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Electrical impedance tomography in neonatal and pediatric populations: a systematic review

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ABSTRACT

OBJECTIVE

Electrical impedance tomography (EIT) is a non-invasive and radiation-free monitoring technique. The evaluation of EIT results can guide the effectiveness of different therapies, enabling better decisions, standardized behavior, and optimization in the use of resources. The objective is to characterize the use of electrical impedance tomography in the neonatal and pediatric population.

METHODS

This is a systematic review, in which articles without language restrictions that addressed the applicability of electrical impedance tomography in the neonatal and pediatric population were analyzed. This review followed the PRISMA recommendations (Key Items for Reporting Systematic Reviews and Meta-analysis).

RESULTS

A total of 309 studies were found, of which 302 were excluded according to the eligibility criteria, and 7 were included. All studies investigated the applicability of EIT as an assessment tool for pediatric or neonatal patients. EIT was shown to be effective in evaluating ventilation before extubation, comparing transverse alterations and total lung volume, evaluating the effects of body and head positions on the spatial distribution of ventilation, for potential diagnostic use in pediatric patients with asthma, feasible as a complementary tool in the assessment of community-acquired pneumonia in children, monitoring ventilation and perfusion in newborns and critically ill children, and evaluating recent advances in EIT related to cardiopulmonary imaging.

CONCLUSION

EIT has been shown to be an effective monitoring technique for pediatric and neonatal patients. Future studies are needed to improve clinical practice.

DESCRIPTORS

Electrical impedance tomography, Neonatal, Pediatrics.

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INTRODUCTION

Advances in pediatric and neonatal intensive care over the past 10 years have provided greater patient survival. The reduction in mortality is directly related to the development of technologies to assist and monitor critically ill patients, minimizing systemic injuries and reducing long-term morbidities[1].

In the early 1980s, electrical impedance tomography (EIT) began to be used in healthcare[2]. By the mid-1990s, more than 30 research groups were already actively involved in research with EIT. The first devices, although technologically limited, were used in an exemplary manner in several scientific areas[3]. Unlike conventional radiography or computed tomography, EIT is radiation-free and allows for continuous real-time monitoring of lung function[1]. Understanding respiratory physiology enables understanding of the clinical evolution and prognosis of patients[4].

EIT is a technique that enables cross-sectional images related to the local electrical impedance within an object to be reconstructed from sets of measurements taken on its surface. EIT uses electrical stimulation and measurement on the surface of the body to obtain images of the electrical properties of internal tissues[5].

The main advantage of using EIT is that it is a non-invasive therapy with high temporal resolution, useful for applications in conducting contrasts between tissues, fluids or gases, such as imaging of cancerous tissue, ischemic or functional monitoring of respiration, blood flow, and neural activity[4].

This test is based on differences in electrical properties generated by alterations in air content in small lung regions, creating an impedance relationship between these regions. The pixels generated in the monitor image represent alterations in the percentage of local impedance compared to a reference obtained at the beginning of image acquisition. Therefore, the dynamic image of the thoracic EIT monitor shows the local airflow variation during ventilation in real time. The variation in alveolar ventilation shows color changes in the image generated by the tomograph on a scale that goes from dark blue (lower aeration) to light blue (higher aeration)[6].

In Brazil, the Faculty of Medicine of the University of São Paulo launched Electrical Impedance Tomography (EIT) on December 18, 2008. According to Prof. Dr. Marcelo Britto Passos Amato, responsible for the Experimental Pneumology Laboratory at FMUSP, who coordinated the research for the development of EIT, the main objective of this new technology is to try to reduce the mortality of patients in critical care caused by complications induced by mechanical ventilation itself[7].

The evaluation of EIT results can guide the effectiveness of different therapies, enabling better decisions, standardized approaches, and optimization in the use of resources[8]. In recent years, a growing number of studies have attempted to address the issue of the feasibility and usefulness of EIT as a non-invasive monitoring method in neonates, children, and adults with different respiratory pathologies[9].

Patients in neonatal and pediatric intensive care with a diagnosis of respiratory diseases used EIT to monitor ventilation and pulmonary perfusion during surfactant administration and to adjust ventilatory parameters[10].

EIT has been observed as a reliable method to evaluate alterations in lung volume during and after aspiration of the tracheal tube in neonatal patients, with a sudden and sharp drop in lung volume reflected by the decrease in global impedance[11].

