Randomized Clinical Study of Electrical Impedance Tomography-guided Chest Physiotherapy in Difficult-to-Wean Patients: Study Protocol

Hao Wang1,Jianing Xi1,Hongying Jiang2*
1. Beijing Rehabilitation Hospital, Capital Medical University, China
2. Department of Pulmonary and Critical Care Medicine, Beijing Rehabilitation Hospital, Capital Medical University, China

* Corresponding authors
Dr. Hongying Jiang, Department of Pulmonary and Critical Care Medicine, Beijing Rehabilitation Hospital, Capital Medical University, Xixiazhuang, Badachu Road, Shijingshan District, Beijing 100144, China
Email address: bjkfdr@163.com

Abstract

Background: Diaphragm dysfunction and inadequate chest wall and respiratory muscle function are common in critically ill patients who face difficulties in weaning from mechanical ventilation (MV). This can lead to secretion retention and impaired airway clearance. Chest physiotherapy (CPT) in these patients can help reduce secretion retention. This study protocol outlines an investigation into the feasibility and effectiveness of CPT guided by electrical impedance tomography (EIT) in Difficult-to-Wean patients.

Methods: This single-center, single-blind, randomized pilot study employed a parallel-group design. Participants were randomly assigned to either an intervention group receiving EIT-guided CPT or a control group receiving only conventional rehabilitation. Interventions, lasting 20 minutes each, were administered up to twice daily from ICU admission until discharge.

Results: Primary outcomes included peak expiratory flow, 30-day weaning success rate, maximum inspiratory pressure, diaphragm thickening rate, diaphragmatic excursion, ICU stay duration, and days from baseline to MV removal or Day 30. Adverse events were documented.

Conclusion: This study aimed to assess the feasibility and effectiveness of EIT-guided CPT versus conventional CPT in Difficult-to-Wean patients. If successful, this approach could enhance ICU rehabilitation methods.

Trial registration: This study prospectively registered at the National Library of Medicine (https://clinicaltrials.gov/; Reference: NCT06677099；Date of registration: 5th November 2024)

Commented [az1]: On (outcomes???)

Commented [az2]: Where is the gap/need for study??

Commented [az3]: Use the future tense instead.

Commented [az4]: In form of what???

Commented [az5]: Apply results,discussion, concl to hypothesis

Commented [az6]: In methods

Commented [az7]: Future
Apply for all

Commented [az8]: repeated

Commented [az9]: how?

Commented [az10]: space

Introduction

Mechanical ventilation (MV) is a critical life-support technique widely used in ICU settings,

with 20–40% of patients requiring it daily. Despite its benefits, MV is associated with risks like ventilator-induced lung injury and pulmonary infection[1]. Patients who struggle to wean from MV often experience diaphragm dysfunction and weakened chest wall and respiratory muscles, resulting in small tidal volumes and ineffective coughing[2,3]. These issues increase the risk of retained airway secretions, which can lead to atelectasis and lower respiratory tract infections (LRTIs). Preventing or reversing these complications could reduce MV duration, mortality, and overall inpatient costs for difficult-to-wean patients[4].

Airway clearance is essential for patients in long-term care, as it promotes mucociliary clearance, optimizes gas exchange, and reduces infections caused by mucostasis, ultimately enhancing quality of life[5]. This clearance is achieved by mechanically or manually removing mucus from the airways through chest percussion.

Previous research has demonstrated that chest physiotherapy (CPT) including methods like postural drainage, percussion, vibration, and mechanical airway clearance—benefits critically ill patients by promoting lung recruitment, increasing lung volume and expiratory flow, and helping prevent and manage ventilator-associated pneumonia[6]. However, a significant limitation of current CPT practices is the lack of individualized treatment plans.

Electrical impedance tomography (EIT) is an innovative, radiation-free imaging technology that enables bedside monitoring of ventilation and perfusion[7]. In clinical practice, EIT is primarily used to assess patients' ventilation/perfusion status[8] and to evaluate treatment effectiveness[9]. Recent studies have explored EIT-guided ventilation strategies[10,11] and used EIT to observe ventilation changes due to physiotherapy interventions[12,13]. However, to date, no studies have investigated the feasibility of using EIT to directly guide CPT.

