chest Xray and CT Scan on Day 1: Posterior lung consolidation on patient's CT and EIT images

Figure 2. Ventilator Parameters Monitored on Day 1 with PEEP 15 cmH_2O, FiO_2 60%, Vt 380 ml

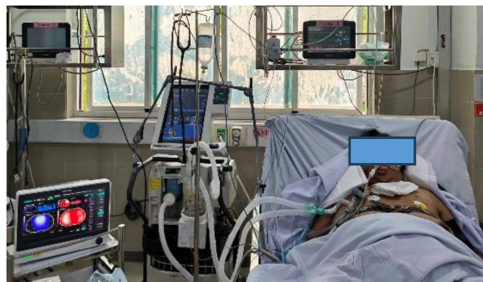

Figure 3. Bedside electrical impedance tomography

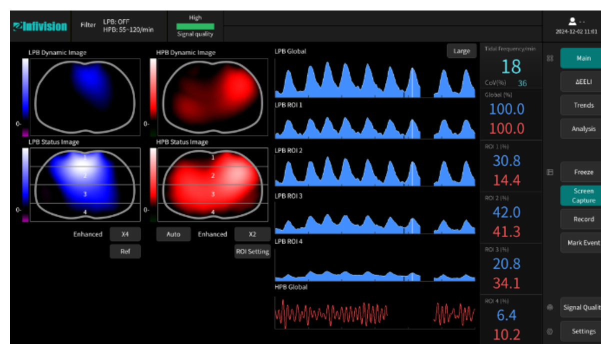

Figure 4. EIT image on day 1, ventilation was mainly concentrated in the abdominal region, with no ventilation in the basal and dorsal regions

On the first day, with a PEEP of 15 cmH_2O, imaging revealed significant regional lung inhomogeneity and high regional ventilation delay (RVD). Ventilation was predominantly concentrated in the dependent lung regions. We prioritized maintaining the PEEP at 15, focusing on bedside physical therapy, including 90-degree lateral turns every 2 hours. After 24 hours, consolidation in the posterior lung regions significantly improved, with only consolidation remaining in the axillary regions.

Figure 5. EIT image on day 2, ventilation was less concentrated in the abdominal region. More distributed in the dorsal region

After 48 hours, we reduced the PEEP from 15 cmH_2O to 13 cmH_2O. The patient was weaned off sedation, transitioned from controlled ventilation to spontaneous breathing trials. Concurrently, the patient continued intensive bedside exercise, primarily focusing on diaphragmatic movements. Four days after implementing EIT for lung ventilation assessment, imaging showed improved ventilation in the dependent lung regions. Oxygenation improved to a P/F ratio of 365. The patient demonstrated significant improvements in respiratory symptoms and pulmonary mechanics.

Figure 6. EIT image on day 4, ventilation was less concentrated in the abdominal region. More distributed in the dorsal region and the lateral base of the lung

Typically, we proceeded with weaning and extubation when the patient tolerated spontaneous breathing with pressure support of 8 cmH_2O and a PEEP of 5–8 cmH_2O. However, upon EIT evaluation, we observed that the patient exhibited good ventilation with a PEEP of 10 cmH_2O, low regional ventilation delay, and favorable extubation prognosis. The patient was successfully weaned and extubated after 7 days.