In the adult population, EIT has been used to verify the feasibility of personalized selection of PEEP (positive end-expiratory pressure) based on its effectiveness in stabilizing the increase in end-expiratory lung volume through lung recruitment maneuvers[12].

EIT enables monitoring of the regional distribution of ventilation during Spontaneous Breathing Tests (SBTs) and is suitable for estimating extubation success. In this way, EIT can support clinical approaches in relation to ventilatory weaning[13].

The justification for this work was to demonstrate the importance of EIT for pediatric and neonatal intensive care, being a promising technique to evaluate critically ill patients. This technology allows bedside monitoring, enabling real-time conduct, and avoiding the harmful effects of radiation offered by other monitoring methods. There is great potential for evaluating different pathologies, providing maximum comfort and speed for the patient throughout the examination.

The aim of this study was to characterize the use of electrical impedance tomography in the neonatal and pediatric population, embracing the main difficulties/limitations of the use of electrical impedance tomography in the neonatal/pediatric population and the use of electrical impedance tomography in ventilatory weaning in the neonatal and pediatric population.

METHODS

Source of information:

This is a literature review, where searches were performed in the following databases - LILACS – Bireme (Database of Latin American Literature in Health Sciences), SciELO (Scientific Electronic Library Online), PubMed (maintained by National Library of Medicine), and PEDro (Physiotherapy Evidence Database). Searches were performed according to the Health Sciences Descriptors (Decs) in Portuguese: “Physiotherapy”, “Electrical Impedance Tomography”, “Pediatrics”, “Neonatal”, “Mechanical ventilation”, “Weaning ventilation”.

Protocol and registration:

This review followed the PRISMA recommendations (Key Items for Reporting Systematic Reviews and Meta-analysis) using a checklist and flowchart for systematic reviews and meta-analyses.

Inclusion criteria:

The eligibility criteria included articles in which the authors investigated the approach of electrical impedance tomography and its applicability in the pediatric and neonatal population. For inclusion we considered studies whose authors evaluated: ventilation before extubation through EIT, comparison of transverse alterations and total lung volume through EIT and respiratory induction plethysmography (RIP), evaluation of the effects of head and body positions on the spatial distribution of EIT ventilation, the potential diagnostic use of EIT in pediatric patients with asthma, the viability of EIT as a complementary tool in the assessment of community-acquired pneumonia in children, EIT in monitoring ventilation and perfusion in newborns and critically ill children, and recent advances in EIT related to cardiopulmonary imaging. All original indexed articles were included, regardless of the period of publication, with the following experimental designs; randomized clinical trials, cohort studies, literature reviews, and case studies, without language restrictions.

Exclusion criteria:

Studies were excluded according to the following criteria: dissertations, book chapters, editorials, letters, and expert opinions, as well as those that did not present the subject covered in this review in the title, abstract, or text. Manuscripts that did not specifically report the applicability of EIT in pediatric or neonatal patients were also excluded.

Data collection process:

The articles were selected based on the use of descriptors and identification was carried out in steps: step one: reading the titles of the studies found and excluding those that did not meet any of the inclusion criteria for this study. Step two: reading the abstracts of the studies selected in step one and excluding those that did not meet the inclusion criteria. Step three: full reading of all remaining studies from previous steps and selection of those that meet the inclusion criteria. The articles that met all the inclusion criteria and that made it possible to answer the questions in this review were selected.

Data collected:

For each of the included studies, key characteristics were extracted, such as: author, year of publication, age of participants, sample size, characteristics, and main results related to the use of EIT in pediatric and neonatal patients. For literature reviews, the searched database was also included.

Risk of bias in studies:

Quality assessments were divided between evaluating the study level and the level of outcomes, characterizing the biases of each study. The final score attributed to the quality of the studies was obtained through the sum of designated points and the quality of the articles was categorized as poor, moderate, good, and excellent.

Summary measures:

Any prevalence outcome measure that presented EIT as an assessment method in pediatric and neonatal patients was considered.

Synthesis of results:

To reduce heterogeneity between studies, the results were separated according to the methods for identifying the assessment of EIT in pediatric and neonatal patients, as well as a table created for the literature review studies, respectively: ventilation before extubation through EIT, comparison of transverse alterations and total lung volume through EIT and RIP, evaluation of the effects of body and head positions on the spatial distribution of ventilation through EIT, potential diagnostic use of EIT in pediatric patients with asthma, feasibility of EIT as a complementary tool in the assessment of community-acquired pneumonia in children, evaluating EIT in monitoring ventilation and perfusion in newborns and critically ill children, and evaluating recent advances in EIT related to cardiopulmonary imaging.

