Recommendations for lung ventilation and perfusion assessment with chest electrical impedance tomography in critically ill adult patients: an international evidence-based and expert Delphi consensus study

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Summary

Background Electrical impedance tomography (EIT) is a non-invasive, radiation-free imaging technique that allows for monitoring of lung ventilation and perfusion at the bedside. However, there is a lack of evidence-based and international expert consensus statement of EIT clinical applications in adult critically ill patients. The purpose of this study was to provide evidence-based and expert consensus recommendations for lung ventilation and perfusion assessment with chest EIT in adult critically ill patients.

Methods A English literature search was conducted of MEDLINE, EMBASE, Web of Science and Cochrane Library databases between January 1, 1990, and J March 22, 2024. Eligible literature included systematic reviews, meta-analyses, cohort/clinical trials, case reports and review articles that focused on chest EIT application for lung ventilation and perfusion in adult population. The animal studies were excluded. An international global panel of intensivists, physicians, biomedical engineers with expertise in the field of EIT clinical applications, guideline methodologists and biostatisticians, was convened. The Oxford Centre of Evidence Based Medicine's Levels of Evidence method was used to rate the quality of evidence and the strength of recommendations. Subsequently, with a Delphi process (two online surveys at June 3 and September 13, 2024), a group of expanded global experts from 12 different countries developed recommendations. We defined a strong consensus as agreement of >95% experts, consensus as agreement of 75–95% experts and no consensus as agreement<75%. The study is registered with PREPARE, PREPARE-2024CN166.

Findings The final 14 questions generated a total of 11,159 abstracts, of which 242 publications were identified relevant to develop 87 recommendations. The 87 statements focused on data acquisition and analysis, clinical application, and future perspectives were developed and modified. Twenty experts in the expanded group completed the survey in the first round, and eighteen experts in the expanded group completed the survey in the second round. At the end of the Delphi process, 15 recommendations were identified as strong consensus, 70 recommendations as consensus, and two recommendations did not reach consensus. The statements with strong consensus were focused on data acquisition, analysis, training and interpretation, assessment of posture effect on lung ventilation, lung perfusion and ventilation/perfusion match, and the statements without agreement were focused on regional ventilation delay ratio, perfusion assessment with heart-beat related EIT signal. Recommendations were mostly based on moderate quality of evidence (3/87 was A grade, 47/87 was B grade, 37/87 was C-D grade of recommendation).

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Interpretation Our study provides evidence-based recommendations with high consensus for using chest EIT for lung ventilation and perfusion in adult critically ill patients. Evidence and expert consensus supports the application of EIT in the detection of dynamic pulmonary abnormalities and inhomogeneities, which may significantly influence clinical management and final diagnosis. High quality evidence is urgently needed for the development of EIT guidelines in the future.

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Research in context

Evidence before this study

Increasing clinical evidence of chest Electrical impedance tomography (EIT) has been emerging, and important advances have been made in the application of EIT in the clinical practice. Before conducting this study, we searched on Pubmed ("electrical impedance tomography" or "EIT"; "chest" or "thorax" or "lung"; "respirat*" or "ventilat*"; "adult".) AND ("evidence-based" OR "evidence-based recommendations" OR "evidence-based statements" OR "evidence-based guideline" OR "Delphi") but did not identify relevant publications on May 15, 2023. A subsequent broader search using this strategy also did not identified relevant publications in MEDLINE, EMBASE, Web of Science and Cochrane Library databases on June 15, 2023.

Added value of this study

To our knowledge, this is the first study to develop evidence-based recommendations and form global experts consensus on the clinical application of chest EIT in critically ill adults by Delphi method. Based on a systematic review of 11,159 publications, our multidisciplinary panel formulated 87 evidence-based statements addressing: standardized data acquisition and analysis protocols, clinical applications across critical care settings, future research and technological directions.

Implications of all the available evidence

Our work demonstrates that EIT offers unique clinical value in detecting dynamic pulmonary abnormalities and ventilation inhomogeneities, with the potential to directly improve diagnostic accuracy and inform therapeutic decisions. This document was elaborated to guide implementation, development, and training on use of EIT in all relevant settings; it will also serve as the basis for further research and to influence and enhance the associated standards of EIT application. However, the general low level of evidence of the available literature might affect the interpretation and applicable value of the statements. High quality of evidence is urgently needed for the development of EIT guideline in the future.

Introduction

Electrical impedance tomography (EIT) is a non-invasive, radiation-free imaging technique that allows for real-time monitoring of ventilation at the bedside. Increasing evidence suggests that functional lung imaging by EIT is valuable in guiding mechanical ventilation and monitoring different physiological conditions within the lung, with the goal of protecting the lungs in critically ill patients. Current clinical EIT applications also include monitoring ventilator weaning, patient self-inflicted lung injury, lung perfusion, ventilation/perfusion (V/Q) matching and identifying the etiology of respiratory failure.[1]

The use of EIT in clinical practice depends on many factors, including the availability of EIT devices, hospital setting, patient population and specialties.[2] Even within the same hospital, practice varies among clinicians and their expertise.

The first international EIT consensus statement was published by TRanslational EIT developmeNt study (TREND) group in 2017.[3] New EIT parameters and clinical trials have been emerging during the past seven years.[1] Despite increasing evidence, important clinical questions regarding EIT application remain unanswered in critically ill patients.[4] Moreover, there is a lack of international consensus or well-established standardised protocols for EIT clinical applications.

With the aim to create evidence-based and expert recommendations to reflect the current state of the art, an international working group was established. We named it REspiratory and Critical Care medicine EIT study (RECCE) group with the focus of EIT applications in critically ill adult patients. Evidence method and Delphi process were used to establish the consensus in this paper.

Methods

Steering committee establishment and clinical questions generation

The steering committee was established and comprised an international group of intensivists, physicians, and biomedical engineers with expertise in the clinical translation and application of EIT.

This multidisciplinary team developed the recommendations by conducting a comprehensive review of relevant literature and assessing the quality of evidence. Additionally, guideline methodologists and biostatisticians were involved to oversee and guide the implementation of evidence-based grading and Delphi surveys. The study was prospectively registered with the Practice guideline REgistration for transPAREncy (PREPARE), registration number PREPARE-2024CN166. The study was adhered to the Accurate Consensus Reporting Document (ACCORD) reporting guidelines.

A total of 14 clinical questions were generated regarding three dimensions (data acquisition and analysis statements, clinical application statements, further perspectives). Eighty-eight corresponding statements were developed by the steering committee based on evidence and expert group discussions during two virtual meetings.

