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Electrical Impedance Tomography Can Identify Ventilation and Perfusion Defects: A Neonatal Case

To the Editor:

The interaction between ventilation and lung perfusion is fundamental for effective gas exchange. Increasingly, clinicians are seeking to understand ventilation–perfusion matching at the bedside. Electrical impedance tomography (EIT) is emerging as the most promising bedside tool to define regional ventilation, being noninvasive and radiation free and offering continuous monitoring across different clinical environments (1). The ability to determine lung perfusion at the bedside is limited, especially in infants. EIT can measure the heartbeat-related impedance signal within the chest and has been proposed as a method of also defining regional lung perfusion (1–3). Unlike the impedance signal during ventilation, the cardiac signal is of lower amplitude and occurs at a faster and more variable rate. This, and a lack of a true biological model, has limited validating EIT measures of lung perfusion.

Herein we report the case of a 13-day-old infant born with an antenatal complete left pulmonary artery thrombosis and infarction of the left lung. This resulted in an almost complete absence of ventilation and perfusion in the left lung and a normal right lung. This provides a unique natural biological model in which to determine the role of perfusion and direct cardiac movement within the heartbeat-related signal generated during EIT.

Case Report

A 34-weeks' gestation male infant (birth weight, 2,720 g; Apgar score, 8 and 8 at 5 and 10 min) developed tachypnea and 25% oxygen requirement over the first 6 hours of life requiring continuous positive airway pressure in a regional hospital. He did not require any respiratory intervention at birth. An initial chest radiograph demonstrated complete consolidation of the left lung with extensive air bronchograms and a normal right lung (Figure 1A). The infant was transferred to the regional neonatal intensive care unit of the Royal Children's Hospital (Melbourne, Australia) for further management. Respiratory symptoms improved and continuous positive airway pressure was ceased on Day 3 of life. Chest computerized tomogram on Day 8 of life demonstrated complete occlusive thrombosis at the origin of the left pulmonary artery with extensive distal propagation and infarction of the left lung (Figure 1B). Further ultrasound imaging confirmed no structural heart disease and identified a left renal artery thrombosis and left adrenal thromboembolic infarct. Central nervous system imaging, including vessels, was normal. Intravenous heparin (until Day 10) and ongoing enoxaparin were administered.

EIT Methods

After obtaining informed written parental consent, EIT measurements were recorded on Day 13 at 48 scans during four 10-minute intervals of quiet unsupported breathing (no respiratory support) in a supine position using our previously detailed methods (Pioneer-Set with LuMon belt; Swisstom AG) (4). EIT images were reconstructed using the vendor-provided human model atlas with thoracic shape and lung and heart regions defined from a collection of computed tomography images. The image sequence was separated into heartbeat- and ventilation-related components by ensemble averaging. End-inspiratory peaks were detected in the average signal in the lung regions, and peaks corresponding approximately to systole were detected in the average heart-region signal. EIT pixel waveforms were aligned at each peak and averaged to create ventilation- and cardiac-synchronized components, and functional images were calculated corresponding to the times at which the maximum change in the lung regions occurred. Heartbeat-related EIT signals in the lungs and heart are normally out of phase, and the inverse conductivity change is not shown (primarily in the heart region).

EIT Results

Figure 2A shows representative impedance time course signals for the right and left lung and heart regions from a 45-second recording containing 32 consecutive breaths and 87 heartbeats. The mean total tidal volume was distributed as 93:7 between the right and left lung (Figure 2B). Similarly the right:left heartbeat-related signal within the lung regions was distributed as 81:19 (Figure 2C).

Discussion

This case provides a unique biological model to investigate the ability of EIT to define regional ventilation–perfusion patterns. Currently, ventilation–perfusion matching in infants is rarely determined because of the difficulties obtaining images outside of

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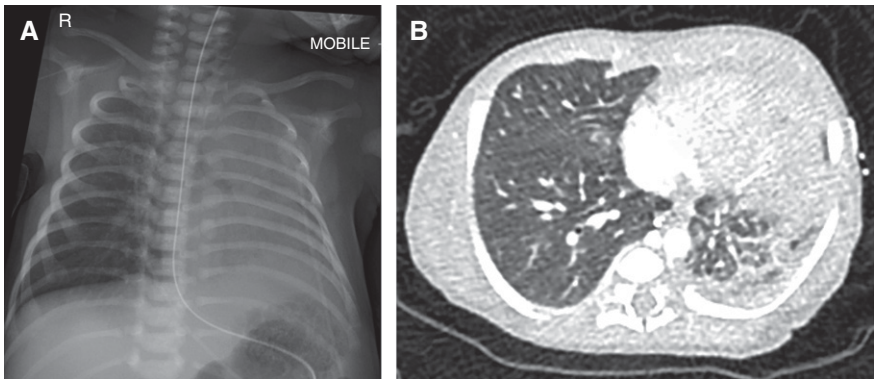

Figure 1. (*A*) Chest radiograph (Day 5 of life). (*B*) Computed tomography image at the level of electrical impedance tomography imaging (performed Day 8 of life).