Risk of bias between studies:

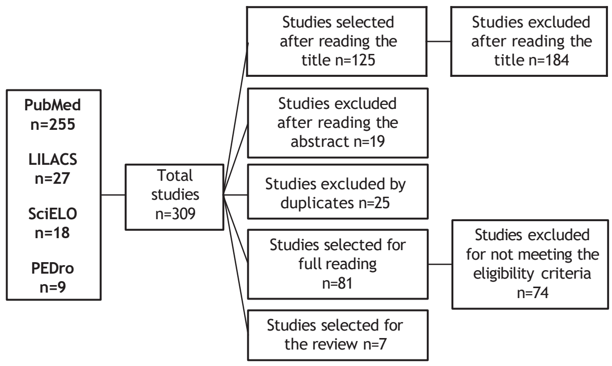
The divergence between the studies was evaluated by comparing the characteristics of the studies and the results obtained.

RESULTS

Selection of studies:

A total of 309 studies were found; 255 studies in PubMed, 27 in LILACS, 18 in SciELO, and 9 in PEDro. According to the inclusion criteria, in step one, 184 studies were excluded after reading the title, then in step two, 19 articles were excluded after reading the abstract, and 25 for being duplicates. In step three, 81 studies were selected for full reading, 74 of which were excluded for not meeting the eligibility criteria. Only 7 articles were included in the synthesis. The flowchart describing the study selection process is shown in Figure 1.

Figure 1. Flowchart of the number of articles found after applying the inclusion and exclusion criteria.



Characteristics of the studies:

Of the 7 selected studies, one is from Brazil[14], one from Holland [15], three from Germany [16,17,20], one from Milan [18], and one from Poland [19] (Tables 1 and 2).

The sample sizes varied between 10[16] and 116[17] participants, with ages ranging from 28.1 gestational weeks[14] to 15 years[18] (Table 1). The sample size of the review studies varied between 25[19] and 102[20] studies (Table 2).

Regarding the databases found in the review studies, two studies used PubMed[19,20], one used Google Scholar[19], and one study used the US National Library of Medicine and National Institutes of Health[20] (Table 2).

All studies used EIT as a tool for the respiratory assessment of pediatric or neonatal patients, one study evaluated ventilation before extubation in PTNB by EIT PTNB[14], one study compared EIT with respiratory induction plethysmography (RIP) to evaluate alterations in end-expiratory lung volume[15], one study evaluated the effects of body and head positions on spontaneous breathing and mechanically ventilated infants using EIT[16], one study compared EIT and spirometry in children[17], and one study compared EIT images with chest radiography in children with community-acquired pneumonia[18] (Table 1).

Of the review articles, one study viewed the EIT as a tool for monitoring the distribution of ventilation in healthy individuals and in critically ill newborns and children[19] and one study looked at advances in EIT related to cardiopulmonary imaging[20] (Table 2). Regarding the quality assessment, three studies were classified as good[14,18,20], two studies as moderate[16,17], and two studies as weak[15,19] (Tables 1 and 2). No study was rated as excellent.

Table 1. Variables analyzed in the selected studies.

YEAR	AUTHOR	COUNTRY	SAMPLE (N)	AGE	CHARACTERISTICS	RESULTS	EVALUATION OF QUALITY
2006	Heinrich, S et al.	Germany	10 PTNB and 10 term babies	38 weeks to 58 days of life	Evaluation of different decubitus and head positions with EIT in PTNB and at term in spontaneous breathing and MV.	In spontaneous breathing: decrease in left lung tidal volumes in supine posture with head turned to the left and prone posture. MV: prone posture combined with head rotation to the left reduced tidal volume.	MODERATE
2013	Rossi FS et al.	Brazil	14 PTNB	28.1 weeks	EIT before extubation in PTNB	Use of EIT to determine the PEEP level associated with better ventilation. Extubation failure was observed in 21.4% of PTNB.	GOOD
2014	Van der Burg et al.	Hollanda	15 PTNB	28.0 weeks	Compare transverse and total lung volume alterations using EIT and RIP	End-expiratory lung volumes measured by EIT were statistically significant with RIP measurements.	WEAK
2018	Chuong et al.	Germany	116 children	11.86 ± 3.13 years	Investigate the potential diagnostic use of EIT compared to spirometry in pediatric patients with asthma.	Spirometry and EIT-based FV global loops showed a strong correlation. A typical concave shape of the EIT derivative demonstrated mean FV loops for asthmatic children with improvement after bronchodilation.	MODERATE
2017	Mazzoni et al.	Italy	19 children	2 to 15 years	Feasibility of EIT and chest radiography in the assessment of community-acquired pneumonia in children.	A significant agreement was observed between EIT and chest radiography in the identification of pulmonary alterations; Improvement in ventilation was documented at the three-month follow-up, with complete recovery within six months.	GOOD

