REVIEW ARTICLE

Electrical Impedance Tomography: a new study method for neonatal Respiratory Distress Syndrome?

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Abstract
Treatment of cardiorespiratory system diseases is a procedure that usually demands data collection on terms of the anatomy and the operation of the organs that are under study. Electrical Impedance Tomography (EIT) is an alternative approach, in comparison to existing techniques. With EIT electrodes are placed in the perimeter of the human body and images of the estimated organ are reconstructed, using the measurement of its impendence (or resistance) distribution and determining its alteration through time, while at the same time the patient is not exposed to ionizing radiation. Its clinical use presupposes the correct placement of the electrodes over the perimeter of the human body, the rapid data collection and electrical safety. It is a low cost technique and it is implemented near the patient. It is able to determine the distribution of ventilation, blood supply, diffused or localized lung defects, but it can also estimate therapeutic interventions or alteration to assisted ventilation of the neonate. EIT was developed at the beginning of the 1980s, but it has only recently begun to be implemented on neonates, and especially in the study of their respiratory system function. The low rate of image analysis is considered to be a drawback, but it is offset by the potential offered for the estimation of lungs' function (both under normal and pathological conditions), since ventilation and resistance are two quite similar concepts. In this review the most important studies about EIT are mentioned as a method of estimating respiratory distress syndrome in neonates. In terms of the above mentioned development, it is supposed that this technique will offer a great amount of help to the doctor in his / her estimations of the cardiorespiratory system and to his / her selection of the best intervening strategies. Hippokratia 2011; 15 (3): 211-215

Key Words: electrical impedance tomography, respiratory distress syndrome, neonates, review

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Neonatal Respiratory Distress Syndrome (RDS), a disease that primarily affects premature infants, is due to surfactant deficiency resulting in increased surface tension and atelectasis[1]. RDS affects approximately 80% of infants less than 28 weeks and is reduced with increased gestational age[2]. Clinical RDS presents with respiratory distress (cyanosis, grunting, retractions, tachypnea) and the diagnosis is confirmed by blood gas analysis and chest X-ray. Its natural course commences at or after birth and increases in severity over the first 2 days of life and, if it is left untreated, death can occur from progressive hypoxia or respiratory failure. Surfactant administration by stabilizing and recruiting the collapsed unventilated units of neonatal lungs with RDS plays a key role in its treatment. As a result it improves oxygenation and increases lung compliance[3]. Until recently RDS was thought to be a homogeneous disease, affecting both lungs. Poor response to the surfactant is -among other reasons- related to its non-uniform distribution into the lungs[4].

After Brown and Barber had developed Electrical Impedance Tomography (EIT) in the mid 80's (at the Dept. of Medical Physics and Clinical Engineering, in Sheffield, UK) a large number of researchers have been working in this field[5-7]. By placing electrodes at the perimeter of the thorax and by injecting a high frequency alternating current in two of them, it is possible to measure voltage differences between the remaining. The obtained data can be used to calculate the electrical impedance of the tissues in the cross section under study, leading to the reconstruction of two dimensional images. EIT calculates the distribution of impedance (or resistance) of tissues over time, without exposing them to ionizing radiation, and, thus, estimates function of organs and obtains morphological information (image reconstruction)[8]. Since biological tissues exhibit different values of impedance, EIT measures these differences. EIT has been used under in vivo conditions mainly for the assessment of the cardiopulmonary and the digestive system[9].

In order to apply EIT as a clinical system, it is needed to have all the electrodes stable and well connected to the body surface, the data rapidly acquired and to comply with safety standards[10]. Since EIT was introduced, several articles have been published, mostly for adults[7,11-16]. Assessment of lung function in neonates with RDS seems to have come under investigation only recently, with a limited number of articles published. This article is a review of EIT application on neonates with RDS, so that it could provide the neonatologist with an alternative approach to the **diagnosis** and **management** of RDS.

