Prone Positioning Improves Ventilation-Perfusion Matching Assessed by Electrical Impedance Tomography in Patients with ARDS: A Prospective Physiological Study

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Abstract

Background: The physiological effects of prone ventilation in ARDS patients have been discussed for long but remained not fully elucidated. Electrical impedance tomography (EIT) emerged as a tool for bedside monitoring of pulmonary ventilation and perfusion, giving the chance to find proofs. This study aimed to investigate the effect of prone positioning (PP) on ventilation-perfusion matching by contrast-enhanced EIT in patients with ARDS.

Design: Monocenter prospective physiologic study.

Setting: University medical ICU.

Patients: Ten mechanically ventilated ARDS patients who underwent prone positioning.

Interventions: We performed EIT evaluation at the initiation of PP, 3h after PP initiation and at the end of PP during the first PP session.

Measurements and Main Results: The regional distribution of ventilation and perfusion was analysed based on EIT images and compared to the clinical variables regarding respiratory and hemodynamic status. Prolonged prone ventilation improved oxygenation in the ARDS patients. Based on EIT measurements, the distribution of ventilation was homogenized and dorsal lung ventilation was significantly improved by PP administration, while the effect of PP on lung perfusion was relatively mild, with increased dorsal lung perfusion was observed. After merging, the ventilation-perfusion matched region was found to increase and correlate with the increased $\text{PaO}_2/\text{FiO}_2$ by PP, which was mainly attributed to reduced shunt in the lung based on further quantification showed decrease of the only perfused regions.

Conclusions: Prolonged prone ventilation increased dorsal ventilation and perfusion, which resulted in improved ventilation-perfusion matching and oxygenation.

Trial registration: ClinicalTrials.gov, NCT04725227. Registered on 25 January 2021.

Introduction

Prone positioning (PP) has been used for long in ARDS patients who received mechanical ventilation for oxygenation improvement and lung protection purposes [1, 2], and has been shown associated with improved survival in selected ARDS patients [3]. Physiologically, PP reduces ventilator-induced lung injury (VILI) by improving lung homogeneity, promoting alveolar recruitment and reducing hyperinflation [4]. For oxygenation improvement, PP restores lung aeration, decrease shunt while preserve perfusion in dorsal lung regions without impairing gas exchange in ventral regions, which consequently improve ventilation-perfusion matching in the injured lung [5–8]. However, although these physiological findings have been widely acknowledged, most of them were derived from animal models and direct evidence was hardly ever observed in patients due to the lack of proper harmless evaluation methods over the past decades.

The emergence of electrical impedance tomography (EIT) has been promisingly removing the bottleneck. As a radiation-free and non-invasive technique, EIT, which images regional impedance distribution in a cross-sectional area of the body, provides real-time visualization of lung ventilation at the bedside [9], besides, contrast-enhanced EIT allows concurrent estimation of regional pulmonary perfusion based on the kinetics of a bolus of hypertonic saline contrast injected through a central venous line [10, 11]. With these characteristics, EIT is no doubt an ideal tool for dynamic evaluation of pulmonary physiological changes, especially for regional ventilation-perfusion matching in ARDS patients, which remains poorly illustrated. Recently, studies involving EIT for lung ventilation assessment have revealed notable effects of PP on ventilatory mechanics in ARDS patients, including regional gas redistribution, improved alveolar recruitment and lung homogeneity [7, 8, 12, 13]. Even though, few study has set to demonstrate the influence on pulmonary ventilation-perfusion matching during PP in ARDS patients.

In this study, we aimed to evaluate the impact of PP on ventilation and pulmonary perfusion in patients with moderate to severe ARDS using contrast-enhanced EIT, trying to unveil the underlying physiological alterations beyond the improved oxygenation to

some extent.

