Nauka praktyce / Science for medical practice

ARTYKUŁ ORYGINALNY / ORIGINAL PAPER
Otrzymano/Submitted: 24.04.2017 • Zaakceptowano/Accepted: 19.03.2018

Difference in lung distribution of ventilation between positive end-expiratory pressure 5 cmH_2O and 10 cmH_2O in postoperative patients using electrical impedance tomography assessment

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Abstract

Background. Atelectasis is one of the most common perioperative respiratory complications seen in the first 24 hours postoperatively and it can actually persist for several days afterwards. Application of Positive End-Expiratory Pressure (PEEP) can prevent postoperative alveolar collapse which is behind atelectasis. The study compares the influence of PEEP either 5 cmH_2O (PEEP-5) or 10 cmH_2O (PEEP-10) on the distribution of ventilation in postoperative patients using Electrical Impedance Tomography (EIT). ***Material and methods.*** A single-blind randomized clinical trial was conducted in the Intensive Care Unit of University Hospital upon 35 patients. The subjects were randomized into two groups: either postoperative mechanical ventilation with PEEP-5 or with PEEP-10. The patients were monitored with EIT PulmoVista 500® with values of the following parameters being taken: global Tidal Impedance Variation (gTIV), regional Tidal Impedance Variation (rTIV) for both anterior and posterior parts of the lungs, global End-Expiratory Lung Impedance (gEELI), regional End-Expiratory Lung Impedance (rEELI) for both anterior and posterior parts of the lungs, Regional Dynamic Compliance Change (RC) for both anterior and posterior parts of the lungs. Then the calculated parameters and their relationship were analyzed for PEEP-5 and PEEP-10 group over time points taken (0-20-40-60 min) and lung regions (anterior/posterior). ***Results.*** Analysis of rTIV and gTIV values in PEEP-5 and PEEP-10 group have shown statistically significant difference in measurements taken at the 20th minute ($p<0.05$) of the study. The analysis of gEELI and rEELI values taken at both anterior and posterior parts of the lungs in PEEP-5 and PEEP-10 group have shown statistically significant difference in every measurement taken ($p < 0.05$). ΔRC difference values (ΔRC) at both anterior and posterior parts of the lungs between PEEP-5 and PEEP-10 group were statistically significantly different ($p < 0.05$) in every measurement taken. There were no differences between two groups in terms of PaO_2/FiO_2 ratio, the length of intubation and the duration of hospitalization. ***Conclusions.*** Despite statistically significant differences in pulmonary parameters (TIV, EELI, RC) measured between PEEP-5 and PEEP-10 groups short term patients' outcome defined by PaO_2/FiO_2 ratio, the length of intubation and the duration of hospitalization did not differ between both groups. *Anestezjologia i Ratownictwo 2018; 12: 5-17.*

Introduction

Inappropriate settings of mechanical ventilation can cause damage to lung tissue that can lead to pulmonary complications such as atelectasis, pneumonia and Acute Respiratory Distress Syndrome (ARDS). This is all known as Ventilator-Associated Lung Injury (VALI). The incidence of VALI in post-operative patients is

about 2.7% what is comparable with the prevalence of post-operative cardiovascular complications (2.5%) [1].

Atelectasis belongs to most common perioperative respiratory complications with almost 90% incidence rate [2]. It appears usually within 24 hours post-operatively and can linger for even several days. If atelectasis is mismanaged with poor ventilation strategy it can lead to VALI with increased morbidity and mortality, extended length of hospital stay and thus vastly increased hospital cost and possible litigations [3]. The current pulmonary protective ventilation strategy is to use low tidal volume to prevent overdistention of alveoli, high positive end expiratory pressure (PEEP) to prevent alveoli's collapse and applying recruitment maneuvers [4]. Surgical patients mainly upon major or prolonged procedures are often admitted to the Intensive Care Unit (ICU) on scheduled basis and sometimes require a period of mechanical ventilation. Lung protective ventilator settings are required for them particularly in the early postoperative phase to ensure recruitment of collapsed alveoli.