This study was conducted in compliance with ethical standards. Because the study was only based on systematic literature review and application of the Delphi method, the Ethics Committee of Peking Union Medical College Hospital determined that this study does not fall within the scope of research requiring ethics approval or individual informed consent, and informed consent from those who participated in the Delphi surveys was waived.

Literature search and grade of recommendations

The search strategy was jointly developed through consultation between the librarians and the guideline methodologists. The general keywords are as follows: "electrical impedance tomography" or "EIT"; "chest" or "thorax" or "lung"; "respirat*" or "ventilat*"; "adult". For each of the 14 questions, additional key search words were defined, and specific search combinations of English literature were developed in the databases (MEDLINE, EMBASE, Web of Science and Cochrane Library) between January 1, 1990, and June 30, 2023. The searching was updated on March 22, 2024. Eligible literature included systematic reviews, meta-analyses, cohort/clinical trials, case reports and review articles that focused on chest EIT application for lung ventilation and perfusion in adult population. The animal studies were excluded. To identify eligible studies involving adult participants for the evidence-based rating, we consolidated results from multiple databases into EndNote. The duplicate entries were eliminated. The resulting studies were assigned to at least two working group members to conduct a standardised screening of the abstracts independently. HH, ZZ, YL and the collaborators GY, CY, SL screened and reviewed the selected papers and established relevance based on the content. Subsequently, these developed recommendations were graded, and levels of corresponding evidence were assessed based on the Oxford Centre of Evidence Based Medicine's Levels of Evidence method.[5] With aim to reflect the current state of the art of EIT applications, some relevant clinical evidence from March 22, 2024 to October 1, 2024 were updated and suggested by the steering committee in October, 2024.

Delphi survey and consensus-building process

The steering committee members did not participate in the vote of the Delphi surveys but recruited and convened an international group of intensivists, physicians, biomedical engineers and respiratory therapists with expertise in the field of EIT clinical application in adult critically ill patients. Clinical experts who significantly contributed to adult patient management in the last 10 years, were identified by the steering committee during the online meeting. To be more representative, we tried to invite experts from different regions and limit the number of experts from the same organization for the Delphi survey. Lastly, a total of 25 international experts were selected and invited to participate in the Delphi survey by email. Upon acceptance, experts were included in the Delphi process to generate agreement. Surveys disseminated to the experts were prepared using Microsoft office online form.

The first round of online voting had open-ended questions to receive feedback from the experts, which were used to modify and improve the recommendations to reach a higher degree of consensus. To address potential non-response bias, reminders were sent and the deadline for responses was extended to maximize participation.

The survey involved voting on each recommendation using a 7-point Likert scale with three categories: agreement (scores 7–5) or neutral (scores 4) or disagreement (scores 1–3). We defined strong consensus as agreement of >95% experts (in the case of 20 experts, everyone has to agree to reach "strong consensus"), consensus as agreement of 75–95% experts and no consensus as agreement<75%.[6]

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, writing of the report. HH and ZZ have accessed and verified the data, and were responsible for the decision to submit the manuscript.

Results

A total of 11,159 abstracts were screened. Subsequently, 242 publications in English were reviewed, and data were extracted (The search strategy is shown in the Supplementary File 2) and included in the development of 87 recommendations (Tables 1–5).

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
Q1 What's the recommended position of EIT measurement plane for adult critically ill patients?	1.1: 4th–5th intercostal spaces are recommended for the placement of the EIT electrode interface for EIT chest examination.	B-2b	**Strong consensus 20/20 (100%)**	[7]
	1.2: Electrodes should be in direct contact with the skin, without interposition (e g. drapes, tubes)	D-5	Consensus 19/20 (95%)	N/A
	1.3: When the recommended measurement plane is not accessible, 3rd–4th intercostal spaces should be considered as primary alternative.	B-2b	Consensus 18/20 (90%)	[8]
	1.4: The preexisting passive cables and tubes within the thorax (e.g. central venous catheter, esophageal pressure transducer) do not influence the EIT measurements.	D-5	Consensus 17/20 (85%)	N/A
	1.5: In the case of known elevation of one or both hemi-diaphragms, the position of measurement plane can be raised up to the 3rd intercostal space	B-2b	Consensus 15/20 (75%)	[8–10]
	1.6: Typical anatomical landmarks should be used to unambiguously describe the placement of the EIT electrode interface.	D-5	Consensus 18/20 (90%)	N/A
	1.7: When comparing EIT examinations performed on separate occasions, an identical EIT-belt position should be aimed for.	B-2b	**Strong consensus 20/20 (100%)**	[11–14]
	1.8: In all publications describing the results of EIT examinations, the exact position of the EIT electrode interface should be reported.	B-2b	Consensus 19/20 (95%)	[11–13]
	1.9: The effects of electrode measurement planes and body positions on lung ventilation images should be taken into consideration when comparing results and outcomes.	B-2b	Consensus 19/20 (95%)	[11–27]
Q2 How does the electrode-skin contact impedance and obesity impact EIT examinations?	2.1: Electrode-skin contact impedance should be lower than the vendor-specific threshold and remain stable over time in order to obtain high-quality EIT images.	D-5	Consensus 19/20 (95%)	N/A
	2.2: Electrode gel or spray or other solutions can be used to enhance electrode-skin contact.	B-3a	Consensus 18/20 (90%)	[28,29]
	2.3: Inflatable air mattresses should not alternate their chamber pressure during EIT recordings, to avoid changes in electrode-skin contact.	C-4	**Strong consensus 20/20 (100%)**	[30]
	2.4: The absolute impedance values (e.g. tidal impedance variation, end-expiratory lung impedance (EELI)) might not be comparable between different postures, and the changes in EIT parameters should not be interpreted as physiological effects solely.	D-5	Consensus 2nd vote 15/18 (83%)	N/A
	2.5: Obesity impacts the lung contour and area in functional chest EIT images.	B-2b	Consensus 18/20 (90%)	[31,32]
	2.6: Obesity does not affect the ability of EIT for continuous and dynamic lung ventilation monitoring.	B-2b	Consensus 17/20 (85%)	[33–46]

CEBM Evidence level recommendation grade - Grades of Recommendation: A, consistent level 1 studies; B, consistent level 2 or 3 studies or extrapolations from level 1 studies; C, level 4 studies or extrapolations from level 2 or 3 studies; D, level 5 evidence or troublingly inconsistent or inconclusive studies of any level. Levels of Evidence:1a, Systematic review (with homogeneity) of RCTs; 1b, Individual RCT (with narrow confidence interval"); 1c, all or none; 2a, Systematic review (with homogeneity*) of cohort studies; 2b, Individual cohort study (including low quality RCT; e.g. <80% follow-up); 2c,"Outcomes" Research; Ecological studies; 3a, SR (with homogeneity*) of case–control studies; 3b, Individual case–control study; 4, Case-series (and poor quality cohort and case–control studies); 5, Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles". "Extrapolations" are where data is used in a situation that has potentially clinically important differences than the original study situation.(more detail was shown in https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009). The statements with "consensus" and noted with "2nd vote" indicated that the consensus was obtained on the 2nd vote. Electrical Impedance Tomography EIT, N/A Not Applicable.