Materials And Methods

Patients

This prospective study was conducted in the intensive care unit (ICU) of Zhongshan Hospital, Fudan University, and was approved by the Institutional Ethics Committee of the hospital (NO.B2019-230R). All patients were recruited upon obtaining written informed consent. Inclusion criteria included moderate to severe ARDS patient (defined as $\text{PaO}_2/\text{FiO}_2 < 150$ mmHg with positive end-expiratory pressure (PEEP) ≥ 5 cmH₂O, and $\text{FiO}_2 \geq 0.6$ according to the Berlin definition [14]) who underwent mechanical ventilation and prone positioning upon clinical decision within the first PP session. Exclusion criteria included age < 18 years, severe hemodynamic instability, pregnancy, length of prone positioning < 12 hours; contraindications to EIT administration, inability of EIT belt placement. This study was registered clinicaltrials.gov (NCT04725227).

Study Protocol

Baseline characteristics of the patients were collected at enrollment, including height and weight, acute physiology and chronic health evaluation II (APACHE II) score at ICU admission, etiology of ARDS, and arterial partial oxygen pressure to fractional concentration of inspired oxygen ($\text{PaO}_2/\text{FiO}_2$) ratio.

EIT assessment was respectively administered at PP initiation (T_0), 3 hours after PP initiation (T_1) and the end of PP (T_2) within the first PP session. Arterial blood gas (ABG) analysis results, end-tidal expiratory carbon dioxide pressure, ventilator parameters and hemodynamic parameters including heart rate (HR), central venous pressure (CVP) and mean arterial pressure (MAP) were also recorded at T_0 , T_1 and T_2 , respectively. Ventilator settings except FiO_2 remained unchanged during the PP period.

EIT data

The EIT belt containing 16 electrodes was placed around the chest wall at the forth or fifth intercostal space and connected to the EIT monitor (PulmoVista 500; Dräger Medical GmbH, Lübeck, Germany). Technical details of EIT have been previously described [11]. The EIT signals were recorded at frame rate of 50Hz. After a baseline recording of EIT data for 5 min, we performed an end-inspiratory breath hold lasting 20 s. After 2 s from start of the occlusion, a bolus of 10 ml of 5% NaCl solution was manually injected via the central venous catheter. The bolus of saline solution, injected in less than 2 s, passes through the pulmonary circulation producing an impedance dilution curve that follows typical first-pass kinetics [15]. EIT ventilation maps were obtained from offline analysis of tracings by averaging values over five consecutive respiratory cycles (Fig. S1A). From the analysis of ventilation maps we measured: [16]

1. the pixel-level ventilation measured as impedance change between expiration and inspiration. Pixels were then classified as non-ventilated if pixel ventilation was $\leq 10\%$ of the highest pixel-level value measured in that patient
2. Tidal image region-global (%) = The relative pixel-level ventilation / the relative pixel-level detected lung size [17]
3. the percentage of ventilated pixels in the respective region (Region of Interest: ROI 1, ROI 2, ROI 3 and ROI 4) (Fig. S1D)
4. Ventral/ Dorsal of tidal image region (%) = Tidal image region-global $\times$ the ventral/ dorsal fraction of ventilation distribution
5. The Global Inhomogeneity (GI) index [18]

EIT perfusion maps (Fig. 1B) were derived from offline analysis of the time-impedance curve obtained during the first pass of the saline solution during occlusion, after removing the cardiac region from the images. From the analysis of perfusion maps we measured [16]:

1. the relative pixel-level perfusion: after preprocessing, the steepest (maximal) slope of the temporal EIT signal deflection during the saline bolus injection in each pixel was normalized to the overall detected signal, yielding the relative pixel perfusion. Pixels were classified as non-perfused if pixel perfusion was $\leq 10\%$ of the highest pixel-level value measured in that patient

2. Blood flow region-global (%) = The relative pixel-level perfusion / the relative pixel-level detected lung size
3. the percentage of perfusion in each region (ROI 1, ROI 2, ROI 3 and ROI 4) (Fig. S1D)
4. Ventral/ Dorsal of blood flow region (%) = Blood flow region-global (%) × the ventral/ dorsal fraction of perfusion distribution
5. The Global Inhomogeneity (GI) index [18]