This study aims to evaluate the feasibility and effectiveness of EIT-guided CPT for Difficult-to-Wean patients.

Commented [az11]: ref???

Commented [az12]: Elaborate more about need for EIT, mechanism, significance???

Commented [az13]: on which outcomes???

Methods

2.1 Trial design and study setting

This single-center, single-blind, randomized pilot study employed a parallel-group design. This protocol adhered to the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines [14](see S1 Table).

Inclusion criteria are mechanical ventilation patients who are ⩾18 years old, are received to invasive mechanical ventilation more than 96 hours before randomization, are meted the preconditions for the machine to be withdrawn, and at least have one failed attempt to withdraw

Commented [az14]: received

Commented [az15]: use another simple word

the ventilator (re-need ventilator support within 48 hours after extubation), and willing to participate in the study and sign the informed consentsent.

Exclusion criteria are as follows: Malignant arrhythmia or acute myocardial ischemia; Pneumothorax, pulmonary bulla and barotrauma and other lung diseases; Hemorrhagic disease or abnormal coagulation mechanism with bleeding tendency; Chest skin trauma; Pulmonary hypertension and pulmonary embolism; With a permanent or temporary pacemaker; There is malignant tumor; Present and previous history of neuromuscular diseases affecting respiratory muscle; Participated in another clinical study related to mechanical ventilation withdrawal; Can not cooperate with the study for any reason or the researcher thinks that it is not suitable to be included in this experiment.

A member of the study team will obtain written consent during ICU admission for a baseline evaluation, and the research process will not proceed until consent is obtained. Through screening, the members of the research team will verify their eligibility.

2.2 Recruitment

Clinicians in the ICU at our hospital will collaborate to enroll patients for this clinical trial. Additionally, posters about this study are planned to be affixed on the noticeboard in front of the ICU, facilitating easy access to information regarding the clinical trial for representatives of patients. The principal investigator will provide a detailed explanation of the study to the participants' legal representatives since most admitted patients are critically or severely ill.

2.3 Interventions

Control group: Two sessions of CPT (morning and afternoon, 20 minutes each) are conducted. The CPT session consist of modified postural drainage[15], assisted cough technique[16], positive expiratory pressure[17] and chest percussion, vibration[18]. The appointed therapist performed pulmonary auscultation and thoracic palpation to assess the status of pulmonary ventilation and secretion retention, and whether the patient's cough ability can complete effective airway clearance. Individualized program is formed according to the assessment, internal guidelines, the patient's tolerance, education level, and patient's preference prior to the randomization. All CPT sessions are performed by the same physiotherapist to avoid potential bias.

EIT-guided group: Similar to the patients in the Control group, the CPT techniques are predefined for the patients according to the assessment prior to the randomization. For each

Commented [az16]: consent

Commented [az17]: m
avoid undue capitals

Commented [az18]: you said that the only problem is individualization and you intend to solve it by EIT
Here you individualize the control????

Commented [az19]: c

CPT session, EIT measurement is conducted and the images are used to guide the CPT treatments. The uses of EIT to guide individual treatments are briefly described as follows.

EIT-guided modified postural drainage combined with vibrations and chest percussion: tidal variation images in EIT reveals heterogeneously ventilated regions. Physiotherapist identified such regions at the bedside and instructed the patient to take the appropriate drainage position, so that the poorly ventilated regions became gravity non-dependent regions. Subsequently, the physiotherapist put her hands on the poorly ventilated area with a vibratory force. A compressive pressure is produced by the therapist's arms.

EIT as a tool for instant feedback and motivation: After each treatment session, the effect of the treatment is assessed immediately. The ventilation improvement is visible and explained using the EIT images. The patient visualized the improvement and is motivated for further CPT sessions.

2.4 Outcomes (primary and secondary)

2.4.1 Primary outcomes measure

The primary endpoint is assessing the peak expiratory flow through passive expiration, being considered the greatest value of the flow in the expiratory phase. All data will be recorded at the baseline (T1), 14 days (T2) and 28 days (T3)).