Electrical Impedance Tomography

Methological aspects of EIT

EIT is a promising method, since it is not intervening, not competitive to other well known techniques that study the respiratory system[17]. Regional ventilation depends on body and head position, lung pathology (lateral or bilateral) and ventilator pattern (spontaneous or mechanically supported breaths). Acid base status, oxymetry, transcutaneous CO_2, graphics, lung mechanics (minute volume, tidal volume, compliance, resistance etc.) provide only global information for lung function[17]. For the time being there isn't any monitoring/diagnostic method beside the neonate that could estimate regional ventilation, blood perfusion, lung tissue pathology and the effectiveness of interventions in assisted ventilation. Computerized Tomography and scanning could achieve this goal but not at the bedside. Lungs have high resistivity compared to other tissues, because of high air content[18]. Impedance changes are linearly related to air volume and consequently lung volume changes[16,19-21]. EIT can assess lung function and identify changes in regional ventilation in a mechanically supported neonate (Assisted Ventilation, Continous Positive Airway Pressure) or after certain therapeutic interventions, i.e. after surfactant administration[22,23].

Technical aspects[24]

EIT by using high-frequency, low-amplitude electrical current between pairs of electrodes, measures electrical potentials between the rest of electrodes. Rapid collection of data produces EIT scans by detecting relative changes in local electrical impedance with respect to a local reference impedance value. The latter is derived from the average impedance values in each pixel from the same subject. Simple scans generate functional snapshots, which show the pixel values of the ventilation related (end-inspiratory to end-expiratory) amplitude of relative impedance averaged over a number of breaths.

Best image reconstruction is achieved using the back-projection algorithm. The image result related to a "reference state" is dynamic or static. Dynamic images are more advantageous than static, because of their better analysis[9]. Because air is of high resistivity, electrical conductance decreases with inspiration and increases with expiration. These cyclic changes of conductance, along with novel methods of data analysis, resulted in the development of functional EIT. A functional EIT image is derived from dynamic or static EIT images.

Over the past two decades, a significant effort was put on evolving EIT equipment, so that data could be easily and safely collected from human body tissues. One of the main uses of EIT systems is to monitor regional ventilation[25-27] and fluid changes. The research group at the University of Sheffield have built several EIT systems (Mark 1, 2, 3, 3a, 3b and 3.5) either as single-frequency (SF) or multi-frequency (MF) (for the injected electric current) devices, with two of them commercially available. The Mk3a EIT system using sixteen electrodes and its successor EIT Mark 3.5 using eight electrodes were developed also for neonates[28]. The Sheffield Mk3 EIT system measures impedance at eight frequencies (between 9.6 kHz and 1.2 MHz) while Mk3.5 EIT system at 30 frequencies (between 2 and 1.6 MHz) (Figure.1). Placing 16 electrodes around the thorax of a neonate presented ergonomic problems and this was dealt with by its successor EIT Mark 3.5. However, the fact that fewer electrodes were used resulted into a poorer image resolution. In general, development of EIT devices did not lead to a satisfactory level of image detail, although multi-frequency systems offer a better functional surveillance of tissues[29-31]. Electrode contact to the skin is assessed by the "reciprocity value", which is calculated from the values of impedances determined between electrodes before and after reversal of current application and voltage measurement. GoeMF II EIT system, another multi-frequency device was developed in the University of Gottingen (scans acquired at a rate of 13-44Hz).

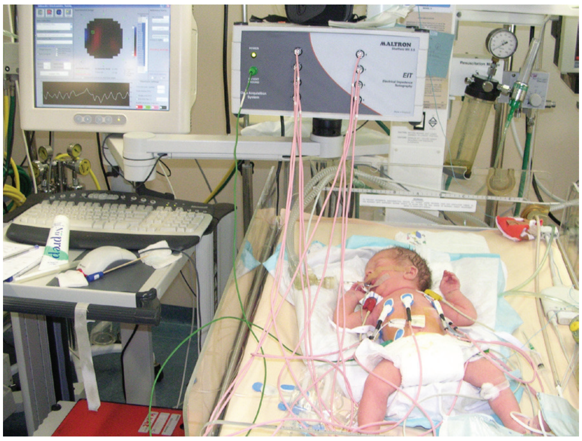

Figure 1: Data collected by Maltron Sheffield Mk 3.5 EIT system in mechanically ventilated infant with RDS.

