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# Electrical impedance tomography in children with community acquired pneumonia: preliminary data

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ABSTRACT

*Background:* Electrical impedance tomography (EIT) is a noninvasive pulmonary function test that provides spatial and temporal information of changes in regional lung ventilation. We aimed to assess the feasibility of EIT as a supplementary tool in the evaluation of community acquired pneumonia in children. Furthermore, we performed a prospective evaluation of regional lung ventilation changes during a six-month follow-up period.

*Methods:* We enrolled otherwise healthy children aged 2–15 years with radiological diagnosis of community acquired pneumonia on admission at pediatric emergency department. Chest EIT was performed at enrollment, at three and six-months from baseline.

*Results:* Nineteen children were enrolled. A significant agreement between EIT and chest radiography in identifying the affected lung (left or right) was observed (Cohen K statistic = 0.73, 95% CI 0.5–0.98). Ventilation improvement was documented at three-month follow-up, but a full recovery only at six months.

*Conclusion:* EIT reliably provides additional information on lung ventilation disorders due to CAP in children. It further allows bedside, real time and radiation free monitoring of lung functional recovery. Future studies are needed to expand the generalizability of this method and evaluate effectiveness on clinical practice.



## 1. Introduction

Community acquired pneumonia (CAP) can be clinically defined as the presence of persistent or repetitive fever >38.5 °C together with chest recession and a raised respiratory rate due to an infection acquired outside the hospital [1]. Children with CAP usually show a rapid clinical recovery with antibiotic treatment and routine follow-up chest radiography is usually not necessary [1–3]. Yet, it is well known that radiographic changes normally persist much longer than clinical signs and disappear in 4–6 weeks in most cases [2,3]. Furthermore, it has been suggested that CAP at an early stage of lung development may impair lung growth and reduce lung function later in life [4]. Recently Eastham et al. reported persisting deficits in lung function in children with CAP requiring admission to the hospital [5].

Electrical impedance tomography (EIT) is a recent, non-invasive technique for real time evaluation and monitoring of distribution of lung ventilation. The potential of EIT in adults has been studied in several conditions such as lower tract respiratory infection, acute respiratory distress syndrome, chronic obstructive pulmonary disease and cystic fibrosis [6–8].

Recently, the application of EIT in infants affected with bronchiolitis, in children presenting with asthma exacerbation and in

*Abbreviations:* CAP, Community Acquired Pneumonia; EIT, Electrical Impedance Tomography; LUS, Lung Ultrasound.

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pediatric patients after cardiac surgery has also been explored [9–11].

Aim of this preliminary study was to investigate the changes of lung ventilation by means of EIT in children with CAP. Furthermore, we evaluated the modifications in lung ventilation at a follow-up of 3 and 6 months.

## 2. Material and methods

### 2.1. Subjects and study design

This prospective observational study was carried out at the Pediatric Emergency Department and Ambulatory Department of Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan (Italy), between November and December 2014. Inclusion criteria were: 1) clinical signs and symptoms consistent with pneumonia such as repetitive fever >38.5 °C together with chest recession and a raised respiratory rate in a previously healthy child due to an infection acquired outside the hospital, 2) chest radiography obtained at admission with typical radiographic infiltration findings, 3) age ≥2 and <15 years. We excluded children with: 1) hospital acquired pneumonia or requiring hospitalization, 2) unstable cardio-pulmonary conditions, 3) antibiotic treatments in the previous month.

In eligible children, EIT was performed on the day of enrollment. The antibiotic treatment with penicillin and/or macrolide, chosen by the attending pediatrician, was prescribed at home for 10 or 12 days, respectively. The compliance to antibiotic treatment was verified by a phone interview with caregivers at 12 days after enrollment.

Further EIT measurements were obtained at three and six months. The occurrence of any following infection of the lower respiratory airways during the six-month follow-up period was considered an exclusion criterion from further analysis.

### 2.2. Imaging studies

Chest X-rays were evaluated by an independent expert radiologist: radiographic evidence of left-sided or right-sided pneumonia was defined as the presence of a consolidation (a dense or fluffy opacity with or without air bronchograms), other infiltrates (linear and patchy alveolar or interstitial densities), or a pleural effusion [12].

### 2.3. Impedance study

Impedance measurements were performed by a biomedical engineer blinded to the clinical and radiological findings. The device (Pulmovista 500, Drager, Lubeck, Germany) was connected to patients by a silicone belt with 16 integrated electrocardiographic electrodes. The belt was placed around the thoracic cage at the fifth or sixth intercostal space.