Table 1: **Recommendations for data acquisition.**

The general level of evidence of CEBM grading system was low: out of the 242 publications, 3/87 were graded A-1b, 3/87 were graded B-2a, 29/87 were graded B-2b, 3/87 were graded B-3a, 12/87 were graded B-3b, 9/87 were graded C-4 and 28/87 were graded as D-5.

The flow chart of Delphi process is shown in Fig. 1. The demographics of steering committee and experts in the expanded group (Table S1), geographic distribution (Figure S1) and members list of the RECCE group were shown in the Supplementary File 1. Twenty experts from 12 different countries subsequently responded to the first round of survey in June 3, 2024. Eighteen experts completed the re-voting for 13 recommendations without consensus during the second round in September 13, 2024. There was strong agreement on 15 recommendations and agreement on 60 recommendations after first-round voting. Thirteen recommendations without consensus were re-worded and re-voted in

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
Q3 What are the general rules to analyse EIT data?	3.1: Standardised functional EIT analyses and measures are recommended[3] and the original calculations should be referred to.	D-5	Consensus 19/20 (95%)	3,47
	3.2: Caution should be taken when interpreting the results if the applications go beyond the originally described purpose of the respective EIT measure.	C-4	**Strong consensus 20/20 (100%)**	48–50
	3.3: For novel or non-standard methods of analysis, the exact methods of calculation and evaluation should be described in detail.	D-5	**Strong consensus 20/20 (100%)**	51–55
Q4 How to assess the end-expiratory lung volume and tidal volume with EIT?	4.1: The change of end-expiratory lung impedance (EELI) reflects the change of lung volume at the end of expiration.	B-2a	Consensus 17/20 (85%)	56–60
	4.2: Only changes in EELI from baseline should be reported and analysed, not the absolute values.	D-5	Consensus 18/20 (90%)	N/A
	4.3: Changes in EELI should not be used for determination of changes in end-expiratory lung volume during rapid alterations of fluid status or blood pressure, patient position and during the use of pulsating inflatable mattresses.	B-2b	Consensus 18/20 (90%)	30,61
	4.4: The absolute value of EELI cannot be compared between individuals.	D-5	**Strong consensus 20/20 (100%)**	N/A
	4.5: Changes in EELI cannot be compared within individuals across measurements in case of interruptions (e.g. measurements conducted on different days; electrodes detached and reconnected).	B-3b	Consensus 19/20 (95%)	50
	4.6: Changes in tidal impedance variation correlate with changes in tidal volume.	A-1b	**Strong consensus 20/20 (100%)**	62–68
	4.7: Tidal impedance variation could be calibrated with actual tidal volume to calculate volume-impedance ratio.	C-4	**Strong consensus 20/20 (100%)**	69
	4.8: The volume-impedance ratio should be recalibrated with actual tidal volume before comparison between measurements.	B-2b	Consensus 19/20 (95%)	64,70,71
	4.9: Changes in volume-impedance ratio should be taken into account when comparing different ventilator settings.	D-5	Consensus 15/20 (75%)	N/A
	4.10: Volume-impedance ratios can be changed when PEEP or positions are altered. The change can be extreme when the position of electrodes is suboptimal.	B-2b	Consensus 16/20 (80%)	13,17,72
Q5 What are the common EIT-based measures?	5.1: The ventral-to-dorsal centre of ventilation (CoV v-d) weighs the ventilation distribution in the ventral-to-dorsal direction.	B-2b	Consensus 19/20 (95%)	73,74
	5.2: The right-to-left centre of ventilation (CoV r-l) weighs the ventilation distribution in the right-to-left direction.	B-2b	Consensus 18/20 (80%)	75–77
	5.3: A dorsal shift (increase) in ventrodorsal CoV can be caused by ventral overdistension or dorsal recruitment.	D-5	Consensus 19/20 (95%)	N/A
	5.4: Dorsal fraction of ventilation is a surrogate for CoV with lower spatial resolution since its calculation is based on just two image regions compared with typically 32 regions in case of CoV.	C-4	**Consensus 2nd vote, 14/18 (78%)**	47,77,78
	5.5: The global inhomogeneity (GI) index is influenced by the definition of lung region.	B-3a	Consensus 18/20 (90%)	79,80
	5.6: The GI value can be unrealistically low if the lungs remain collapsed or overdistended throughout the entire measurement period.	B-2b	Consensus 19/20 (95%)	81,82
	5.7: Regional ventilation delay (RVD) assesses the inflation delay at the beginning of inspiration.	D-5	Consensus 17/20 (85%)	83–86
	5.8: The standard deviation of regional ventilation delay (SDRVD) during a low-flow inflation manoeuvre correlates with tidal recruitment.	D-5	Consensus 16/20 (80%)	N/A
	5.9: For assessment of tidal recruitment, SDRVD (that calculates the standard deviation of RVD over all ventilated pixels) should be preferred over RVD ratio (that calculates the ratio between the number of pixels whose RVD values exceed a certain threshold to the total number of ventilated pixels), due to the uncertainty of the threshold setup.	D-5	Disagreement 2nd vote, 13/18 (72%)	N/A
	5.10: Assessment of tidal recruitment with SDRVD requires a slow increase in airway pressure during inspiration, as in a slow inflation maneuver with continuous low flow. SDRVD during PCV is unreliable due to the rapid step change in airway pressure.	D-5	Consensus 2nd vote, 14/18 (78%)	N/A
	5.11: A brief inspiration time (e.g. 1–2 s) can introduce considerable noise to RVD calculation.	B-2b	Consensus 15/20 (75%)	87

(Table 2 continues on next page)

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
(Continued from previous page)				
	5.12: The calculation of poorly ventilated lung areas (also described as 'silent spaces' by one of the EIT vendors) requires a subject-related model of thorax and lung geometry to define the expected anatomical lung regions.	B-3b	Consensus 17/20 (85%)	49