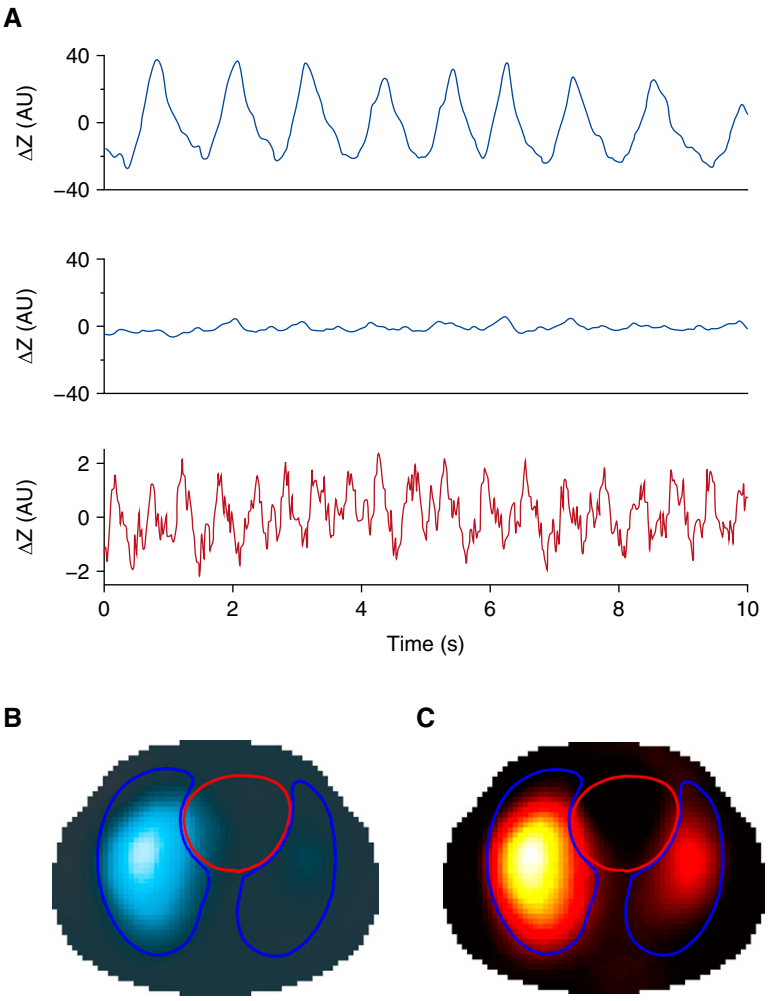

Figure 2. (*A*) Representative respiratory (blue) and heartbeat-related (red) impedance time course signals for the right (top tracing) and left lung (middle tracing), and anatomical heart region (bottom tracing) over 10 seconds. Note the absence of electrical impedance tomography (EIT) signal within the left lung compared with right. (*B*) Functional EIT (fEIT) image of the ventilation-related changes within the right and left lung during the same 10-second period showing 93% of all tidal ventilation occurring in the right lung. Relative tidal ventilation is represented with a blue hot-map scale with black (no ventilation) to white (maximum). (*C*) fEIT image of the heartbeat-related EIT signal within the right and left lung, with only 19% of all heartbeat-related EIT signal within the lungs occurring in the left lung. Relative heartbeat-related signal shown with a red-hot map scale from dark red (minimum) to yellow-white (maximum). For both fEIT images, the anatomical regions of the chest corresponding with the lungs are outlined in blue and the heart in red. During the presented EIT recording, the measured respiratory rate was 54 breaths/min, heart rate 115 beats/min, and peripheral oxygen saturation 98% in 0.21 fraction of inspired oxygen.

the radiology department. This, arguably, limits the optimization of respiratory support during neonatal intensive care with existing monitoring tools focusing on ventilation alone. A further strength of this case report is the lack of any adjunctive respiratory support during the measurements.

EIT demonstrated an almost complete lack of tidal ventilation in the left lung. EIT has been repeatedly shown to be able to differentiate single-lung ventilation in animal and human reports (5). Interestingly, EIT detected some residual tidal ventilation that clinicians would not have seen without the EIT recordings. The pulmonary artery infarct likely occurred after the pseudoglandular period and airway development. The residual ventilation likely represents bronchial tidal air movement and collateral ventilation via pores of Kohn. This suggests that EIT is able to image complex ventilation patterns within the lung at a resolution not currently possible within a bedside tool. EIT holds potential in monitoring ventilation and perfusion development in conditions characterized by unilateral lung differences and altered pulmonary blood flow, such as congenital diaphragmatic hernia and after cardiac surgery, over longer time periods.

To date, the use of EIT to measure lung perfusion has been limited to human observations in which the perfusion state was not known (2) or animal models with selective occlusion of a single pulmonary artery and injection of an electrical impedance contrast agent (3). Our data support the preclinical data demonstrating the ability of EIT to selectively measure lung perfusion. The clear differentiation between the heartbeat-related signals within the left and right lung suggests that the cardiac-domain impedance measures within the anatomical regions of the chest containing lung are not exclusively due to heart movement being transmitted through lung regions.

Conclusions. This case report describes the first report of EIT to measure perfusion and ventilation patterns in a newborn with a known loss of both in a single lung. EIT was able to demonstrate the perfusion and ventilation defects found on static radiological imaging. Importantly, EIT recordings within the heart-rate domain were independent of heart movement and at a respiratory resolution able to identify small areas of tidal ventilation. This suggests that EIT may hold promise as the first tool able to dynamically measure ventilation–perfusion matching over time in infants. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

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Pharmacologic Exhaustion of Suppressor Cells with Tasquinimod Enhances Bacterial Clearance during Tuberculosis

To the Editor:

Suppressor cells, such as regulatory T cells (Tregs) and myeloid-derived suppressor cells (MDSCs), are important components of the immune response generated against tuberculosis (TB).

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