2.4.2 Secondary outcome measures. The secondary endpoints are:

•The cumulative incidence of successful weaning by Day 30(In nontracheotomized patients, the time point of successful weaning was defined as the time after which reintubation had not been necessary for 48 hours. In tracheotomized patients, the time point of successful weaning was defined as the time after which patients had been kept separated from the ventilator for 24 hours and not reconnected to it in the following 48 hours).

•Maximum inspiratory pressure(All data will be recorded at the baseline (T1), 14 days (T2) and 28 days (T3)).

•Diaphragm thickening rate(All data will be recorded at the baseline (T1), 14 days (T2) and 28 days (T3)).

•Diaphragmatic excursion(All data will be recorded at the baseline (T1), 14 days (T2) and 28 days (T3)).

•Length of ICU stay.

•The number of days from baseline to removal from MV as a result of successful weaning or Day 30, whichever came first.

•Cumulative incidence for death before successful weaning.

Commented [az20]: this is helpful at the beginning, introd.

Commented [az21]: This may be done with help of tactile focal fremitus or stethoscope
If so, there is a need for EIT??

Commented [az22]: Provide examples for clarity

Commented [az23]: Valid, reliab, MCID fo all outcomes???

Commented [az24]: You stated in abstract, at discharge ?? match

Commented [az25]: Space
Apply for all

•The number of advers.

Commented [az26]: complete

2.5 Sample size

Because of the lack of previous similar studies, the sample size was calculated using the results from a previous preliminary experiment which compare mean(media) of peak expiratory flow at T2 were different between the two groups(powered at 80% with 5% significance level) , and assuming a 15% drop-out rate, we ultimately decided to enrol a sample of 80 patients.

Commented [az27]: ref???

Commented [az28]: ?

Commented [az29]: effect size??

Commented [az30]: enroll

2.6 Randomization

Eligible patients will be randomly assigned (1:1) to either the EIT-guided or control group using a computer-generated block design managed by an independent operator. Treatment allocation will be concealed through sequentially numbered, opaque, sealed envelopes, ensuring that neither researchers nor participants are aware of group assignments. An impartial researcher, uninvolved in data collection, will oversee the randomization process.

2.7 Blinding

An independent researcher, uninvolved in outcome evaluation, will assign group allocations. Blinding will extend to physiotherapists assessing outcomes. Participants and EIT-guided CPT providers will be instructed to avoid disclosing allocation to evaluators. Blinding will be maintained until data entry is completed, with any accidental unblinding documented. Outcome assessors will receive thorough training to ensure data quality.

Commented [az31]: ?
Will be doc

2.8 Data collection and management

To protect confidentiality, all real-time data will be coded, and random checks will be performed to ensure consistency across original records, forms, and database entries, with any discrepancies promptly corrected. Tomographic data will be securely stored alongside participant codes for future reference if needed. A comprehensive checklist will ensure strict adherence to research protocols, minimizing data omission or bias. In cases where missing data cannot be retrieved, affected participants will be excluded from the analysis. Data and analysis codes can be accessed by contacting the corresponding author.

2.9 Statistical analysis

Normally distributed continuous data are described as means and standard deviation(SD) and non-normal distributed data are described as median(IQR). Normality of continuous data are

Commented [az32]: space

Commented [az33]: space

assessed through the Kolmogorov-Smirnov test. Comparisons between groups are performed by using the independent-samples t test or the Mann-Whitney U test, for the continuous variables normally or non-normally distributed, respectively. Categorical variables is reported as numbers and percentages and compare with a Chi-square test or Fisher test. We will use GraphPad Prism software(version 5.0) for the paper drawing, all statistical analyses is done with SPSS 22.0 (IBM, USA). Significant differences between groups or across time are reported at the alpha level of 0.05. All reported *p* values are two-sided.

Commented [az34]: justify its use
apply to all tests

Commented [az35]: Are
Or will be

Commented [az36]: space

2.10 Quality assurance

An external researcher uninvolved in measurements will perform random audits every 14 days to verify consistency between original equipment data, recorded formats, and the database. Detected errors will be corrected promptly. The study's progress will be reviewed at monthly project meetings.