CEBM Evidence level recommendation grade -Grades of Recommendation: A, consistent level 1 studies; B, consistent level 2 or 3 studies or extrapolations from level 1 studies; C, level 4 studies or extrapolations from level 2 or 3 studies; D, level 5 evidence or troublingly inconsistent or inconclusive studies of any level. Levels of Evidence:1a, SR (with homogeneity) of RCTs; 1b, individual RCT (with narrow Confidence Interval"); 1c, all or none; 2a, SR (with homogeneity*) of cohort studies; 2b, Individual cohort study (including low quality RCT; e.g. <80% follow-up); 2c,"Outcomes" Research; Ecological studies; 3a, SR (with homogeneity*) of case–control studies; 3b, Individual Case-Control Study; 4, Case-series (and poor quality cohort and case–control studies); 5, Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles". SR, systematic review "Extrapolations" are where data is used in a situation that has potentially clinically important differences than the original study situation.(more detail was shown in https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009). The statements with "consensus" and noted with "2nd vote" indicated that the consensus was obtained on the 2nd vote. The statements with "disagreement" and noted with "2nd vote" indicated that the consensus was NOT obtained even after the 2nd vote. Electrical Impedance Tomography EIT, N/A Not Applicable.

***Table 2*: Recommendations of general rules and common EIT-based measures for data analysis.**

the second round. At the end of the Delphi process, 15 recommendations with 100% agreement was identified as strong consensus, 70 recommendations with 75–95% agreement were identified as consensus, and two recommendations without consensus was identified. The result of vote was summarized in Supplementary File 3 (Table S2).

The core recommendations are summarized in Fig. 2. A detailed discussion of 14 questions with the corresponding recommendations are presented in Supplementary File 4–17.

Discussion

This position statement with clinical recommendations provides new guidance based on published evidence, as well as reinforcing most of the recommendations in the TREND 2017 consensus.[3] Seven TREND members were involved in this consensus. The RECCE focuses rather on the clinical application field in adult critically ill patients, while TREND covers a much larger field of thoracic EIT applications. Evidence and expert consensus support the application of EIT in the detection of dynamic pulmonary abnormalities and inhomogeneities, which may significantly influence clinical management and final diagnosis. Key strengths include detecting changes in recruitability, lung volumes, ventilation distribution, and V/Q mismatches. These capabilities highlight EIT's potential as a valuable bedside tool in routine clinical practice.

Chest EIT for lung perfusion and ventilation is becoming important for individualized mechanical ventilation and for identification of respiratory etiologies at the bedside. The number of publications reporting on EIT-related clinical studies has recently markedly increased. There is increasing evidence of clinical benefits associated with EIT for lung ventilation management.[149,156] With aim to reflect the state-of-the-art of EIT, a narrative review reported EIT acquisition and processing, applications during controlled ventilation and spontaneous breathing, V/Q assessment, and novel future directions.[1] However, evidence-based international guidelines and standardised clinical protocols are necessary to facilitate the adoption of EIT as a routine clinical tool. With the present manuscript, we seek to provide the first evidence-based recommendations on clinical use of chest EIT for adult critically ill patients.

Following PICOS principle, we tried to answer the main question: Does point-of-care EIT provide any clinical advantage in adult intensive care practice? This question was quite general, as EIT is not a therapeutic intervention, but rather a diagnostic and monitoring technique. We expected few randomized controlled trials or high-quality diagnostic accuracy studies with EIT specifically aiming to improve certain clinical outcomes. The vast majority of papers on use of EIT in the last 30 years were summarized, and these specific 87 recommendations were elaborated. The rationales of selecting the clinical questions over the others are provided in the Supplementary Files 4–17.

In the present study, 3/87 recommendations for using EIT to reflect tidal volume and guide mechanical ventilation had a high-level clinical evidence. Meta-analyses on EIT guiding mechanical ventilation appeared in the last two years summarizing the evidence.[149,150,156] No multicentre RCTs have been published so far regarding this topic. Most other recommendations were based on moderate quality of evidence. Hence, well-designed studies with high quality are needed to assess these practice statements and the remaining uncertainties of EIT application. Recently, two multi-centre RCTs have been launched.[249,250] We are eager to learn the study results soon.

The current consensus was achieved by Delphi method. The statements with strong consensus were focused on data acquisition, analysis, training and

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
Q6 How to titrate PEEP and tidal volume to minimize overdistension and collapse?	6.1: Regional respiratory compliance approach (also known as Costa approach) for PEEP titration calculates relative compliance changes, not the absolute ones.	B-3b	Consensus 19/20 (95%)	88
	6.2: During PEEP titration according to the Costa approach, regional compliance loss towards higher PEEP levels should be interpreted as relative overdistension.	B-3b	Consensus 18/20 (90%)	88
	6.3: During PEEP titration according to the Costa approach, regional compliance loss towards lower PEEP levels should be interpreted as relative derecruitment.	B-3b	Consensus 18/20 (90%)	88
	6.4: The "optimal PEEP" can be defined according to the crossover point of the relative hyperdistension and relative collapse curves, depending on the patient's specific needs and clinical goals.	B-3b	Consensus 2nd vote, 14/18 (78%)	89,90
	6.5: Regional compliance changes with higher/lower PEEP are more sensitive measures for recruitment/derecruitment than increases/decreases in silent spaces, since the calculation of silent spaces depends on the matching of lung shapes between the model and the subject.	B-3b	Consensus 2nd vote, 15/18 (83%)	51
	6.6: The "optimal PEEP" selected with regional compliance approach is influenced by the highest and lowest PEEP value during the titration, number of PEEP steps, pressure difference between PEEP steps and duration of each PEEP level.	B-2b	Consensus 19/20 (95%)	91
	6.7: During controlled mechanical ventilation (no patient efforts), a brief reduction in tidal volume can be performed for assessment of regional overdistension and tidal recruitment by measuring the change in regional compliance. a) Regional compliance gain with lower tidal volume should be interpreted as overdistension with previously set tidal volume. b) Regional compliance loss with lower tidal volume should be interpreted as tidal recruitment with previously set tidal volume.	B-2b	Consensus 2nd vote, 16/18 (89%)	88,92,93
	6.8: Decreases in dependent "silent spaces" with higher positive end-expiratory pressure (PEEP) should be interpreted as recruitment of dependent lung areas.	B-3a	Consensus 19/20 (95%)	51
	6.9: Assessment of regional overdistension and derecruitment during a decremental PEEP trial should be based on the analysis of regional changes in pixel compliance.	B-3b	**Strong consensus 20/20 (100%)**	88
	6.10: Although optimal PEEP should lead to a "stable" end-expiratory lung impedance (EELI) over time, EELI is influenced by numerous factors, such as fluid status and electrode-skin contact impedance, making EELI stability a potentially unsuitable target for PEEP setting in routine clinical practice for many patients.	B-2b	Consensus 2nd vote, 16/18 (89%)	94,95
	6.11: EIT can be used for assessment of recruitability and efficacy of recruitment maneuvers.	B-2a	**Strong consensus 20/20 (100%)**	96–103
Q7 How to perform contrast-enhanced EIT method for analysis of regional lung perfusion?	7.1: A bolus of 10 ml with hypertonic (e.g. 5–10%) saline is commonly used as the contrast agent.	B-2b	Consensus 17/20 (85%)	104–111
	7.2: Bolus should be administered and EIT images acquired during a period of breath holding of at least 8 s.	B-3b	Consensus 17/20 (85%)	107,112
	7.3: Breath holding during spontaneous breathing could be difficult to achieve and caution should be paid for corresponding data analysis.	C-4	**Strong consensus 20/20 (100%)**	107,112
	7.4: Technical specifications and analytical standards for lung perfusion imaging need to be unified.	D-5	Consensus 19/20 (95%)	N/A

