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Electrical impedance tomography in adult patients undergoing mechanical ventilation: A systematic review☆

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ABSTRACT

Purpose: The purpose of the study is to systematically review and summarize current literature concerning the validation and application of electrical impedance tomography (EIT) in mechanically ventilated adult patients.
Materials and methods: An electronic search of MEDLINE, EMBASE, CINAHL, Cochrane Central Register of Controlled Trials, and the Web of Science was performed up to June 2014. Studies investigating the use of EIT in an adult human patient population treated with mechanical ventilation (MV) were included. Data extracted included study objectives, EIT details, interventions, MV protocol, validation and comparators, population characteristics, and key findings.
Results: Of the 67 included studies, 35 had the primary objective of validating EIT measures including regional ventilation distribution, lung volume, regional respiratory mechanics, and nonventilatory parameters. Thirty-two studies had the primary objective of applying EIT to monitor the response to therapeutic MV interventions including change in ventilation mode, patient repositioning, endotracheal suctioning, recruitment maneuvers, and change in positive end-expiratory pressure.
Conclusions: In adult patients, EIT has been successfully validated for assessing ventilation distribution, measuring changes in lung volume, studying regional respiratory mechanics, and investigating nonventilatory parameters. Electrical impedance tomography has also been demonstrated to be useful in monitoring regional respiratory system changes during MV interventions, although existing literature lacks clinical outcome evidence.

1. Introduction

Electrical impedance tomography (EIT) is a noninvasive and radiation-free imaging modality that can be used in real time at the bedside [1]. It has been used to monitor changes in lung volume, ventilation distribution, and regional respiratory mechanics during mechanical ventilation (MV) [2]. Computed tomography (CT), the current criterion standard for imaging regional thoracic aeration and pathology, is limited by its intermittent use, machine size, and necessity to move the patient and expose them to radiation. Electrical impedance tomography is not subject to these limitations. Although CT outperforms EIT in terms of spatial resolution, EIT offers substantially better temporal resolution making it more practical for bedside monitoring. Indeed, one of the most promising potential applications of EIT is in dynamic lung imaging during MV for the purpose of optimizing ventilator settings [1].

The potential for injury to the lung from MV has been studied extensively [3]. Especially in the context of acute respiratory distress syndrome (ARDS), ventilator-induced lung injury (VILI) contributes to the morbidity and mortality of patients undergoing MV [4]. Lung-protective ventilation strategies—a central component of supportive care in these patients—require the use of low tidal volume with high positive end-expiratory pressure (PEEP) to prevent VILI while maintaining adequate gas exchange [4]. During EIT monitoring, impedance data from a transverse section of the thorax can be used to obtain information on global and regional lung aeration and ventilation because change in regional air content is linearly related to change in thoracic impedance [5–7]. Thus, EIT can monitor regional ventilation and respiratory mechanics throughout the lung regions. This real-time bedside monitoring technique may provide a means to optimize lung-protective ventilation in individual patients by identifying the ventilator settings that result in improved parameters of regional ventilation and respiratory mechanics.

To date, most research surrounding the use of EIT in monitoring respiratory function during MV has been conducted in animal models and pediatric patients. Several reviews have examined this literature to provide an update on the status of EIT in lung imaging [1,8–11]. However,

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no review has focused on synthesizing the existing literature specifically in adult patients undergoing MV. We therefore conducted a comprehensive systematic review to summarize the published literature on techniques for EIT monitoring and validated EIT-based physiological measurements in adult humans treated with MV.

2. Materials and methods

2.1. Data sources

We conducted electronic searches of MEDLINE, EMBASE, CINAHL, Cochrane Central Register of Controlled Trials, and the Web of Science. Databases were searched from inception to June 2014. Search strategies were developed for each database and are presented in the Supplementary Material. Bibliographies of relevant reviews and included articles were additionally searched. Conference proceedings from the American Thoracic Society, European Society of Intensive Care Medicine, International Society of Intensive Care and Emergency Medicine, and Critical Care Medicine were searched between 2009 and 2014.

2.2. Eligibility criteria

We included all English-language studies using EIT on adult patients older than 18 years treated with MV. We included published conference abstracts. We excluded case reports, reviews, and studies focused on neonatal/pediatric populations (ie, age <18 years).

2.3. Study selection

Study titles and abstracts were independently screened for eligibility by 2 reviewers (JK and AM); differences were resolved by consensus and discussion with coauthors (EF and EG). We retrieved full texts of potentially eligible articles. Data from full-text articles were preferred over conference abstracts in situations of duplicate reports; however, when full-text articles could not be accessed, corresponding conference abstracts were included.