Clinical pulmonary applications

Studies with EIT published in mid 1980's by Harris proved the linear relationship between the measured impedance change and lung volume change confirmed by many researchers in experimental and human models. Harris also showed the first image with lung pathology and the ability of EIT to detect differences in regional lung ventilation between left and right lung according to body position[32]. Holder and Temple using EIT in subjects with and without lung pathology concluded that EIT is appropriate for intra-individual and not inter-individual monitoring. Another major finding was the inability of EIT to compare sufficiently with techniques like radiography or computed tomography because of low image resolution even on extensive lung pathology[33]. Hahn et al. and Adler et al. showed that EIT could detect fluid accumulation up to 10 ml into the lungs[34,35]. Adler et al. found a high correlation between lung expansion - and not only lung volume - to impedance change[36].

The gravity dependent variation in the distribution of ventilation with the body position (supine, prone, left and right lateral position) was studied by Frerichs et al[37]. EIT showed shift of ventilation in the non-dependent areas in neonates breathing under assisted ventilation, contrary to spontaneous breathing[38]. Clinical studies with neonates under assisted ventilation, detecting changes in regional lung ventilation were also conducted. EIT could separate the effect in ventilation of mechanically supported breaths in relation to spontaneous breaths during assisted ventilation, like no other technique does[17].

Mainly single frequency EIT devices were used in clinical and experimental studies. Multi-frequency EIT measurements have a high degree of reproducibility, which gives them the advantage of repeatability. On the contrary, image reconstruction although feasible is of low resolution, because of the small number of electrodes used.

Applications of EIT at neonates with RDS

Effects of surfactant administration on regional lung ventilation

Gravity affects ventilation and, consequently, postural changes distribute differently regional lung volume. These effects are identified by EIT in the mechanically and spontaneously breathing neonate. Differences in lung ventilation between upper non dependent from lower dependent areas of the lungs can be detected by EIT[19].

This ability of EIT[19,23,39-42] to detect local alteration in regional lung ventilation and volume has been validated with computed tomography, ventilation scintingraphy, staining techniques and nitrogen-washout test[38,39,42,43]. EIT provides information about ventilation inhomogeneity of lungs through time during respiration[20,44]. EIT is the only non-invasive bedside method of demonstrating differences of regional ventilation between nondependent and dependent areas relating to body position, ventilatory pattern (spontaneous breathing/ assisted ventilation), lung pathology and surfactant administration (figure.2) [27,44-46].

Surfactant instillation after recruitment maneuver (by modification of positive end-expiratory pressure) in piglets when additional recruitment maneuver was performed, a significant shift in ventilation toward the dependent lung regions with less asymmetry in the right- to left lung ventilation distribution took place. Comparing surfactant administration with or without disconnecting the endotracheal tube resulted in no differences in distribution of ventilation[47]. In general instillation of surfactant leads to a more homogenous distribution of ventilation through the lung after recruitment of collapsed alveoli[48].

Monitoring RDS

Optimal lung strategy for ventilator therapy is simultaneously a lung protective strategy. Therefore, optimal lung strategy before and after surfactant administration is of extremely importance for the intensivist.

RDS usually affects both lungs mainly homogeneously. Many other pathological processes like pneumonia, atelectasis, pulmonary interstitial emphysema affect lung parenchyma in certain regions. Non- uniform administration of surfactant leads to poor clinical response and also to different degree of ventilation of both lungs with areas hypoventilated, hyperventilated and normally ventilated. This could lead to atelectasis or volutrauma and implications in a neonate with RDS under assisted ventilation. EIT is useful in detecting these differences in regional ventilation[20].