By integrating the pixel-level data on ventilation and perfusion (Fig. S1C), we calculated:

1. Dead Space-EIT %: corresponding to the ventilated but non-perfused pixels divided by the total number of pixels ventilated and/or perfused
2. Shunt-EIT %: corresponding to the perfused but non-ventilated pixels divided by the total number of pixels classified as ventilated and/or perfused
3. Matched Region %: corresponding to the pixels which are both ventilated and perfused divided by the total number of pixels ventilated and/or perfused

Statistical Analysis

Sample size was similar to previous physiologic studies[19, 20]. Statistical analysis was performed via SPSS 26.0 (SPSS Inc. Chicago, IL) and Prism 8 (GraphPad Software, San Diego, CA, USA). All continuous variables were subjected to Shapiro-Wilk test for normality. Data was presented as mean ± SD if normality was met, or otherwise as median and interquartile range. To test the effect of the time points on the variables, Mauchly's test was performed for sphericity and repeated measures ANOVA was applied with post hoc Bonferroni's multiple comparison. When violation of sphericity occurred (i.e. Mauchly's test p value < 0.05), Greenhouse-Geisser method was used for correction. Correlation between continuous variables was assessed by Pearson regression coefficient. All statistical tests were two-tailed, and p < 0.05 was considered statistically significant.

Results

Patient characteristics

A total of 10 ARDS patients who underwent mechanical ventilation in the ICU of Zhongshan Hospital, Fudan University from February 2021 to July 2021 were enrolled (Table 1). The patients consisted of 9 male and 1 female, aged 66 ± 15 with average body mass index (BMI) being 24 kg/m^2 . The average APACHE II score at ICU admission was 14 ± 9 . Three patients (30%) had moderate ARDS and 7 patients (70%) had severe ARDS. All patients underwent continuous PP for over 12 hours, with the average duration being 15.45 ± 2.5 hours.

Table 1
Main characteristics of the patients

Patient NO.	Sex (M/F)	BMI (kg/m ²)	APACHE II score at ICU admission	PaO ₂ /FiO ₂ at baseline (mm Hg)	PEEP(cmH ₂ O)	Duration of prone positioning (h)	ARDS Etiology (pulmonary/extrapulmonary)
1	M	25	33	83	10	12	Pulmonary ARDS
2	M	26	11	123	8	17	Pulmonary ARDS
3	F	35	9	51	14	18.5	Extrapulmonary ARDS
4	M	24	19	81	11	16	Extrapulmonary ARDS
5	M	23	15	97	8	18.5	Pulmonary ARDS
6	M	21	2	97	8	16	Pulmonary ARDS
7	M	21	7	140	5	15.5	Extrapulmonary ARDS
8	M	26	11	96	5	12	Pulmonary ARDS
9	M	19	23	64	12	16.5	Pulmonary ARDS
10	M	23	8	122	12	12.5	Extrapulmonary ARDS
Summary	9M/1F	24 ± 4	14 ± 9	95.4 ± 27	9.3 ± 3.02	15.45 ± 2.5	6 Pulmonary ARDS / 4 Extrapulmonary ARDS
M, male; F, female; BMI, Body Mass Index; APACHE-II Acute Physiology and Chronic Health Evaluation II; ARDS, acute respiratory distress syndrome; PaO ₂ /FiO ₂ , arterial partial pressure of O ₂ /inspired fraction of O ₂ ratio; PEEP, positive end-expiratory pressure.							