Studies show that PEEP decreases post-operative pulmonary complications, improves oxygenation and lungs` mechanics. Application of PEEP within range 5-12 cmH_2O minimizes the risk of VALI in susceptible patients [5]. Studies carried out on animals show that high PEEP does not cause lung injury [6]. PEEP level is usually based on the arterial oxygenation parameters, although it is regarded as neither sensitive nor specific enough to reflect the proper ventilation distribution in the lungs or so called open lung status. Electrical Impedance Tomography (EIT) is an imaging modality that can demonstrate the cross-sectional ventilation distribution; it is noninvasive, real-time and without radiation [7]. EIT measures pulmonary tissue impedance by sending small electrical waves and recording the obtained voltage with electrodes attached to the skin surface. Studies with EIT have been done mostly on ICU patients with ARDS. The EIT can provide some important data as to lung ventilation pattern in various modes of mechanical ventilation [8] as well as shows changes in the ventilation distribution pinpointing collapsed or over-stretched areas of the lungs [7].

Purpose of the work

This study aims to compare the influence of strategy with lower or higher PEEP on global and regional distribution of ventilation in the lungs in postoperative patients under mechanical ventilation in ICU using measurement of three EIT parameters over time points: Tidal Impedance Variation (TIV), End Expiratory Lung Impedance (EELI) and Regional Dynamic Compliance Change (RC).

Material and methods

After approval from Ethics Committee, IRB, and consent from patients, a single-blind randomized clinical trial was carried out in the Intensive Care Unit (ICU) of Cipto Mangunkusumo Hospital, Jakarta, Indonesia. The study was based upon adult patients in post-operative period after elective surgery who required mechanical ventilation in the surgical ICU from May to July 2015. The inclusion criteria were set as follow: adult post-operative patients meeting ICU admission criteria requiring mechanical ventilation, intubated, after high-risk elective surgery (either craniotomy or laparotomy) which lasted at least 3 hours, aged between 18-60 years.

Exclusion criteria were : history of mechanical ventilation of more than one hour in the last two weeks prior to surgery, history of pulmonary diseases (COPD, pneumonia, pneumothorax, ARDS, ILD) or PaO_2/FiO_2 ratio < 300 mmHg, history of cardiovascular diseases (coronary heart disease, congestive heart failure), sepsis or septic shock, progressive neuromuscular disease, previous thoracic surgery and pregnancy. Additional exclusion criteria were: severe changes of saturation and unstable hemodynamic status in the postoperative ICU which could not be managed without changing ventilator settings.

Research sample was obtained by consecutive sampling and block randomization to allocate subjects. Sample size was calculated based on unpaired numerical comparative analytic sample size formula, resulting in 35 samples, 17 samples for PEEP-5 group and 18 samples for PEEP-10 group (Figure 1). Standard deviations were obtained from prior studies.

Following subjects' characteristics were recorded: age, sex, height, actual body weight, predicted body weight (PBW), body mass index (BMI), confounding factors, surgical procedure, anaesthesia procedure, ASA physical status. After the patient was admitted to the ICU, endotracheal tube was connected to the ventilator with initial setting: Volume Control Ventilation, PEEP 5 cmH_2O with tidal volume target 6 ml/kg of PBW, respiratory rate 12 breaths/min and fraction of