EIT data were generated by means of an imperceptible alternating electrical current of 5 mA at 50 kHz in a sequential rotating process. Measurements of the resulting surface potential differences between neighboring electrode pairs were performed. Then, images of lung ventilation were reconstructed with a resolution of 32 × 32 pixel using the back projection algorithm. All the EIT images were recorded with a scan rate of 13 Hz (Draeger EIT data analysis tool 6.1, Draeger Lubek Germany) and stored on a personal computer [13]. EIT images were recorded for 2 minutes with children in sitting position. A static image with the lowest ventilation was chosen and used for analyses in each patient. The EIT images were divided into four quadrants: the upper left quadrant (Q1), the upper right quadrant (Q2), the lower left quadrant (Q3) and the lower right quadrant (Q4). Each quadrant, in physiological conditions, represents 25% of global amount ventilation, which corresponds to the most homogeneous regional ventilation. Hypoventilation was defined as a reduction ≤15% of the ventilation in at least one quadrant.

Chest radiography and EIT images were then compared to evaluate the correspondence of the two techniques in detecting ventilation distribution disorders between left and right lung.

### 2.4. Statistical analyses

Cohen K statistic with its corresponding 95% confidence interval (CI) was used to evaluate agreement between EIT and chest radiograph in identifying the affected lung (left or right). We also calculated sensitivity (with the corresponding 95% confidence interval) of ≤15% ventilation in one quadrant for detecting pulmonary infection.

Non-parametric techniques were used to analyze the data, due to the relatively small sample size. In particular, a non-parametric repeated measures ANOVA (i.e., Friedman test) was used to assess the evolution of the regional ventilation over time, using as baseline the lung area with the lowest ventilation in each patient at enrollment. Wilcoxon signed-rank tests were then used to evaluate regional changes in ventilation between different time points.

The study was approved by the local ethical committee. Written informed consent was obtained from the parents of children under the age of 12 years and from both patients and parents for older children.

## 3. Results

Diagnosis of CAP was performed in 26 children, but 7 did not met the inclusion criteria (two needed hospitalization, four were on antibiotic treatment before the admission in emergency department, one was affected with cystic fibrosis). Hence, 13 male and 6 female children were enrolled. The median age of the included patients was 6.5 years (range 2–15 years).

Radiographic findings were consistent with a right pneumonia in 14 children and with a left pneumonia in the remaining 5. None presented with a bilateral pneumonia. EIT disclosed hypoventilation in one of the right quadrants in all of the 14 patients presenting clinical and radiologic signs of right pneumonia. The former exam disclosed a hypoventilation in one of the left quadrants in 3 out of the 5 patients presenting clinical and radiologic findings of left pneumonia (Cohen K coefficient = 0.73, 95%CI 0.5–0.98; sensitivity = 0.89, 95%CI, 0.65–0.98).

Patients with discordance between radiographic findings and EIT measurements were excluded from follow-up analyses, which therefore included 17 children (89%). All the enrolled subjects showed a good compliance to the antibiotic treatment at 12-day follow-up. No subjects reported any further infection of the lower respiratory airways at six months.

EIT measurements at 3-month follow-up showed a partial ventilation improvement compared to baseline evaluation, but the functional recovery evaluated by EIT technique was complete only at 6-month follow-up.

Among the 17 children analyzed, the median ventilation improvement between enrollment and 3-month follow-up was 8% (interquartile range 5–11, $P < 0.0001$), while it was 6% between 3 and 6-month follow-up (interquartile range 5–9, $P < 0.005$). A