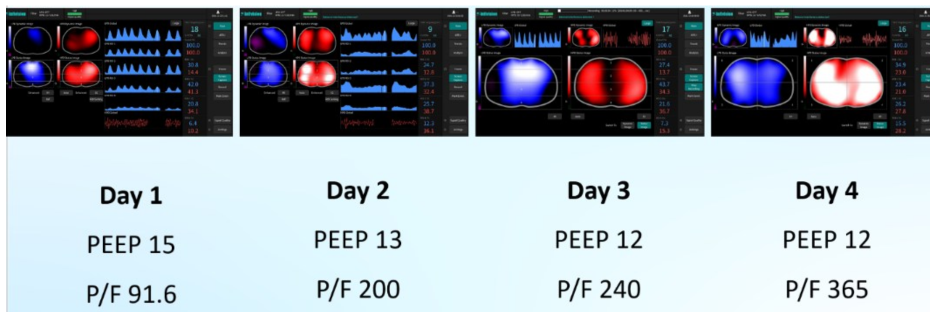

Figure 7. Compare the improvement of the P/F ratio over time

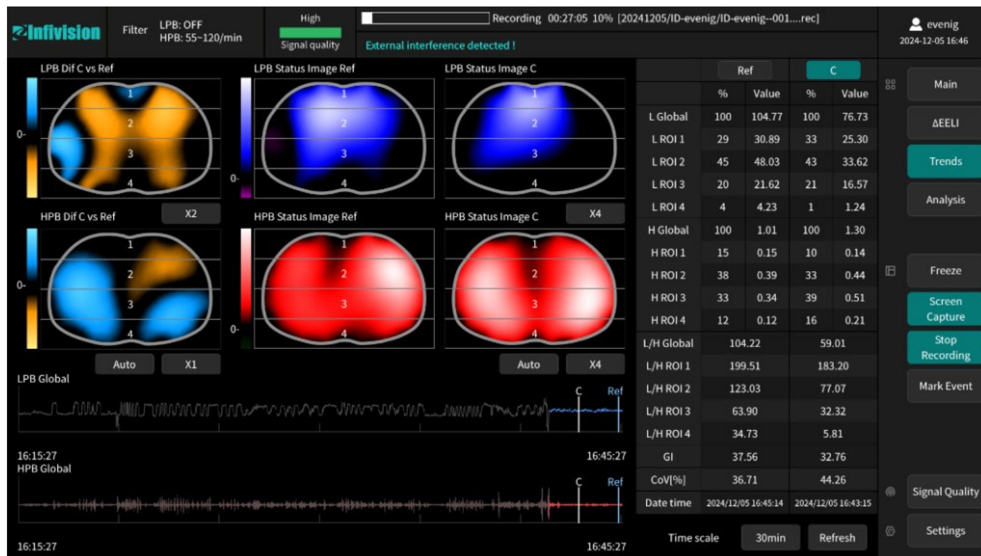

Figure 8. GI index on day 5 indicated successful weaning

The patient's pulmonary mechanics were assessed using EIT, and they subsequently entered the weaning process from mechanical ventilation. The patient was extubated after 7 days.

3. DISCUSSION

Electrical impedance tomography is a medical imaging technology that obtains impedance changes through corresponding imaging algorithm by injecting low intensity current and measuring surface voltages through attaching electrodes around chest, 4 to 6th intercostal space. This process is sequentially repeated by changing the pair of current-injecting electrodes, and with each injection, all remaining electrode pairs measure the voltage. This generates a large number of independent measurements. From these data, an impedance image is reconstructed. Dynamic determination of regional bioelectrical properties within the thoracic cavity [1].

A typical Electrical Impedance Tomography (EIT) system comprises (Figure 9) [15]:

- Current Injector: This component generates a low-frequency alternating current (typically ranging from a few kHz to several hundred kHz).
- Electrode System: A ring of electrodes (commonly 16 to 32 electrodes) is placed in contact with the skin.
- Data Acquisition Unit: This unit measures the electrical voltages between the electrode pairs.
- Processing and Display Unit: This section utilizes sophisticated image reconstruction algorithms to generate and display the impedance images.

Measurement Procedure:

The patient has the electrode belt positioned around their chest. The EIT device automatically injects current and collects data. This measurement process occurs continuously, enabling real-time monitoring of impedance changes [1].

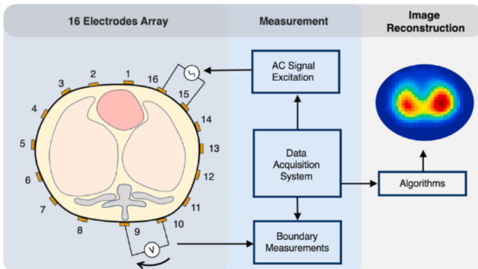

Figure 9. Measuring Principle of Electrical Impedance tomography [15]

In the domain of pulmonary ventilation monitoring, EIT allows for the estimation of regional lung overdistension and atelectasis during mechanical ventilation. A study by Gómez-Laberge et al demonstrated EIT's capability to detect individual breaths with a sensitivity of 96% and a specificity of 97.6%. This ability is fundamental for dynamically assessing changes in atelectasis and overdistension. The study also showed that tidal breath duration and volume erred by an average of only 0.2 seconds and 5%, respectively. Furthermore, respiratory system compliance measured by EIT and ventilator measurements had a correlation coefficient of 0.8, confirming EIT's reliability in assessing lung mechanics. The research also indicated that stepwise pressure increases could reverse atelectasis in 17% of the lung [8].

