Electrical impedance tomography in high frequency ventilated preterm infants: the search for the Holy Grail

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Pneumothorax in a preterm infant monitored by electrical impedance tomography: a case report

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Abstract

Electrical impedance tomography (EIT) is a non invasive bedside tool for monitoring regional changes in ventilation. We report, for the first time, the EIT images of a ventilated preterm infant with a unilateral pneumothorax, showing a loss of regional ventilation in the affected lung during both high frequency oscillation and spontaneous ventilation.
Introduction

Pneumothorax is a potentially life-threatening complication in preterm infants treated with nasal continuous positive airway pressure (nCPAP) or mechanical ventilation 1. Most infants with a pneumothorax show signs of clinical deterioration, such as hypoxia, hypercapnia, hypotension and increased work of breathing 2. However, initially these clinical signs can be mild, which can lead to a delay in the timing of the chest X-ray (CXR) and the start of adequate treatment 3. Shortening this delay has, up to now, been difficult because online monitoring of the regional distribution of air and ventilation within the thorax has not been possible at the bedside.

Electrical impedance tomography (EIT) is a novel non-invasive monitoring technique, capable of continuously measuring global and regional changes in lung impedance, which correlates well with intrathoracic changes in air content and ventilation 4. These characteristics make EIT a promising real-time screening tool for pneumothoraces, as also indicated by three recent animal studies 5-7. In this article we describe, for the first time, the EIT recordings in a ventilated preterm infant with a unilateral pneumothorax.

Methods

Preterm infants with respiratory distress syndrome (RDS) admitted to the neonatal intensive care unit of the Emma Children’s Hospital AMC, Amsterdam The Netherlands, are initially treated with early nCPAP. In case of progressive respiratory failure infants are intubated and treated with open lung high-frequency ventilation 8. Some of the ventilated patients are enrolled in an ongoing observational study aiming to monitor lung recruitment with EIT during high-frequency ventilation. In one of the included patients, diagnosed as having progressive RDS, CXR unexpectedly revealed a unilateral pneumothorax.

Case report

The index patient was a male preterm infant, born at 31 weeks of gestation with a birth weight of 1170 g. He was admitted with mild respiratory distress and started on nCPAP with a pressure of 6 cmH$_2$O. Almost 24 h after birth his clinical condition deteriorated with an increasing oxygen requirement and progressive hypercapnia. The patient was intubated and high-frequency ventilation initiated, delivered with a Sensormedics 3100A oscillator (Cardinal Health, Yorba Linda, CA, USA), with a working diagnosis of progressive RDS. The initial continuous distending pressure was 8 cmH$_2$O with a driving pressure of 23 cmH$_2$O and the frequency was set at 10 Hz. The CXR obtained to evaluate lung inflation after recruitment and the endotracheal tube position, unexpectedly showed a right-sided pneumothorax (Figure 1). Following pleural drainage via an intercostal drain placed into the right lateral fifth intercostal space, the ventilator settings could
be rapidly weaned and no surfactant was administered. The patient was successfully extubated twelve hours later. No surfactant was administered.

EIT measurements
Prior to intubation sixteen hand-adjusted ECG electrodes (Blue Sensor, BRS-50-K, Ambu, Inc., Linthicum, MD) were placed equidistantly on the chest circumference just above the nipple line and thereafter connected to the “Goettingen Goe-MF II” EIT system (Carefusion, Hoechberg, Germany) using an electrical current of 5 mA_{rms} (50 kHz) and a scan rate of 44 Hz. Continuous EIT registration was started as soon as the patient was connected to the high-frequency ventilator, until the electrodes had to be removed for drain insertion.

Off-line analysis
EIT recordings obtained at the start of the recruitment manoeuvre were used to construct amplitude ventilation maps displayed as functional EIT (f-EIT) images, as previously described. Ventilation distribution was assessed for both the high-frequency oscillations and the spontaneous breaths, by filtering out impedance changes occurring in a frequency range, below 400/min or above 130/min, respectively. Because no EIT data were available before the onset of the pneumothorax or after its resolution, we also performed a similar EIT analysis at the start of recruitment in a second HFV ventilated RDS patient with a comparable birth weight, ventilatory settings, but with no pneumothorax on the CXR (control patient).

Results
Figure 1 shows the CXR and f-EIT images of the index and the control patient. The CXR of the index patient clearly shows a right-sided pneumothorax with a mediastinal shift into the left thoracic cavity. In accordance with this finding, the f-EIT images show an asymmetrical distribution of both oscillatory and spontaneous (tidal) ventilation in favour of the left lung. This in contrast to the f-EIT images of the control patient with no pneumothorax, which show a much more symmetrical distribution of ventilation.

Discussion
To our knowledge, this is the first neonatal case report, describing the changes in lung impedance in a ventilated premature infant with unilateral pneumothorax. The functional EIT images clearly show that a pneumothorax is accompanied by a loss of regional ventilation in the affected lung.
Previous animal studies have also evaluated the EIT changes in the presence of a pneumothorax and reported a similar loss of regional ventilation in the affected lung 5-7. The fact that our patient was treated with high-frequency ventilation allowed us to assess the ventilation distribution during both non-tidal and tidal ventilation. We could show that the loss of ventilation in the affected lung was present during both non-tidal high-frequency ventilation and spontaneous tidal ventilation.

There is only one other human report, describing the EIT images in a spontaneously breathing adult subject with a post-traumatic unilateral pneumothorax 10. EIT images obtained during deep, forced inspiration also showed a loss of ventilation in the affected lung. Unfortunately, we were not able to obtain EIT recordings before the onset of the pneumothorax or after its resolution. Due to this limitation we were not able to assess the actual change in regional ventilation before and after the pneumothorax. We therefore analyzed the EIT data of a control patient with no pneumothorax, which showed an almost symmetrical distribution of ventilation. This finding, together with the comparable findings in animal studies, strongly suggests that the loss in regional ventilation is indeed caused by the pneumothorax.

The fact that the loss of regional ventilation was already present at the start of ventilation, suggests that the clinical deterioration during nCPAP was not caused by progressive RDS but instead by the pneumothorax. This is also supported by the rapid clinical recovery after pleural drainage. This report indicates that the delay in diagnosis and treatment can potentially be shortened with continuous EIT monitoring.

![Figure 1](image-url) Chest X-ray (CXR) and functional EIT images showing the distribution of ventilation during both high-frequency oscillation and spontaneous ventilation in the index patient (upper panel) and the control patient (lower panel). The CXR of the index patient clearly shows a right-sided pneumothorax and a concomitant loss of regional ventilation in the right lung.
Conclusion

Pneumothorax causes a loss of regional ventilation measured by EIT in the affected lung. EIT is a promising bedside monitoring tool which may reduce the delay in diagnosis and treatment of pneumothorax.