2.11 Adverse events

In this trial, adverse events are defined as any unexpected medical occurrences presenting symptoms not observed before the study. Predicted adverse events include severe pain, removal of endotracheal, arterial, or central lines, arrhythmia, bradycardia, systolic blood pressure >200 mmHg or <90 mmHg due to hemodynamic instability during exercise, and desaturation ≤88% due to respiratory instability during exercise, along with minor reactions such as dyspnea, dizziness, tachypnea, and sinus tachycardia[19,20]. Predicted side effects are adverse events, with severity categorized as mild, moderate, or severe. Both device-related and unrelated adverse events were recorded. In cases of unexpected serious adverse events or other unintended interventions, reports were submitted to the institutional review board. Data and safety monitoring will occur after every five participants are enrolled.

2.12 Discussion

This study aims to assess the feasibility and effectiveness of EIT-guided CPT compared to conventional CPT in Difficult-to-Wean patients, who are at high risk for secretion clearance issues and have complex lung conditions that warrant precise and safe CPT techniques[21].

The goals of CPT are to reduce airway obstruction, improve ventilation and gas exchange, and enhance respiratory muscle function. Effective secretion clearance is essential for infection control and pulmonary recovery. Traditional clinical observations and laboratory tests lack objective measures for monitoring changes in ventilation distribution and lung function during

Commented [az37]: show this early in introd

CPT. Our previous work has demonstrated that EIT can reliably assess ventilation improvement at the bedside in pneumonia patients[22,23]. Inspired by these findings, we propose using EIT feedback to guide CPT, as initial feedback from both physiotherapists and patients has been positive.

This pilot randomized controlled trial is the first, to our knowledge, to systematically evaluate a bedside feedback approach for guiding CPT in Difficult-to-Wean patients. EIT's low cost and high sensitivity to thoracic air content changes make it a promising tool for individualized CPT planning, allowing physiotherapists to tailor treatments to each patient's ventilation profile and adjust as needed.

2.13 Ethics

After approval from our ethics committee (Ethics Committee of Beijing Rehabiliation Hospital of Capital Medical University, Agreement number 2022bkky-139). If adjustments or changes to the protocol are necessary, a project amendment will be requested from the committee. Before enrollment, patients will be required to sign the informed consent form and agree to participate in the study.

Commented [az38]: rehabilitation

Author Contributions

Conceptualization; Data curation; Methodology; Writing – original draft: Hao Wang, Beijing Rehabilitation Hospital, Capital Medical University, China

Validation;Jianing Xi,Beijing Rehabilitation Hospital, Capital Medical University, China

Writing – review & editing:Hongying Jiang,Department of Pulmonary and Critical Care Medicine, Beijing Rehabilitation Hospital, Capital Medical University, China

Consent for publication

consent for publication is obtained from all participants.

Commented [az39]: C

Funding

This research had no financial support.

Data availability

The datasets will be used and analysed during the current study are available from the corresponding author on reasonable request.

Commented [az40]: analyzed

Conflicts of interest

The authors declare no conflicts of interest.

References:

[1]Wunsch H, Kramer A, Gershengorn HB. Validation of intensive care and mechanical ventilation codes in Medicare data. Crit Care Med 2017;45:e711–e714.

[2]Slutsky AS, Ranieri VM. Ventilator-induced lung injury. N Engl J Med 2014;370:980.

[3]Timsit J-F, Esaied W, Neuville M, et al. Update on ventilator-associated pneumonia. F1000 Res 2017;6:2061.

[4]Dasta JF, McLaughlin TP, Mody SH, et al. Daily cost of an intensive care unit day: the contribution of mechanical ventilation. Crit Care Med 2005;33:1266–1271.

[5]Rosenthal VD, Maki DG, Mehta Y, et al: International Nosocomial Infection Control Consortium (INICC) report, data summary of 43 countries for 2007-2012. Device-associated module. Am J Infect Control 2014, 42(9):942-956.