Regarding PEEP selection, EIT plays a crucial role in individualized PEEP titration to optimize ventilation and protect the lungs. A large study (RECRUIT study) involving 108 COVID-19 ARDS patients, reviewed by Francovich JE (2025), revealed that the PEEP level corresponding to EIT's Overdistension-Collapse (OD-CL) crossing point led to low rates of overdistension (below 10%) and atelectasis (below 5%), independently of lung recruitability. This demonstrates EIT's capacity to effectively guide PEEP to achieve desired lung mechanics objectives [7]. Additionally, a meta-analysis by Chen et al. (2023) concluded that EIT-guided PEEP titration can improve lung mechanics and has the potential to enhance patient clinical outcomes [4].

3.1. Assessment of lung homogeneity and injury severity

EIT is a tool used to assess lung homogeneity. Typically, doctors interpret the images displayed on the EIT screen based on color to evaluate the ventilatory function of different lung regions: blue indicates good ventilation; black indicates no ventilation; and bright white indicates hyperventilation. In a normal, healthy lung, the image is predominantly blue, reflecting uniformly ventilated areas. In ARDS, lung injury is diverse, with healthy and diseased lung regions (consolidation, hyperventilation) interspersed.

By analyzing changes in lung impedance during ventilation, we can visually assess the homogeneity of impedance signals at the bedside. This allows us to identify different levels of injury in various lung regions: consolidated areas with poor ventilation, well-ventilated areas, and regions with increased air trapping.

On Day 1, the EIT image showed the patient had over-ventilation in the anterior lung regions, while the posterior and basal lung regions were not ventilated. This corresponded to the patient's chest CT scan results, which showed extensive consolidation in the posterior lung. This indicates that a PEEP level of 16 cmH_2O was too high. The patient could gradually reduce this PEEP level to select the most even ventilation image across lung regions on the EIT monitor.

Figure 10. On Day 1, the EIT image displayed different lung ventilation levels using the following color scheme: white: over-ventilation, blue: appropriate ventilation, black: no ventilation

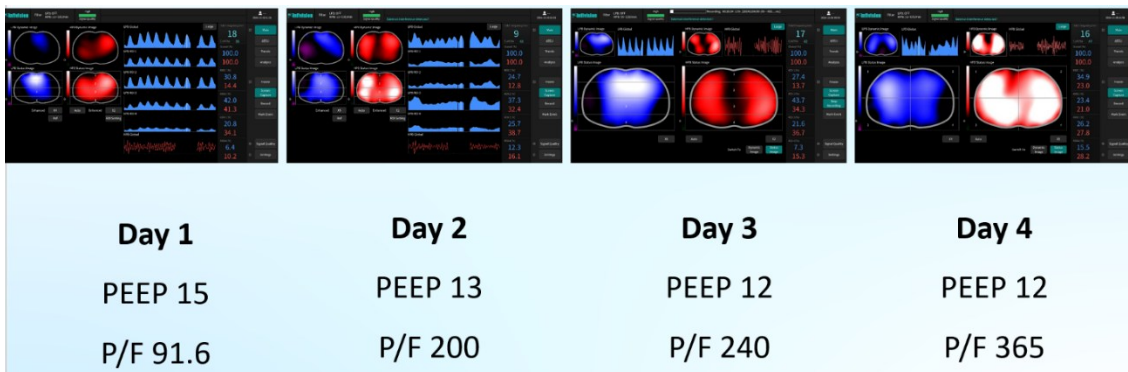

Figure 11. Images of lung ventilation regions changed with different PEEP levels

3.2. Assessment of VQ matching:

Critically ill patients in the intensive care unit (ICU) are often immobilized and on mechanical ventilation, placing them at increased risk for thromboembolic diseases, particularly deep vein thrombosis (DVT) and, to a lesser extent, pulmonary embolism [1]. Vascular EIT can be used to assess ventilation-perfusion matching in different lung regions, allowing for early detection of pulmonary embolism or pulmonary vasoconstriction.