2.4. Data extraction

Data from included studies were collected independently by2 reviewers (JK and AM) using a data abstraction form. Items included the following: (1) study details—author, publication year, design, and objectives; (2) EIT details—purpose of use, measures, and technical characteristics; (3) intervention details—validation and comparator (where applicable), intervention type (where applicable), and MV protocol; (4) population details—sample size, indication for MV, and demographics; and (5) key findings.

2.5. Quality assessment

The main goal of this review was to qualitatively summarize the existing data on EIT in adult MV patients rather than perform a quantitative synthesis (ie, meta-analysis). Therefore, given the challenges of assessing methodological quality for observational studies [12], quality assessment was not performed for observational studies. However, randomized trials were assessed for risk of bias based on allocation sequence generation, allocation concealment, blinding of personnel, blinding of outcome assessment, completeness of data, and selective reporting.

3. Results

After removing duplicates, a total of 559 articles were identified (Fig. 1). Title and abstract review led to the exclusion of 361 articles. Twenty-eight additional abstracts were identified by hand-searching conference proceedings and bibliographies. Full-text articles were retrieved for 222 studies; we were unable to access 4 articles using available institutional resources, the abstracts of which have been included within the Supplementary Material. Of these 222 articles, 86 met our inclusion criteria. Nineteen conference abstracts were excluded because the same data were presented in subsequent full-text publications. All 67 included studies (21 abstracts, 46 full-text publications) used EIT to monitor adult humans undergoing MV (Table 1 and Table 2). Overall, the 11 included randomized trials had poor methodological quality (Table 3).

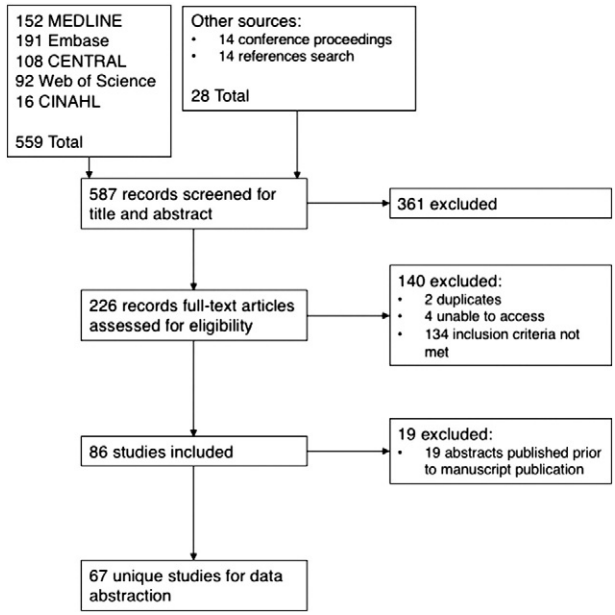

Fig. 1. Flowchart illustrating literature search and exclusion process.

Thirty-five studies were conducted to validate EIT-based measurements. One study validated EIT against dynamic CT [7]. Six evaluated EIT-measured lung volume changes, using nitrogen washout [13,14], oxygen washout [15], helium dilution [16,17], and spirometric techniques [18] for comparison. Thirteen studies validated the use of EIT in quantifying a wide variety of regional respiratory mechanics measures, such as global and regional pressure-volume (PV) curves [19], inhomogeneity [20–22], potentially recruitable lung volume [23], regional intratidal ventilation distribution [24], regional opening and closing pressures [25,26], regional compliance [27], regional filling characteristics [28], regional lung density [29], regional filling dynamics [30], and collapse and hyperdistension [31]; 5 of these parameters were successfully validated against comparators [19,21,26,27,31]. Four studies validated EIT for the monitoring of nonventilatory parameters, including regional oxygen uptake [32], pulmonary perfusion [33], extravascular lung water [34], and correct endotracheal tube placement [35]. Eight studies were identified in which components of EIT data processing methodology were developed and validated, including image reconstruction [36,37], functional tomogram production [38–40], and region of interest (ROI) selection [41–43]. Studies were also conducted to assess interference of critical care equipment [44] and disease processes [45] with EIT data. One study validated EIT-selected ventilator pressure settings against clinical protocol [46]. Based on these studies, EIT can be used as a valid measure of regional ventilation and changes in lung volume. Preliminary investigation of other parameters in humans has also been performed.

Thirty-two studies were designed to assess the effect of various ventilator strategies and maneuvers. Eight studies evaluated the effect of changing ventilation mode on several EIT parameters [47–54]. One study assessed the effect of changing patient position on regional ventilation distribution [55]. One study evaluated whether using EIT to guide ventilation altered the ventilatory strategy [56]. Three studies measured