Legend: EIT= Electrical impedance tomography; PTNB= preterm newborn; MV: Mechanical ventilation; PEEP= Positive end-expiratory pressure; RIP= Respiratory induction plethysmography; FV= Mean Flow Volume Loops

Table 2. Variables analyzed in literature review studies.

ANO	AUTOR	DATA BASE	SAMPLE	CHARACTERISTICS	RESULTS	EVALUATION OF QUALITY
2013	Durlak et al.	Google Scholar and Pubmed	25 articles	Comparison of pulmonary ventilation in critically ill newborns and children.	EIT is a promising tool to monitor the regional distribution of ventilation for long periods.	POOR
2014	Frerichs I et al.	PubMed, US National Library of Medicine and National Institutes of Health	102 articles	Recent advances in EIT related to cardiopulmonary imaging and monitoring in the context of the 30 years of development of this technology.	EIT was effective in observing regional tidal volumes and end expiratory volumes.	GOOD

Legend: EIT= Electrical impedance tomography.

DISCUSSION

Rossi FS et, al[14], carried out a study with the objective of evaluating 14 patients diagnosed with bronchopulmonary dysplasia using the ideal PEEP through EIT to provide homogeneous pulmonary ventilation (HV) before tracheal extubation in PTNB. Three patients evolved with extubation failure, one with central apnea, and two with respiratory distress. The variability in the HV index during spontaneous breathing was a characteristic observed in all patients studied. This study demonstrates that EIT can be used safely and successfully in patients with indication for tracheal extubation, suggesting that better ventilatory homogeneity is influenced by the level of PEEP applied. In accordance with these data, Zhao et al,[22] evaluated the feasibility of PEEP titration guided by ventilation homogeneity using the global inhomogeneity index (GI) through EIT. The authors demonstrate that the EIT GI quantified the distribution of tidal volume in the lung and showed good reliability and comparability between patients. Alveolar recruitment with lower alveolar distension pressure would lead to more homogeneous pulmonary ventilation[22].

The work performed by Van der Burg et al.[15] compared transverse alterations and total lung volume using EIT and RIP in 15 PTNB. The observed correlation between the data from the two methods demonstrates that the volume of changes measured in the cross slice by EIT are indeed representative of the entire lung. RIP was less stable in measuring changes in end-expiratory lung volume (EELV) than in EIT[15]. In line with previous reports, pressure-volume relationships based on EELV alterations verified by EIT and RIP showed clear hysteresis in almost all patients, and more importantly, these volume alterations between EIT and RIP were highly correlated[23,24].

Heinrich, S et al.[16] used EIT to assess the effects of body and head positions on the spatial distribution of ventilation in 10 premature newborns and 10 full-term newborns in spontaneous breathing and mechanical ventilation (MV). EIT showed reduced left lung tidal volumes in the supine position with the head turned to the left in spontaneously breathing patients. In patients on MV, the tidal volumes of the left lung were not altered by the position of the body and head, except for the prone posture combined with the head rotation to the left, which showed a reduction in these volumes[16]. Baird et al.[25] used simple transthoracic electrical impedance to determine the amplitudes of respiration of the impedance signal in the supine and prone postures. This technique uses the same measurement principle as EIT, without providing any spatial information. Significantly lower respiratory amplitudes of the transthoracic electrical impedance were found in the prone posture compared to the supine[25].

Chuong el al.[17] investigated the potential diagnostic use of EIT in pediatric patients with asthma. EIT and spirometry were performed in 58 children with asthma and 58 healthy patients. Mean flow volume (FV) loops were generated for patients with pathological spirometry to demonstrate the feasibility of EIT for graphic diagnosis of asthma. EIT has shown high potential for pulmonary function testing for pediatric patients. Global flow-volume loops obtained by EIT correlate with spirometric findings in asthmatic children and in controls with healthy lungs[17]. Vogt B et al.[26] demonstrated, through EIT, regional lung function in healthy children and children with asthma before and after exercise. EIT was able to detect regional differences in lung function between healthy children and children with asthma during forced expiration[26].