inspiratory oxygen (FiO_2) from 30% to 50% to keep SpO_2 > 92%. At the time of measurements patients were sedated with fixed sedation protocol: Midazolam 1 mg/hour i.v along with Morphine 1 mg/hour i.v without muscle relaxant. Initial hemodynamic data was recorded from the monitor. EIT electrodes were applied encircling the thorax at 5th intercostal space. EIT values (TIV, EELI, RC) as the initial data were recorded using Dräger PulmoVista® 500. Baseline PO_2 and PCO_2 were obtained from intraoperative blood gas analysis (BGA). At minute-0, both groups had PEEP 5 cm H_2O applied. After the initial data was recorded, the PEEP value setting was changed in the subjects allocated to PEEP-10. Patients would be excluded if Peak Inspiratory Pressure (PIP) > 30 cmH_2O, required FiO_2 > 50% or the tidal volume > 8 ml/kg PBW. Hemodynamic and ventilation parameters monitoring were recorded within the first hour in the surgical ICU. EIT parameters (TIV, RC, EELI) were recorded every 20 minutes, while BGA was obtained after 1 hour of ventilator settings according to allocation.

Hypotension (MAP < 60 mmHg) was managed by fluid loading and vasopressor administration (ephedrine, phenylephrine, norepinephrine) via the central vein. Desaturation (SpO_2 < 92%) was managed by increasing tidal volume up to 8 ml/kg/PBW and/or increasing FiO_2 > 50%. Patient was excluded if PEEP had to be changed to manage hypotension and desaturation. If complication developed during the study patient was excluded and managed according to the hospital's standard operating procedure. After one hour of treatment, ventilator settings were returned to the PEEP 5 cmH_2O in PEEP-10 group. The length of mechanical ventilation requirement, length of hospital stay, pulmonary complications and ICU readmission within 7 days after ICU discharge were recorded.

Data analysis of group comparison was tested by unpaired T test and Mann-Whitney-U test for numerical variables and categorical variables were tested by Chi-Square test and Fischer's Exact test.

Results

The Consolidated Standards of Reporting Trials (CONSORT) flow diagram was pictured in Figure 1.

Subjects' characteristics were not different (Table I, Table II, Table III). Hypotension and desaturation were not detected during the study. There were no significant differences in intubation duration, ICU length of stay, PaO_2/FiO_2 ratio, PCO_2 values between both groups after the treatment.

There were 4 layers of ROIs to evaluate the effect of PEEP-5 and PEEP-10 in this study. The ROI was divided into anterior/non-dependent/ventral part and posterior/dependent/dorsal part along a horizontal line. This line was placed exactly in the middle of the vertical lung region dimension by dividing the total number of horizontal rows of EIT data in the ROI by 2. ROI 1-2 represented anterior (ventral) part, and ROI 3-4 represented posterior (dorsal) part. Based on measurements of TIV, EELI, RC parameters recorded by Electrical Impedance Tomography (EIT) we calculated and compared: regional anterior-posterior (rTIV) and global TIV values (gTIV) for PEEP-5 and PEEP-10 over time points (0, 20, 40, 60); TIV difference (rΔTIV) between anterior and posterior parts of the lungs over time points (20, 40, 60 min) for PEEP-5 and PEEP-10; Global EELI (gEELI) values for PEEP-5 and PEEP-10 over time points (20, 40, 60 min); Regional EELI (rEELI) values for anterior parts of the lungs in PEEP-5 and PEEP-10 group at 20, 40, 60 minute; Regional EELI (rEELI) values for posterior parts of the lungs in PEEP-5 and PEEP-10 group at 0, 20, 40, 60 minute; EELI difference (ΔEELI) either regional (rΔEELI) or global (gΔEELI) over study time which were calculated by measuring the difference between respective EELI at the time points 20-40-60 and EELI at minute-0 as a baseline; Regional Dynamic Compliance Difference/Change (ΔRC) in anterior parts of the lungs in PEEP-5 and PEEP-10 group at 0, 20, 40, 60 minute; Regional Dynamic Compliance Difference/Change (ΔRC) in posterior parts of the lungs in PEEP-5 and PEEP-10 group at 20, 40, 60 minute; Regional Dynamic Compliance Differences/Changes (ΔRC) between PEEP-5 and PEEP-10 for anterior and posterior parts of the lungs at 20, 40, 60 min.