On the EIT vascular window, bright red indicates high perfusion, normal red indicates adequate perfusion, and black indicates unperfused lung regions.

Figure 12. The perfusion window (on the right) showed adequate perfusion signals (red color)

3.3. Monitoring lung ventilation closely

Currently, when treating obese patients with ARDS on mechanical ventilation, the most significant challenge lies in monitoring lung mechanics and the progression of lung injury [11]. In cases where transporting obese patients on high PEEP ventilation for CT scans is difficult, bedside EIT allows us to directly monitor changes in ventilation distribution among different lung regions at critical decision-making points such as ventilator setting selection and physical therapy [10]. In this patient, during the initial days, the PEEP level was high, and ventilation in the lung bases was poor. We prioritized maintaining a PEEP of 16 cmH_2O and focused on bedside physical therapy, including 90-degree lateral turns every 2 hours. After a few days, as the consolidation in the lung bases improved on EIT, with only consolidation remaining in the two axillary regions, we reduced the PEEP level and transitioned to bedside exercise therapy involving arm and diaphragm movements. Four days after initiating EIT image monitoring, the patient showed improved ventilation in the dependent lung regions, ROI3 and ROI4 index gradually increases (Figure 6). EIT can be used as a non-invasive bedside tool to assess the effectiveness of ventilation during mechanical ventilation (Figure 14).

3.4. Choose optimal PEEP

EIT offers a visual method to observe the distribution of ventilation within the lungs and how it changes with PEEP adjustments. When PEEP levels are adjusted, particularly in scenarios involving lung pathology, the ventilation distribution can change significantly.

- Inadequate PEEP: PEEP levels that are too low can lead to alveolar collapse (atelectasis), especially in dependent lung regions (typically the dorsal and basal areas when the patient is supine).

- On EIT images: This may manifest as black areas (non-ventilated) or light blue areas (poorly ventilated) in these regions. Conversely, non-dependent areas (often the ventral regions) may show signs of over-distension (white areas), indicating excessive ventilation.
- Optimal PEEP. The goal of optimal PEEP is to identify the level that achieves the most uniform ventilation distribution across all lung regions.
- On EIT images: This will be represented by a large proportion of blue areas (appropriately ventilated), suggesting that the lungs are effectively ventilated without significant collapse or over-distension. This optimization facilitates gas exchange.

- Excessive PEEP: PEEP levels that are too high can result in over-distension of alveoli in healthier lung regions (typically the ventral or non-dependent areas), especially when other pathological lung regions remain consolidated or unrecruited.

- On EIT images: This will appear as widespread white areas (over-ventilated), particularly in the anterior parts of the lungs, while posterior or diseased lung regions may still show black (non-ventilated) or light blue (poorly ventilated) signals.

Clinical Significance of EIT Monitoring

Monitoring EIT images during PEEP adjustments empowers clinicians to refine ventilation strategies, aiming to identify the optimal individualized PEEP level for each patient. This approach seeks to improve ventilation, enhance oxygenation, and minimize ventilator-induced lung injury (VILI) [9]. Using lung impedance measurements, the optimal PEEP level is determined by balancing the risk of atelectasis, overdistension, and minimizing regional ventilation delay.

In our case, we initially set the PEEP

level at 16 cmH_2O, which was gradually decreased to 10 cmH_2O over the following days. Given the low regional ventilation delay observed in this patient, we concluded that there was minimal air trapping. This positive finding suggested that early extubation might be feasible in the following days. EIT shows promise as a tool for individualizing PEEP levels in mechanically ventilated patients with ARDS.