EIT detecting regional lung ventilation changes after surfactant administration could help the neonatologist to adjust ventilatory variables accordingly. Frerichs et al. performed measurements with the EIT system Mk1 and generated images of neonates with RDS after surfactant administration. EIT detected and showed the redistribution of lung ventilation and the variation of regional ventilation of both lungs during modifications in ventilator variables and body position[20]. EIT demonstrated the distribution of air in the lungs by the shift of the centre of ventilation between right –left lung and ventral (non-dependent)/dorsal (dependent) with respect to body position (supine/prone)[20]. The distribution differed when the neonate was breathing either spontaneously or ventilator-

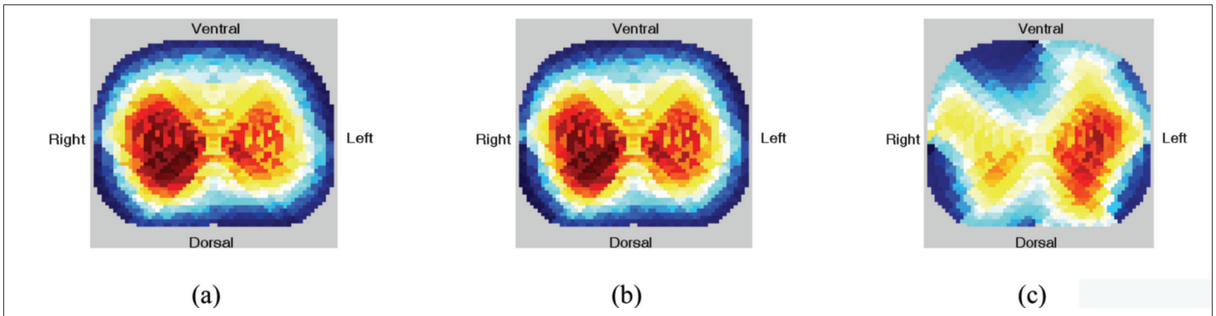

Figure 2: EIT images of the chest of a neonate with RDS (a) before, and (b) fifteen minutes after the instillation of the surfactant. The values are normalized to maximum resistance. Hot colours signify high resistance, i.e. better ventilation. Figure (c) shows the difference between figures (b) and (a); it is clear that the left lung ventilation was improved more than right lung ventilation after surfactant administration .The data for the reconstruction were obtained with the Maltron Sheffield Mk 3.5 EIT system, which uses eight electrodes.

assisted. So, EIT is capable of assessing spatial lung inhomogeneties in lung ventilation in a neonate with RDS under assisted ventilation that no other established technique can do.

EIT also detects changes in regional ventilation induced by various levels of PEEP as it has been shown under experimental and clinical studies[9]. Effects of PEEP on mode of ventilation determined and showed that EIT can **disclose mechanical from** spontaneous ventilation, an apparently useful tool in the process of weaning patients from mechanical ventilation[9]. In neonates with RDS additional information by EIT after recruitment of collapsed alveoli in non-dependent areas could lead to faster adaptation in assisted ventilation. By appropriate decreasing PEEP, overstretching and volutrauma could be avoided[49].

Conclusions

EIT is a cheap, non-invasive, bedside, radiation-free method, which requires no cooperation from the patient. It can be used for intra-individual and not inter-individual quantitative monitoring of regional ventilation, redistribution of lung ventilation, lung volume alterations and fluid accumulation. Its main disadvantages are ergonomic problems with the electrodes placement around the thorax of neonates' and the poor (comparative to other techniques) image resolution. Obtaining additional information by EIT could guide the intensivist to a more optimal strategy in the management of Respiratory Distress Syndrome (RDS). Likewise this could reduce pulmonary leak events, shortage of exposure to high fractions of oxygen and finally to time length in assisted ventilation[25].

It seems probable that EIT could become a useful bedside monitoring as well as diagnostic method for neonates with RDS in addition to the currently used practice.

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