Pp Improved Oxygenation And Hemodynamic Stability During Mechanical Ventilation

Clinical parameters regarding respiratory and hemodynamic status at T₀, T₁ and T₂ were assessed and compared (Table 2). Notably, with PP administration, respiratory system compliance (Crs) (27.70 vs. 30.03 vs. 33.52 ml/cmH₂O, $p < 0.01$), and PaO₂/FiO₂ (95.40 vs. 161.90 vs. 221.40 mmHg, $p < 0.0001$) of the patients significantly increased. No significant difference was identified in minute ventilation (MV) ($p = 0.536$), PaCO₂ ($p = 0.257$), end-tidal expired carbon dioxide pressure (ETCO₂) ($p = 0.348$) or dead space percentage estimated by ABG (Dead space-ABG) ($p = 0.740$) among the 3 time points.

Table 2
Effects of prone position ventilation on respiratory, gas exchange, and hemodynamics

	T ₀	T ₁	T ₂	Trend-P value	Mauchly's test of sphericity P value
MV (l/min)	7.47 ± 1.09	7.29 ± 0.92	7.62 ± 1.32	0.536	< 0.001
Crs (ml/cmH ₂ O)	27.70 ± 11.65	30.03 ± 11.36	33.52 ± 12.87 ^a	< 0.01	0.061
Set FiO ₂	0.70 [0.60–0.89]	0.60 [0.59–0.69]	0.60 [0.40–0.65]	< 0.05	0.441
PaO ₂ (mmHg)	66.98 ± 12.15	100.44 ± 20.54 ^a	125.35 ± 34.85 ^a	< 0.0001	0.119
PaO ₂ /FiO ₂ (mmHg)	95.40 ± 27.45	161.90 ± 44.68 ^a	221.40 ± 54.64 ^{a, b}	< 0.0001	0.957
PaCO ₂ (mmHg)	50.55 [41.50–63.35]	56.45 [46.33–69.93]	49.90 [42.88–68.58]	0.257	0.046
ETCO ₂ (mmHg)	36.00 [34.00–48.75]	41.00 [35.00–50.00]	37.50 [33.00–43.25]	0.348	0.010
Dead space-ABG	26.84 [17.66–34.42]	24.56 [21.64–33.43]	20.02 [17.61–37.17]	0.740	0.003
HR (bpm)	113.30 ± 19.81	108.00 ± 20.56	106.90 ± 24.53	0.387	0.198
SBP (mmHg)	116.20 ± 17.50	120.50 ± 17.80	121.60 ± 19.00	0.763	0.070
MAP (mmHg)	76.93 ± 15.97	84.83 ± 13.77	84.60 ± 17.33	0.360	0.092
CVP (mmHg)	10.00 [8.00–14.50]	14.00 [10.50–15.00]	13.00 [11.00–15.00]	0.123	0.253
Norepinephrine (µg/kg/min)	0.17 [0–0.175]	0.08 [0–0.175]	0.02 [0–0.088] ^a	< 0.05	0.377
CVP, central venous pressure; ETCO ₂ , end-tidal expired carbon dioxide pressure; PaO ₂ /FiO ₂ , arterial partial pressure of O ₂ /inspired fraction of O ₂ ratio; PaCO ₂ , arterial partial pressure of CO ₂ ; HR, heart rate; MAP, mean arterial pressure; SBP, systolic arterial blood pressure. Respiratory system static compliance (Crs) = Vt/(Pplat – PEEPtot) from the analysis of ventilation tracings during occlusions.					
p value by one-way analysis of variance (ANOVA) for repeated measures					
^a vs. T ₀ , <i>p</i> < 0.05					
^b vs. T ₁ , <i>p</i> < 0.05					

For hemodynamic parameters, decrease of heart rate (HR) and increase of systolic blood pressure (SBP), mean arterial pressure (MAP) and central venous pressure (CVP) were observed but with no significant difference reached. However, the dose of norepinephrine significantly decreased after the initiation of PP (*p* < 0.05), indicating the improvement of hemodynamic stability in the patients.