CEBM Evidence level recommendation grade - Grades of Recommendation: A, consistent level 1 studies; B, consistent level 2 or 3 studies or extrapolations from level 1 studies; C, level 4 studies or extrapolations from level 2 or 3 studies; D, level 5 evidence or troublingly inconsistent or inconclusive studies of any level. Levels of Evidence:1a, Systematic review (with homogeneity) of RCTs; 1b, Individual RCT (with narrow confidence interval"); 1c, all or none; 2a, Systematic review (with homogeneity*) of cohort studies; 2b, Individual cohort study (including low quality RCT; e.g. <80% follow-up); 2c,"Outcomes" Research; Ecological studies; 3a, SR (with homogeneity*) of case–control studies; 3b, Individual case–control study; 4, Case-series (and poor quality cohort and case–control studies); 5, Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles". "Extrapolations" are where data is used in a situation that has potentially clinically important differences than the original study situation.(more detail was shown in https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009). The statements with "consensus" and noted with "2nd vote" indicated that the consensus was obtained on the 2nd vote. Electrical Impedance Tomography EIT, N/A Not Applicable.

Table 3: **Recommendations of PEEP and tidal setting and contrast-enhanced EIT method.**

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
Q8 Can EIT help to identify different etiologies of respiratory failure?	8.1: EIT is useful in identifying regional ventilation abnormalities due to a variety of causes.	C-4	Consensus 19/20 (95%)	3,113–117
	8.2: Presence of phase-inverted impedance changes in dependent lung areas indicates possible presence of pleural effusion, or diaphragmatic displacement within the measurement plane.	B-2b	Consensus 2nd vote, 14/18 (78%)	118,119
	8.3: EIT is helpful to assess effects of pleural effusion drainage.	B-2b	Consensus (80%) 16/20	118–123
	8.4: Ventilation defect, progressive reduction of tidal impedance variation with increasing EELI, increasing size of non-ventilated area, right–left asymmetry and phase-inverted impedance changes in non-dependent lung areas indicate possible presence of pneumothorax.	C-4	Consensus 2nd vote, 17/18 (94%)	124–126
	8.5: EIT can help to identify intrinsic PEEP or regional air trapping in obstructive lung diseases by analyzing expiratory flow or changes of EELI.	B-3b	Consensus 2nd vote, 17/18 (94%)	53,127
	8.6: The right and left fractions of ventilation are useful in identifying unilateral lung pathologies or asymmetrical acute lung injury or other effects affecting the lung function primarily at one side (e.g. one-sided intubation).	B-2b	Consensus 17/20 (85%)	128–132
	8.7: Cardiac stroke volume and extravascular lung water assessed by EIT might be helpful in acute respiratory failure.	B-3b	Consensus 17/20 (85%)	133,134
	8.8: Contrast-enhanced EIT using hypertonic saline bolus detects regional perfusion defect caused by pulmonary embolism.	B-2b	Consensus 17/20 (85%)	112,135–142
	8.9: Contrast-enhanced EIT using hypertonic saline bolus detects V/Q mismatches caused by different etiologies.	B-2b	Consensus 19/20 (95%)	107,112
	8.10: Heart-beat related EIT signal is influenced not only by blood flow but also by various other factors, which may limit its suitability for assessment of regional lung perfusion.	B-2b	Disagreement 2nd vote, 13/18 (72%)	143–148
Q9 Can EIT-guided mechanical ventilation improve prognosis?	9.1: Individualization of mechanical ventilation with EIT has the potential of improving the outcomes of patients with ARDS and requires further study.	A-1b	Consensus 2nd vote, 16/18 (89%)	89,92,149–155
	9.2: EIT-guided PEEP for patients undergoing various types of surgery improves oxygenation compared to ZEEP.	D-5	Consensus 17/20 (85%)	N/A
	9.3: EIT-guided PEEP for patients undergoing various surgery improves oxygenation compared to fixed PEEP.	A-1b	Consensus 17/20 (85%)	39–41,44,156–166
Q10 What is the role of EIT-based analysis of regional ventilation and perfusion in respiratory management?	10.1: EIT can be used to evaluate the changes in regional lung ventilation during spontaneous breathing trials and to guide the weaning process.	B-2b	Consensus 15/20 (75%)	84,167–180
	10.2: EIT quantitatively evaluates the effect of prone position on lung ventilation and aeration, lung perfusion and V/Q match.	B-2b	**Strong consensus 20/20 (100%)**	11,26,33,86,105,110,181–205
	10.3: EIT quantitatively evaluates the effect of lateral positions on lung ventilation, lung perfusion and V/Q match.	B-2b	**Strong consensus 20/20 (100%)**	11,26,206–211
	10.4: EIT can assess the effects of endotracheal suctioning.	B-2b	Consensus 19/20 (95%)	212–221
Q11 Can EIT be used to identify self-inflicted lung injury and guide respiration therapy?	11.1: EIT is helpful to detect the patients who are at risk for patient self-inflicted lung injury due to the presence of pendelluft.	C-4	Consensus 15/20 (75%)	222–224
	11.2: EIT evaluates early activity, airway clearance, pulmonary physiotherapy and personalized rehabilitation programs for mechanically ventilated patients from ICU or OR by providing visual feedback to both physiotherapists and patients.	B-2a	Consensus 2nd vote, 15/18 (83%)	225–234
Q12 Can EIT be used to guide ECMO therapy?	12.1: EIT is helpful to individualize PEEP and tidal volume during V–V ECMO therapy.	B-3b	Consensus 16/20 (80%)	235–245
	12.2: Lung perfusion assessment by contrast-enhanced EIT method during V–V ECMO and V-A ECMO therapy requires further validation.	C-4	Consensus 19/20 (95%)	246–248