Figure 13. Optimal PEEP based on the balance between lung overdistension and collapse

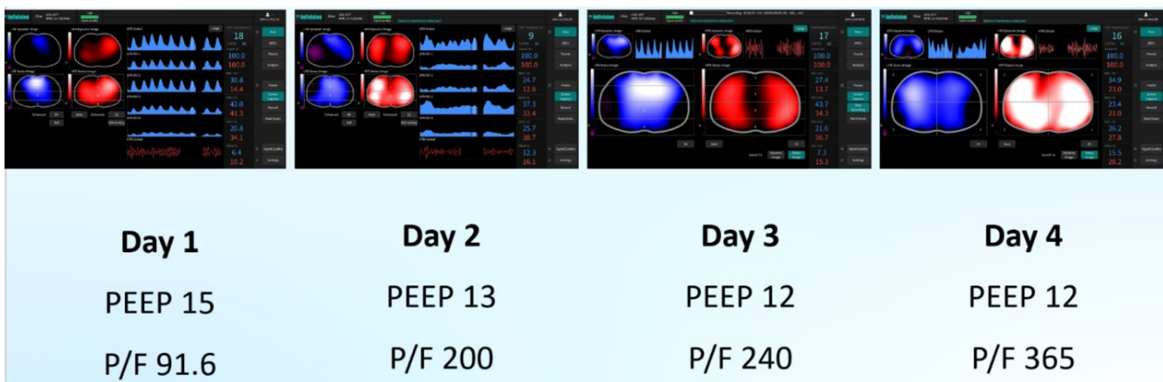

Figure 14. Images of lung ventilation regions changed with different PEEP levels

3.5. GI index

Global inhomogeneity (GI) index describes spatial heterogeneity within the lung. It was found that in patients with an initial GI > 41.5, an SBT should not be performed. From a clinical perspective, predicting SBT failure in this particular patient group with prolonged weaning seems valuable to avoid significant drawbacks. This finding may underscore the importance of EIT as a monitoring tool in SBTs, being more accurate than functional parameters of gas exchange [2]. In this patient, a GI index of 32 indicated a successful weaning prognosis.

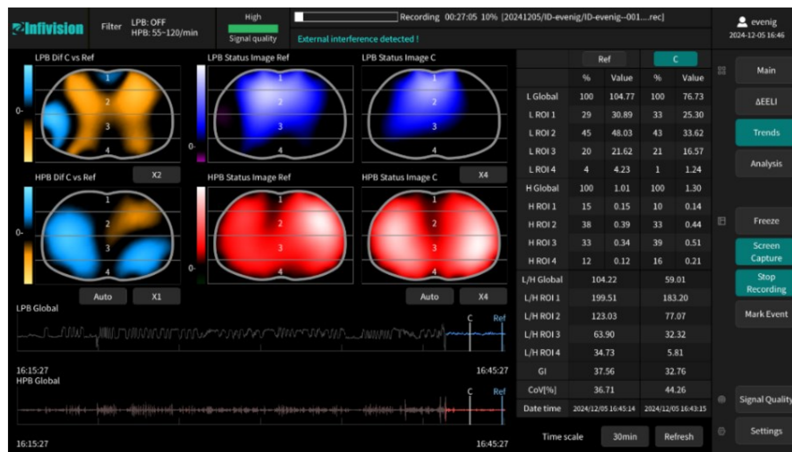

Figure 15. GI index 32 indicates a successful weaning prognosis

3.6. Accuracy and Limitations

Ventilation:

EIT can detect regional ventilation changes due to PEEP variations and identify airway closure, correlating well with CT scans for regional lung volumes and tidal volume [2]

PEEP Optimization:

EIT can guide the adjustment of PEEP, a parameter in mechanical ventilation, to optimize lung recruitment and minimize overdistension. Studies suggest that EIT-guided PEEP titration can reduce mechanical power, driving pressure, and potentially improve lung compliance compared to traditional methods [9, 13].

Limited Spatial Resolution:

EIT's spatial resolution, which refers to its ability to distinguish between closely spaced objects, is relatively low. This means EIT may not be as effective as other imaging techniques like CT scans in identifying subtle structural abnormalities within the lung, such as small areas of consolidation or atelectasis [14].

Clinical Validation:

While EIT offers valuable information, the complexity of data analysis and interpretation can be a barrier to widespread clinical adoption. Further research is needed to validate the clinical benefits of EIT in large multicenter trials and to standardize its application in clinical practice.

4. CONCLUSION

In summary, EIT demonstrates promising potential in obese ARDS management by providing real-time, non-invasive assessment of regional lung function especially when CT scans are limited. It can help guide PEEP optimization, detect ventilation-perfusion mismatch, and potentially predict successful weaning, but further research is needed to address the challenges associated with its widespread clinical implementation.

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