Pp Altered Regional Distribution Of Lung Ventilation And Perfusion

EIT-based measurements regarding lung ventilation and perfusion at the indicated time points were presented in Table 3. Tidal image region-global% significantly increased with PP administration (82.9% vs. 85.6% vs. 92.5%, *p* < 0.0005), and the increments mainly took place in the dorsal region (32.7% vs. 38.0% vs. 49.0%, *p* < 0.005), while no significant decrease in the ventral region

was observed (Fig. 1A). Similarly tendency was also presented in the scale of the 4 ROIs (Fig. 1B). Moreover, the GI index of ventilation progressively decreased from T_0 to T_2 ($p < 0.01$, Table 3).

Table 3

Physiologic variables at the three different time points selected for the analysis of electrical impedance tomography data

Variables	T ₀	T ₁	T ₂	Trend- <i>P</i> value	Mauchly's test of sphericity <i>P</i> value
Tidal image region-global (%)	82.90 ± 5.40	84.60 ± 7.31	92.50 ± 6.52 ^{a, b}	< 0.0005	0.709
Ventral of tidal image region (%)	50.20 ± 10.44	46.60 ± 8.61	43.50 ± 7.03	0.140	0.030
Dorsal of tidal image region (%)	32.70 ± 12.14	38.00 ± 9.24 ^a	49.00 ± 7.32 ^{a, b}	< 0.005	0.001
ROI 1 of ventilation distribution (%)	20.8 ± 9.7	15.8 ± 7.0	11.2 ± 4.5	< 0.05	0.099
ROI 2 of ventilation distribution (%)	39.00 [36.50–43.00]	37.00 [35.25–41.25]	37.00 [31.00–42.00]	0.315	0.030
ROI 3 of ventilation distribution (%)	31.50 ± 11.20	36.30 ± 7.85	37.90 ± 8.06	0.243	0.013
ROI 4 of ventilation distribution (%)	7.50 ± 3.24	8.50 ± 3.10	15.00 ± 3.74 ^{a, b}	< 0.001	0.833
GI index-ventilation (%)	0.53 ± 0.06	0.52 ± 0.07	0.47 ± 0.05 ^a	< 0.01	0.266
Blood flow region-global (%)	73.9 ± 9.9	74.4 ± 12.2	75.3 ± 7.2	0.817	0.022
Ventral of blood flow region (%)	37.70 ± 10.02	36.30 ± 8.52	29.30 ± 10.59	< 0.05	0.102
Dorsal of blood flow region (%)	36.42 ± 6.20	38.20 ± 7.98	46.00 ± 9.29 ^a	< 0.01	0.623
ROI 1 of perfusion distribution (%)	12.10 ± 4.66	10.40 ± 9.28	9.60 ± 10.89	0.742	0.554
ROI 2 of perfusion distribution (%)	38.20 ± 9.35	37.90 ± 5.59	28.80 ± 4.96 ^{a, b}	< 0.01	0.268
ROI 3 of perfusion distribution (%)	40.20 ± 7.00	38.70 ± 7.13	42.30 ± 7.15	0.076	0.280
ROI 4 of perfusion distribution (%)	9.50 ± 6.49	13.00 ± 8.65	19.30 ± 8.03	< 0.05	0.148
GI index-perfusion (%)	0.60 ± 0.12	0.59 ± 0.08	0.59 ± 0.10	0.993	0.088
Matched region (%)	52.50 ± 6.65	61.10 ± 7.39 ^a	67.40 ± 7.09 ^{a, b}	< 0.0005	0.468
Dead space-EIT (%)	18.00 ± 4.69	18.10 ± 5.02	14.30 ± 5.89	0.099	0.154
Shunt-EIT (%)	29.50 ± 7.56	20.80 ± 6.71 ^a	18.30 ± 6.06 ^a	< 0.005	0.023
p value by one-way analysis of variance (ANOVA) for repeated measures					
^a vs. T ₀ , <i>p</i> < 0.05					
^b vs. T ₁ , <i>p</i> < 0.05					