CEBM Evidence level recommendation grade–Grades of Recommendation: A, consistent level 1 studies; B, consistent level 2 or 3 studies or extrapolations from level 1 studies; C, level 4 studies or extrapolations from level 2 or 3 studies; D, level 5 evidence or troublingly inconsistent or inconclusive studies of any level. Levels of Evidence:1a, Systematic review (with homogeneity) of RCTs; 1b, Individual RCT (with narrow confidence interval"); 1c, all or none; 2a, Systematic review (with homogeneity*) of cohort studies; 2b, Individual cohort study (including low quality RCT; e.g. <80% follow-up); 2c,"Outcomes" Research; Ecological studies; 3a, SR (with homogeneity*) of case–control studies; 3b, Individual case–control study; 4, Case-series (and poor quality cohort and case–control studies); 5, Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles". "Extrapolations" are where data is used in a situation that has potentially clinically important differences than the original study situation.(more detail was shown in https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009). The statements with "consensus" and noted with "2nd vote" indicated that the consensus was obtained on the 2nd vote. The statements with "disagreement" and noted with "2nd vote" indicated that the consensus was NOT obtained even after the 2nd vote. Electrical Impedance Tomography EIT, PEEP positive end-expiratory pressure, OR operation room, ICU intensive care unit, V/Q ventilation/perfusion, ECMO Extracorporeal Membrane Oxygenation.

Table 4: **Recommendations of clinical applications.**

Question	Recommendation	CEBM evidence level recommendation grade*	Consensus (percentage of agreement)	References used in synthesis of recommendations
Q13 What recommendations are there for future technological development?	13.1: Technology with two or more electrode layers should be developed to cover the whole lungs and allow 3D EIT imaging.	NA	Consensus 16/20 (80%)	NA
	13.2: Validity and comparability of EIT measurements should be assessed and displayed automatically (e.g. volume-impedance ratio for tidal ventilation images, stability of the EIT electrodes, stability …).	NA	Consensus 19/20 (95%)	NA
	13.3: Technical specifications and analytical standards for lung perfusion imaging need to be unified.	NA	Consensus 19/20 (95%)	NA
	13.4: Proper training is required to perform adequate EIT image analysis and data interpretation.	NA	**Strong Consensus 20/20 (100%)**	NA
	13.5: Regional perfusion assessment based on contrast-enhanced EIT without breath-holding is warranted.	NA	Consensus 16/20 (80%)	NA
	13.6: Contrast agents other than hypertonic saline are currently being tested and hopefully could be used in the near future for centres with ethic approval issues.	NA	Consensus 16/20 (80%)	NA
	13.7: Calibrated heart-beat related signals might be suitable to assess regional perfusion under specific circumstances.	NA	Consensus 18/20 (90%)	NA
Q14 What are the future directions for clinical trials in EIT?	14.1: Reference values of EIT parameters based on large sample population should be identified for the various respiratory and critical illness conditions.	NA	Consensus 19/20 (95%)	NA
	14.2: Clinical trials should be conducted to understand how to guide clinical decisions based on regional ventilation and/or perfusion abnormalities.	NA	Consensus 19/20 (95%)	NA
	14.3: Clinical trials should be conducted to confirm the influence of EIT-guided ventilation strategies on patient outcomes.	NA	Consensus 18/20 (90%)	NA

CEBM Evidence level recommendation grade–Grades of Recommendation: A, consistent level 1 studies; B, consistent level 2 or 3 studies or extrapolations from level 1 studies; C, level 4 studies or extrapolations from level 2 or 3 studies; D, level 5 evidence or troublingly inconsistent or inconclusive studies of any level. Levels of Evidence:1a, Systematic review (with homogeneity) of RCTs; 1b, Individual RCT (with narrow confidence interval"); 1c, all or none; 2a, Systematic review (with homogeneity*) of cohort studies; 2b, Individual cohort study (including low quality RCT; e.g. <80% follow-up); 2c,"Outcomes" Research; Ecological studies; 3a, SR (with homogeneity*) of case–control studies; 3b, Individual case–control study; 4, Case-series (and poor quality cohort and case–control studies); 5, Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles". "Extrapolations" are where data is used in a situation that has potentially clinically important differences than the original study situation.(more detail was shown in https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-20. Electrical Impedance Tomography EIT, N/A Not Applicable.

Table 5: **Recommendations of future perspectives (based on authors' experience, without profound evidence).**

interpretation, assessment of posture effect on lung ventilation and aeration, lung perfusion and V/Q match. These recommendations were based on clinical evidence and expert recommendations and they could help clinicians to correctly interpret and apply EIT. The physiological reasoning and clinical evidence behind the recommendations are discussed and can be found in the online supplements.

Evidence grading showed 28/87 recommendations relied on level D evidence. The low level of evidence of the available literature might affect the interpretation of the statements. High quality evidence is urgently needed for the development of EIT guideline in the future. The Delphi process was designed to mitigate potential bias in recommendations based on weak evidence by incorporating a structured, iterative approach with anonymous expert input. During the Delphi rounds, experts provided feedback and voted on recommendations, allowing for refinement and consensus-building. This iterative process helped to balance individual biases and ensure that recommendations were based on collective expert agreement rather than isolated opinions. Additionally, the expert recommendations were formed based on expert opinions when no evidence was found after systematic reviews, indicating a lack of the current best evidence. However, these expert recommendations can still guide current practice, helping to fill the gap in practice recommendations where evidence is absent. Two recommendations (5.9 and 8.10) were with only 72% agreement (less than 75% threshold). Recommendation 5.9 discussed RVD ratio, which is device specific. Not every expert uses this device model. Recommendation 8.10 discussed perfusion assessment with heart-beat related EIT signal. While the evidence supports that heart-beat related EIT signal is not a good assessment for regional lung perfusion, experts would be keen to see further development of this non-invasive technique.

A number of these recommendations will potentially reshape the future practice and knowledge of the rapidly expanding field of clinical EIT use. These applications will benefit patients with rigorous assessment, classification. Publication efforts continue to make critical information available to all clinicians.