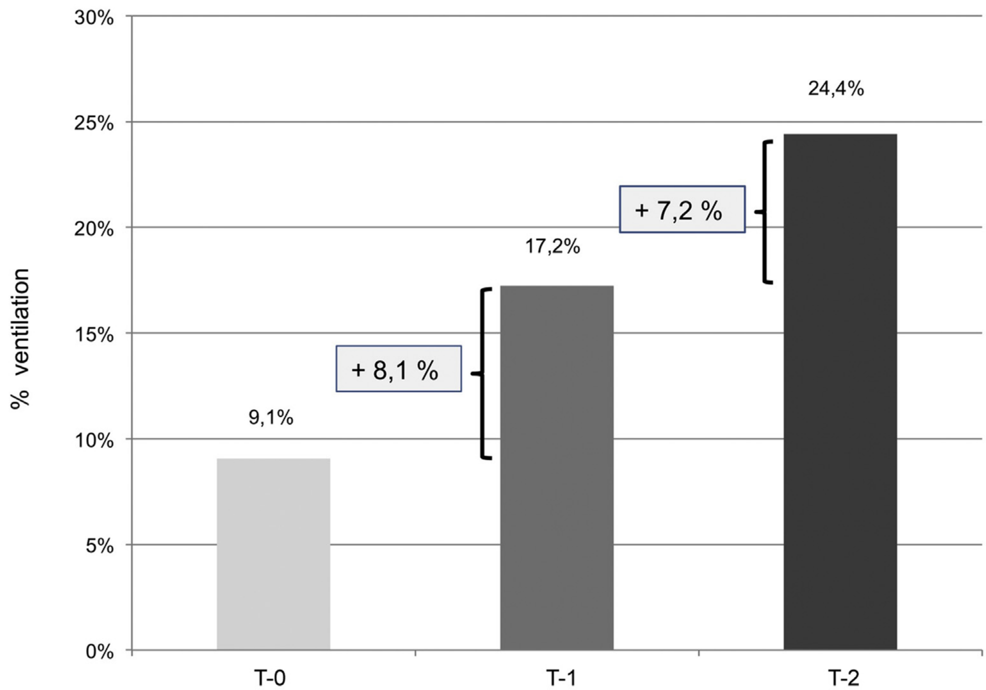


**Fig. 1.** Axis of abscissae: T0 = admission; T1 = 3-month follow-up; T2 = 6-month follow-up. Axis of ordinates: percentage of ventilation of the mainly involved quadrant: 25% corresponds to the most homogeneous regional ventilation. The difference in ventilation improvement at 3 and 6-month follow-up was not statistically significant.

gradual and homogeneous functional recovery was observed through the entire follow-up period (Fig. 1).

## 4. Discussion

This is the first study investigating the lung ventilation in children with CAP by electrical impedance tomography. This study shows a significant agreement of EIT with chest radiography in identifying the affected lung (left or right). Furthermore, EIT seems to be useful for monitoring lung ventilation during CAP follow-up.

Our preliminary data confirm the high concordance between chest radiography and EIT in detecting infiltration processes and ventilation disorder respectively, as previously documented in adults by Karsten et al. [14]. These authors studied EIT as a supplementary tool in monitoring lung ventilation in adult patients with pneumonia. Compared to adults, children have lower elastic pulmonary retraction forces, and relaxation volume. Therefore, pediatric patients are more prone to airways collapse and ventilation monitoring can be very useful in this population. Routine follow-up chest radiography is not indicated unless the child shows a poor response to treatment [1]. Lung ultrasound (LUS) is a sensitive and highly specific diagnostic tool in children with CAP: it provides real time images of regional tissue changes at the bedside, but it does not allow lung functional assessment [15]. EIT may allow a further contribution, providing continuous monitoring of lung ventilation. Interestingly, we observed an improvement of regional ventilation at 3-month follow-up, with a complete resolution only observed at 6 months. Given that thoracic EIT is a valid tool for assessing also lung perfusion, the concurrent evaluation of lung ventilation and perfusion might provide further important information to improve management especially of unstable patients [16].

This study has some limitations. First, the small number of enrolled patients. Second, we did not perform further chest radiography at 3 and 6-month follow up. Third, we enrolled exclusively stable patients undergoing chest radiography.

## 5. Conclusions

EIT might be a very promising supplementary tool for chest radiography and LUS in the evaluation and monitoring of children with CAP. Large prospective studies are necessary to confirm the clinical role of EIT in children with CAP.

### Conflict of interest statement

Please consider following information: this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

- Disclosure of competing interest:
  - Potential conflicts of interests: none;
  - Financial support: none.
- The study has not been published in this or a substantially similar form (in print or electronically, including on a website), nor accepted for publication elsewhere, nor is it under consideration by another publication.

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Authors' contribution: AMP, SF and EFF designed the study. SF and AP performed the study. MBM interpreted the results. MBM, EFF and GPM wrote the first draft of the manuscript. AP, GA, GPM gave a significant contribution in their area of expertise. DC conducted the statistical analysis. EFF supervised the study. All authors approved the study as submitted.

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