For lung perfusion, no obvious change was found in the global or ventral regional distribution of blood flow determined by EIT, but intriguingly, perfusion in the dorsal region was shown to be significantly increased with PP duration (36.20% vs. 38.20% vs. 46.00%, $p < 0.05$) (Fig. 1C). Similarly, lung perfusion slightly decreased in the ventral ROI 1 and 2, while slightly increased in the dorsal ROI 3 and 4, though no statistical significance was reached (Fig. 1D). Besides, The GI index of perfusion remained constant during PP period (Table 3). These results indicated that the overall effect of PP on lung perfusion distribution was relatively mild, but still, PP could remarkably increase perfusion in the dorsal region of the lung.

Pp Improved Ventilation-perfusion Matching

Supplemental Fig. 2 showed ventilation and perfusion matching images of a patient at T_0 , T_1 and T_2 . Based on EIT measurements, Matched Region% significantly increased with PP duration (52.50% vs. 61.10% vs. 67.40%, $p < 0.0005$) (Fig. 2A). Intriguingly, Shunt-EIT % significantly decreased with PP duration (29.50% vs. 20.80% vs. 18.30%, $p < 0.005$, Fig. 2B), especially between T_0 and T_1 . Dead Space-EIT % almost remained the same during PP administration (Fig. 2C). As shown in Fig. 2. D- F, $\text{PaO}_2/\text{FiO}_2$ presented high positive correlation with the percentage of Matched Region % ($\rho = 0.601$, $p < 0.0005$) and high negative correlation with the level of shunt estimated by EIT ($\rho = -0.484$, $p < 0.01$), while no significant correlation with Dead Space-EIT %. What's more, in our study, most of patients' lung had good recruitability after prone position sessions from CT scan (Figure S3).

Discussion

As a relatively new technique available for clinical use, EIT has provided an opportunity to dig into the physiological fundamentals of ARDS. In use of EIT, this study has provided some proof-of-concept evidences regarding the ventilation-perfusion matching effect of PP during mechanical ventilation in ARDS patients. First, the increased ventilation was mainly distributed in the dorsal region while ventral ventilation was hardly changed, suggesting the aeration increment in dorsal lung regions was not offset by loss of aeration in ventral regions. Changes in ventilation were observed early in the prone position. Second, the redistribution effect of PP on lung perfusion was relatively mild compared to ventilation, with the dorsal lung perfusion increased and the trend of the ventral decreased, while global perfusion remained constant. Changes in blood flow were observed during prolonged prone positions. Third, ventilation-perfusion matched region was increased and correlated with the increased $\text{PaO}_2/\text{FiO}_2$ by PP, which was specifically attributed to reduced functional shunt and increased dorsal ventilation and perfusion matching by the procedure.

During PP, patients exhibited a shift of the tidal volume distribution from the ventral to dorsal ROIs, and the inhomogeneity of tidal ventilation distribution (GI) was reduced. In ARDS, with the lung weight usually increases by 2–3 times, the potentially open alveoli at the dorsal region tend to collapse in the supine position. In the prone position, these alveoli may open up as the superimposed pressure of the dorsal regions is released [21]. Previous study reported that the inflation of pulmonary units was far more homogeneous at pronation than supination, which was interpreted as the lung-distending force (i.e. the gravitational gradient of pleural pressure, trans-pulmonary pressure or lung stress) was more homogeneously distributed [21, 22]. The primary reason was considered to be improved shape matching between the chest wall and the lung [23]. The gravitational gradient of pleural pressure, regional end-expiratory and end-inspiratory lung volumes, regional ventilation were all more uniform at prone position than at supine position [24].