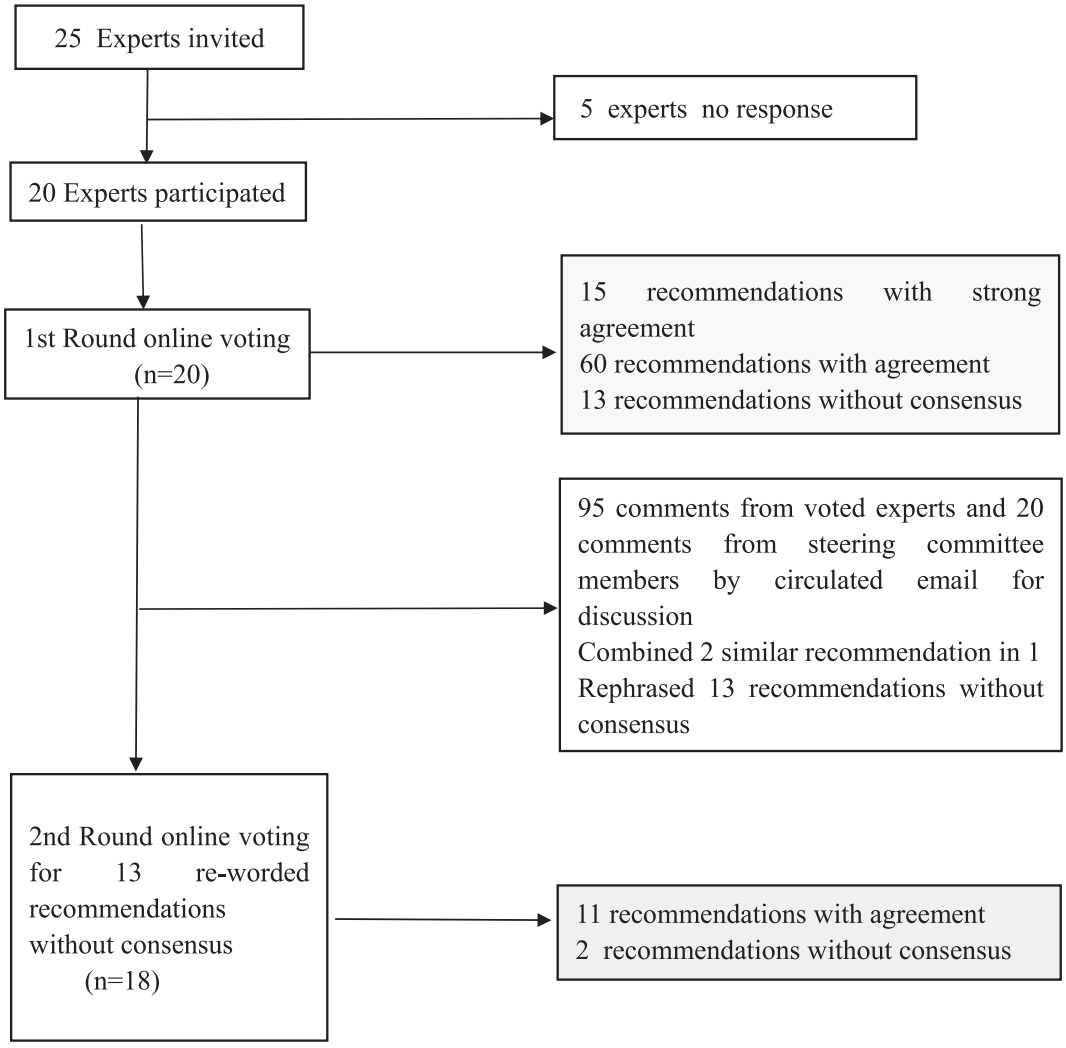

Fig. 1: **Flow chat of the Delphi process**.

This study has certain strengths: (1) the fairly subdivided multidisciplinary panelists' group (including both biomedical engineers and intensivists; experts in different EIT areas and coming from different geographical regions); (2) a standardised methodology of evidence and systematic literature search were performed through consultation from the librarians and the guideline methodologists. (3) With aim to reduce the bias of consensus voting, the steering committee members were not involved, and a new international group of EIT experts was recruited. (4). Since the literature search was done until 2024, we made an updated search until August 31, 2025. Forty-six new relevant literatures were identified, which focused on using EIT to assess lung ventilation and perfusion in different clinical situations. These new literatures had a limited impact on the evidence level for statements (Supplemental File 17). Although the evidence from clinical studies continues to grow, the update search revealed a lack of the high-level evidence from multicentre RCT studies.

The process of selecting clinical questions lacked explicit predefined criteria. The questions were finalized by the steering committee during two online meetings. While the committee members possess extensive frontline clinical experience in EIT applications, we acknowledge that broader stakeholder input (e.g. additional clinicians or end-users) was not systematically incorporated—a limitation of this process. However, the high consensus rate (85 out of 87 statements) suggests that the selected questions align with widely accepted priorities in the field. Moving forward, we aim to adopt a more inclusive approach to question selection in future iterations.

① Position of EIT measurement plane

1.1: 4th to 5th intercostal spaces are recommended for the placement of the EIT electrode interface for EIT chest examination.
1.2: Electrodes should be in direct contact with the skin, without interposition (e g. drapes, tubes)
1.3: When the recommended measurement plane is not accessible, 3rd to 4th intercostal spaces should be considered as primary alternative.
1.7: When comparing EIT examinations performed on separate occasions, an identical EIT-belt position should be aimed for.
1.9: The effects of electrode measurement planes and body positions on lung ventilation images should be taken into consideration when comparing results and outcomes.

② Electrode-skin contact impedance and obesity

2.2: Electrode gel or spray or other solutions can be used to enhance electrode-skin contact.
2.3: Inflatable air mattresses should not alternate their chamber pressure during EIT recordings, to avoid changes in electrode-skin contact.
2.4: The absolute impedance values (e.g. tidal impedance variation, end-expiratory lung impedance (EELI)) might not be comparable between different postures, and the changes in EIT parameters should not be interpreted as physiological effects solely.
2.5: Obesity impacts the lung contour and area in functional chest EIT images.
2.6: Obesity does not affect the ability of EIT for continuous and dynamic lung ventilation monitoring.