Mean rTIV values in the anterior parts were significantly different between PEEP-5 and PEEP-10. Mean rTIV values in the posterior parts were significantly different between PEEP-5 and PEEP-10. TIV difference (rΔTIV) between the anterior and posterior parts showed no significant difference between both group at every time point taken (Table IV, Table V, Figure 2).

Data was presented in median.

At the start of measurements, both groups had global ΔEELI =0 at minute-0. The global ΔEELI (gΔEELI) values showed statistically significant difference at every measured time point between PEEP-5 group

and PEEP-10 group (Table VI, Figure 3).

Data was presented in median for global gΔEELI-20, gΔEELI-40 and in mean for gΔEELI-60.

There was significant difference of rΔEELI values for anterior parts of the lungs between both groups at every measured time point. There was significant difference of rΔEELI values for posterior parts of the lungs between both groups at every measured time point (Table VII and Figure 4).

Data was presented in median.

A. regional ΔEELI values of the anterior part of the lungs.
B. regional ΔEELI values of the posterior part of the lungs.

The RC values in anterior parts of the lungs values had significant difference between both groups, while RC values in posterior parts of the lungs values between both groups had significant difference only at minute-20 and minute-60 (Table VIII).

The RC difference (ΔRC) over time in anterior parts of the lungs compared to RC Minute-0 showed significant differences between both groups at every measured time point. The RC difference (ΔRC) over time in posterior parts of the lungs compared to RC Minute-0 showed significant differences between both groups at every measured time point (Table IX and Figure 5).

Data was presented in median.

A. ΔRC Value in the anterior part of the lungs compared to RC Minute-0.
B. ΔRC Value in the posterior part of the lungs compared to RC Minute-0