Theoretically, the gravitational distribution of pulmonary blood flow is only minimally altered by pronation [25, 26], which is consistent with our findings. The increased perfusion in dorsal region and roughly maintained perfusion in ventral region could be attributed to less lung/heart geometry, fewer airspace compression of vessels (with more end-expiratory volume), and reduction of hypoxic vasoconstriction in dorsal region [5]. Similarly, Perier et al. recently reported that improvement of lung aeration and unmodified dorsal of pulmonary perfusion after three hours of the prone positioning in COVID-19-associated ARDS [27]. Unlike these studies we repeated EIT assessment at PP initiation, 3 hours after PP initiation and the end of PP within the first PP session. Based on theses evidences, we hypothesized that during prone ventilation, pulmonary blood flow remains unmodified at the early stage and then gradually increases in dorsal regions over time.

In the present study, we found that Matched Region% improved before the end of the prone position with the significant decrease in Shunt-EIT%. Dead Space-EIT% showed no significant difference but did show a mild reduction. The matching between lung ventilation and perfusion is fundamental to effective gas exchange, and both shunt and dead space are the determinants of ventilation-perfusion matching. In the present study, ventilation-perfusion matched region was increased by PP, and increased PaO₂/FiO₂ was significantly correlated with increased matched region and reduced shunt, which was in accordance with previous studies [24, 28].

By recruiting the lungs, prone position has the potential to increase ventilation-perfusion matching, decrease hypoxemia, reduce hypoxic vasoconstriction, and thereby improve right ventricular function, hemodynamics and pulmonary perfusion. It is interesting to note that placing patients in prone position had a large impact on dose of vasopressors (norepinephrine was decreased from 0.17 to 0.02 ug/Kg/min at the end of PP).

Although this study has provided notable evidences regarding physiological effects of prone ventilation in ARDS patients, its limitation should be noticed. First, this study was carried out within a small number of patients in a single center, which reduces the statistical power. Second, EIT measures only a portion of the lung, projecting the 3 dimensional distribution of ventilation/perfusion to the 2 dimensional image, which is not enough for assessment of the entire spectrum of ventilation-perfusion matching in the lung [29]. Third, the EIT assessment was only performed at the 3 indicated time points during PP instead of throughout the process, which failed to fully uncover the longitudinal effect of PP. The present study missed the changes in ventilation and perfusion after resupination as well. Forth, cardiac output of the patients were not measured. The potential effect of PPV on CO might influence the oxygenation and V-Q matching.

Conclusions

Bedside EIT evaluation proved the concept that prolonged prone ventilation increased dorsal ventilation and perfusion in the lung, which resulted in improved ventilation-perfusion matching and consequently, oxygenation.

Abbreviations

ARDS
Acute respiratory distress syndrome
EIT
Electrical impedance tomography
PEEP
Positive end expiratory pressure
V_t
Tidal volume
RR
Respiratory rate
FiO₂
Fraction of inspired oxygen
V/Q
Ventilation/perfusion
GI
Global Inhomogeneity
ROI
Region of Interest

Declarations

Ethics approval and consent to participate

The ethics review board of Zhongshan Hospital of Fudan University approved the study protocol and written informed consent was obtained from all participants before enrollment.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors have no potential conflicts of interest to declare.

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Authors' contributions

YW takes responsibility for (is the guarantor of) the content of the manuscript, including the data and analysis. YW and MZ had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis, including and especially any adverse effects. MD, JS, YZ, WW, JT, LZ, and XZ contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Evolution of Tidal image region (%), Blood flow region (%), ventilation or perfusion distribution (%) in the horizontal regions of interest (ROIs) at T_0 , T_1 and T_2 . * vs. T_0 , $P < 0.05$. # vs. T_1 , $p < 0.05$.

Figure 2

A, B, C. Comparisons of Matched Region (%), Shunt-EIT (%), and Dead Space-EIT (%) at T_0 , T_1 and T_2 . * $P < 0.05$. D, E, F. PaO_2/FiO_2 was significantly correlated with Matched Region% and Shunt-EIT%, but not with Dead Space-EIT%.

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