③ Assess end-expiratory lung volume and tidal volume

4.4: The absolute value of EELI cannot be compared between subjects.
4.5: Changes in EELI cannot be compared within individuals across measurements in case of interruptions (e.g. measurements conducted on different days; electrodes detached and reconnected).
4.6: Changes in tidal impedance variation correlate with changes in tidal volume.
4.7: Tidal impedance variation could be calibrated with actual tidal volume to calculate volume-impedance ratio.
4.10: Volume-impedance ratios can be changed when PEEP or positions are altered. The change can be extreme when the position of electrodes is suboptimal.

④ Titrate PEEP and tidal volume

6.1: Regional respiratory compliance approach (also known as Costa approach) for PEEP titration calculates relative compliance changes, not the absolute ones.
6.4: The "optimal PEEP" can be defined according to the crossover point of the relative hyperdistension and relative collapse curves, depending on the patient's specific needs and clinical goals.
6.6: The "optimal PEEP" selected with regional compliance approach is influenced by the highest and lowest PEEP value during the titration, number of PEEP steps, pressure difference between PEEP steps and duration of each PEEP level.
6.11: EIT can be used for assessment of recruitability and efficacy of recruitment maneuvers.

⑤ Contrast-enhanced EIT for lung perfusion

7.1: A bolus of 10 ml with hypertonic (e.g. 5-10%) saline is commonly used as the contrast agent.
7.2: Bolus should be administered and EIT images acquired during a period of breath holding of at least 8 seconds.
7.3: Breath holding during spontaneous breathing could be difficult to achieve and caution should be paid for corresponding data analysis.
7.4: Technical specifications and analytical standards for lung perfusion imaging need to be unified.

⑥ Identify respiratory failure etiologies

8.1: EIT is useful in identifying regional ventilation abnormalities due to a variety of causes.
8.2: Presence of phase-inverted impedance changes in dependent lung areas indicates possible presence of pleural effusion, or diaphragmatic displacement within the measurement plane.
8.5: EIT can help to identify intrinsic PEEP or regional air trapping in obstructive lung diseases by analyzing expiratory flow or changes of EELI.
8.8: Contrast-enhanced EIT using hypertonic saline bolus detects regional perfusion defect caused by pulmonary embolism.
8.9: Contrast-enhanced EIT using hypertonic saline bolus detects ventilation-perfusion mismatches caused by different etiologies.

⑦ EIT-guided mechanical ventilation and prognosis

9.1: Individualization of mechanical ventilation with EIT has the potential of improving the outcomes of patients with ARDS and requires further study..
9.3: EIT-guided PEEP for patients undergoing various surgery improves oxygenation compared to fixed PEEP..

⑧ Respiration management and therapy

10.1: EIT can be used to evaluate the changes in regional lung ventilation during spontaneous breathing trials and to guide the weaning process.
10.2: EIT quantitatively evaluates the effect of prone position on lung ventilation and aeration, lung perfusion and V/Q match.
10.4: EIT can assess the effects of endotracheal suctioning.
11.1: EIT is helpful to detect the patients who are at risk for patient self-inflicted lung injury due to the presence of pendelluft.
11.2: EIT evaluates early activity, airway clearance, pulmonary physiotherapy and personalized rehabilitation programs for mechanically ventilated patients from ICU or OR by providing visual feedback to both physiotherapists and patients.

⑨ Guide ventilation and assess perfusion during ECMO

12.1: EIT is helpful to individualize PEEP and tidal volume during V-V ECMO therapy
12.2: Lung perfusion assessment by contrast-enhanced EIT method during V-V ECMO and V-A ECMO therapy requires further validation.

***Fig. 2:* Summary of core recommendations for clinical practice.** For the details of the recommendations, please refer to Supplementary Files 3–16. EIT Electrical impedance tomography, PEEP positive end-expiratory pressure, OR operation room, ICU intensive care unit, V/Q ventilation/perfusion, ECMO Extracorporeal Membrane Oxygenation.

While the current expert panel reflects core contributors to EIT development, we recognize the need for broader global and multidisciplinary representation. Future updates will prioritize inter-discipline collaboration to align with EIT's expanding role in diverse clinical settings. Besides, some of the recommendations are based upon just a few studies with moderate/low evidence or based upon experts' opinions. This is a marked difference compared to other similar guidelines of technologies applied in adult critical care. The device-specific technical standardization or staffing requirements were not included in the current paper. Moreover, some of the EIT applications may not be immediately used in all intensive care units, because of the specific expertise required in some trainings. We acknowledge that EIT was also used in infants and children in clinical practice in the past. We presume that the present recommendations for adult critically ill patients might be relevant for infants and children as well, but the related evidence was not used in the present study. Recommendations comparable to our study should be developed for neonatal and pediatric patients in the future. The face-to-face meeting was lacking during the Delphi process.

In this study, a multi-disciplinary group of experts achieved a high degree of consensus on evidence-based recommendations for using chest EIT for lung ventilation and perfusion in adult critically ill patients, with 85 out of 87 statements accepted. We concluded that there is reasonable evidence and expert consensus supporting the application of EIT in the detection of dynamic pulmonary abnormalities and inhomogeneities that may significantly influence clinical management and final diagnosis. This document was elaborated to guide implementation, development, and training on use of EIT in all relevant settings; it will also serve as the basis for further research and to influence and enhance the associated standards of EIT application.

Contributors

The steering committee included HH, ZZ, TB, IF, GB, TY, MA and YL. HH, ZZ, TB and IF contributed to conceptualisation, design of the work, data acquisition, data interpretation, methodology, writing original draft, and writing review & editing; GB, TY, MA and, YL contributed to the design of the work, data acquisition, data interpretation, methodology, writing original draft, and writing review & editing. HH and ZZ have accessed and verified the data, and were responsible for the decision to submit the manuscript.

Data sharing statement

The data supporting the findings of this study will be made available upon reasonable written request to the study team. Requests for data access should be directed to: Huaiwu He, tjmuhhw@126.com.Data will be provided to researchers whose proposed use of the data has been approved by the study team, with the intention of achieving the goals of the original research. All data shared will be de-identified to ensure participant confidentiality.

Declaration of interests

ZZ received consulting fee from Clario and Dräger Medical. GB received lecturing fees from Dräger Medical (various countries). IF reports institutional funding from the European Commission (WELMO project: Grant 825572) and personal support for attending a meeting with a honorarium for a guest speaker presentation (Dräger Medical). MBPA reports that his experimental research laboratory has received grants in the last five years from Timpel S.A. MBPA is also a minority shareholder in Timpel.

HH,TB, TY and YL declare no competing interests.

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Appendix A. Supplementary data

List of the RECCE group members and supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2025.103575.

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