Mazzoni et al.[18] noted the feasibility of EIT as a complementary tool in the assessment of community-acquired pneumonia (CAP) in 19 children. Chest radiography and EIT images were compared to assess the correspondence of the two techniques in detecting disturbances in the distribution of ventilation between the right and left lungs. EIT showed hypoventilation in one of the right quadrants in 14 patients who had clinical and radiological signs of right pneumonia. The first examination revealed hypoventilation in one of the left quadrants in 3 of 5 patients who had clinical and radiological findings of left pneumonia. EIT measurements at 3-month follow-up showed partial improvement in ventilation compared to baseline, but functional recovery assessed by the EIT technique was complete only at the 6-month follow-up[18]. In a similar study[27] EIT was used as a means of monitoring ventilation distribution and alveolar inflammation at the bedside in patients with community-acquired pneumonia. EIT was compared with admission chest radiography and used to assess whether inhomogeneous ventilation changed due to treatment. Although the EIT images showed a more homogeneous ventilation distribution, EIT was demonstrated to be an adequate complementary tool to monitor the functional status of the lung in patients with CAP[27].

Durlak et al.[19] used EIT to monitor regional ventilation in critically ill newborns and children. The results demonstrate that the accurate quantification of absolute impedance values is challenging and must take into account many factors, including specific information about the shape of the NB's chest. There is variability in regional ventilation as a function of body position and breathing pattern in a small group of healthy newborns, in addition to irregular breathing patterns in all monitored patients[19]. Another study[21] suggests that EIT may be beneficial to intensive care patients for monitoring regional pulmonary ventilation during surfactant administration, which could decrease the prevalence of complications associated with volutrauma. Adjustments to ventilation settings can be guided by alterations in the impedance signal and monitoring changes in the distribution of ventilation related to severity[21].

Frerichs et al.[20] evaluated the advances in EIT related to cardiopulmonary imaging. Few studies have been performed with the aim of studying the ability of the EIT to assess perfusion. The work investigated different solutions that can be used as contrast agents to determine regional indicator dilution curves, an approach that has previously been validated in two other studies[28,29]. Children with ventricular septal defect and left-right shunt were studied before and after surgical correction. EIT detected redistribution of pulmonary perfusion after surgical correction[30].

These studies show the potential of EIT to help optimize ventilatory support at the individual level and achieve homogeneous ventilation. Although EIT demonstrates great potential, there are still some scientific, technical, and practical issues that need to be addressed.

Limitations

Monitoring ventilation distribution in pediatric and neonatal patients is a challenge, especially at the bedside. Currently available monitoring tools such as chest radiography or inductive respiratory plethysmography present some limitations[15,18].

A major issue reported in the studies is software issues. These observations indicate that the EIT hardware and software need to be optimized[15,17,20]. The results of most studies are based on offline EIT data analysis. Software that allows continuous online analysis of EIT data is being developed[15].

There is still a lack of easy-to-apply equipment, especially in children born prematurely. Feasibility of electrode placement is necessary for successful implementation in clinical practice. These improvements will also allow the use of EIT for longer periods than currently adopted in most observational studies[16,19,20].

There are several issues that need to be studied in depth, such as cancer tissue imaging studies, ischemic monitoring, blood flow monitoring, and neural activity. More relevant EIT measures for clinical decision-making aimed at the pediatric and neonatal population are needed, as there is a limited number of clinical trials. Technical training of the multidisciplinary team is also necessary since this factor could increase the applicability of EIT.

CONCLUSION

The findings of this review demonstrated that EIT proved to be effective for the assessment of pediatric and neonatal patients, in isolation and when compared to other monitoring techniques, such as chest radiography and respiratory induction plethysmography. Despite significant limitations, such as software and hardware problems related to images, equipment that is difficult to apply, especially in preterm newborns, the limited number of clinical trials, and the need for more training of the multidisciplinary team, EIT represents a milestone for advances in bedside monitoring technology in a practical way in critically ill patients. Randomized clinical trials are needed to further evaluate and improve the applicability and advantages of EIT in the pediatric and neonatal population.

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