[6]Longhini F, Bruni A, Garofalo E, et al. Chest physiotherapy improves lung aeration in hypersecretive critically ill patients: a pilot randomized physiological study. Critical Care 2020, 24(1):479.

[7]Frerichs I, Amato MB, van Kaam AH, et al. Chest electrical impedance tomography examination, data analysis, terminology, clinical use and recommendations: consensus statement of the TRanslational EIT developmeNt stuDy group. Thorax 2017, 72(1):83-93.

[8] He H, Chi Y, Long Y, et al. Influence of overdistension/recruitment induced by high positive end-expiratory pressure on ventilation-perfusion matching assessed by electrical impedance tomography with saline bolus. Crit Care 2020, 24(1):586.

[9]Jiang HY, Li Q, Yu X, et al. Ventilation improvement after pneumonia treatment evaluated with electrical impedance tomography: an observational study. Physiological Measurement 2021, 42(10).

[10]He H, Chi Y, Yang Y, et al. Early individualized positive end-expiratory pressure guided by electrical impedance tomography in acute respiratory distress syndrome: a randomized controlled clinical trial. Crit Care 2021, 25(1):230.

[11]Hsu HJ, Chang HT, Zhao Z, et al. Positive end-expiratory pressure titration with electrical impedance tomography and pressure-volume curve: a randomized trial in moderate to severe ARDS. Physiol Meas 2021, 42(1):014002.

[12]Eimer C, Freier K, Weiler N, et al. The Effect of Physical Therapy on Regional Lung

Function in Critically Ill Patients. Frontiers in physiology 2021, 12:749542.
[13]Yuan S, Chi Y, Long Y, et al. Effect of Position Change From the Bed to a Wheelchair on the Regional Ventilation Distribution Assessed by Electrical Impedance Tomography in Patients With Respiratory Failure. Frontiers in Medicine 2021, 8:744958.
[14]Nydahl P, Sricharoenchai T, Chandra S, et al. Safety of Patient Mobilization and Rehabilitation in the Intensive Care Unit. Systematic Review with Meta-Analysis. Ann Am Thorac Soc. 2017; 14(5):766 – 77.
[15]Freitas DA, Chaves GS, Santino TA, et al. Standard (head-down tilt) versus modified (without head-down tilt) postural drainage in infants and young children with cystic fibrosis. Cochrane Database Syst Rev 2018, 3:CD010297.
[16]Spinou A. A Review on Cough Augmentation Techniques: Assisted Inspiration, Assisted Expiration and Their Combination. Physiol Res 2020, 69(Suppl 1):S93-S103.
[17]McIlwaine M, Button B, Nevitt SJ: Positive expiratory pressure physiotherapy for airway clearance in people with cystic fibrosis. Cochrane Database Syst Rev 2019, 2019(11).
[18] Wilson LM, Morrison L, Robinson KA: Airway clearance techniques for cystic fibrosis: an overview of Cochrane systematic reviews. Cochrane Database Syst Rev 2019, 1:CD011231.
[19]Schaller SJ, Anstey M, Blobner M, et al. Early, goal-directed mobilisation in the surgical intensive care unit: a randomised controlled trial. Lancet. 2016; 388 (10052):1377 – 88.
[20]Bailey P, Thomsen GE, Spuhler VJ, et al. Early activity is feasible and safe in respiratory failure patients. Crit Care Med. 2007; 35(1):139 – 45.
[21]Martinez BP, Lobo LL, de Queiroz RS, et al. Effects of ventilator hyperinflation on pulmonary function and secretion clearance in adults receiving mechanical ventilation: A systematic review with meta-analysis. Heart Lung. 2022;56:8-23.
[22]He H, Chi Y, Long Y, Yuan S, et al. Three broad classifications of acute respiratory failure etiologies based on regional ventilation and perfusion by electrical impedance tomography: a hypothesis-generating study. Ann Intensive Care 2021, 11(1):134.
[23]Lim WS, Baudouin SV, George RC, et al.BTS guidelines for the management of community acquired pneumonia in adults: update 2009. Thorax 2009, 64 Suppl 3:iii1-55.

Commented [az41]: space