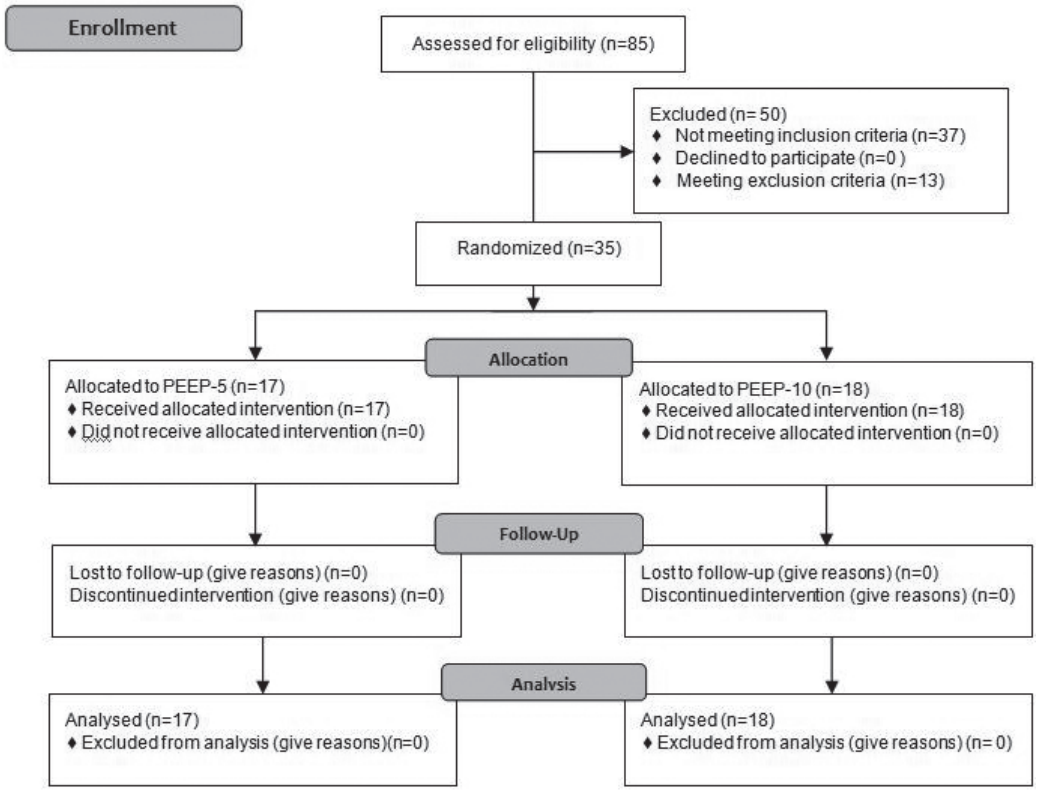

Figure 1. The Consolidated Standards of Reporting Trials (CONSORT) flow diagram

Table I. Basic subjects' characteristics

Characteristics	PEEP-5 (n = 17)	PEEP-10 (n = 18)	p-value*
Age (years)	41.6 ± 9.9	43.3 ± 12.3	0.649†
Sex – n (%) Male Female	 3 (17.6%) 14 (82.4 %)	 6 (33.3%) 12 (66.7%)	0.500‡
Height (cm)	155 (148 – 170)	157 (149 – 183)	0.386§
Weight (kg)			
Actual	51.94 ± 10.17	51.14 ± 9.68	0.813†
Predicted	47.87 (41.50 – 66.02)	49.69 (42.41 – 3.35)	0.369c
BMI (kg/m^2)	21.02 ± 2.87	20.25 ± 2.89	0.433†
Confounding factors – n (%)			
Functional addiction	1 (5.9%)	3 (16.7%)	0.603‡
Preoperative weight loss > 10%	4 (23.5%)	4 (22.2%)	1.000‡
Preoperative decrease of consciousness	0	1 (5.6%)	1.000‡
Preoperative steroid use	4 (23.5%)	6 (33.3%)	0.711‡
Smoking	1 (5.9%)	2 (11.1%)	1.000‡
Alcohol consumption	0	0	-
Intraoperative transfusion	11 (64.7%)	12 (66.7%)	1.000‡
Surgery procedure – n (%)			1.000‡
Craniotomy	7 (41.2%)	7 (38.9%)	
Laparotomy			
Digestive	4 (23.5%)	5 (27.8%)	
Urology	0	0	
Gynecology	6 (35.3%)	6 (33.3%)	
Vascular	0	0	
Anesthesia procedure			1.000‡
General anesthesia	7 (41.2%)	7 (38.9%)	
General anesthesia + regional	10 (58.8%)	11 (61.1%)	
Physical status			1.000‡
ASA-1	2 (11.8%)	0	
ASA-2	10 (58.8%)	12 (66.7%)	
ASA-3	5 (29.4%)	6 (33.3%)	

*P-value is significant if $p < 0.05$. †Unpaired T-test; ‡Chi-Square test; §Mann-Whitney-U test.

Table II. Intraoperative data

Characteristics	PEEP-5 (n = 17)	PEEP-10 (n = 18)	p-value*
Tidal volume for predicted body weight (ml/kgPBW)	7.47 ± 0.60	7.03 ± 0.89	0.094†
Recruitment maneuver – n	0	0	
PEEP usage– n (%)	8 (41.7%)	10 (55.6%)	0.869‡
Volume of fluid administrated (ml)			
Crystalloid	2500 (1000 – 7000)	2000 (1000 – 8000)	0.072§
Colloid	1000 (0 – 1500)	500 (0 – 1500)	0.143§
Volume of intraoperative transfusion (ml)	693 (0 – 2280)	381.5 (0 – 1515)	0.052§
Surgery duration (minutes)	458.82 ± 106.87	390 ± 126.02	0.092†
MAP decline > 20% – n (%)	11 (64.7%)	9 (50%)	0.591‡
Vasopressor administration (%)	9 (52.9%)	6 (33.3%)	0.407‡
PF ratio	414.42 ± 51.40	386.04 ± 78.37	0.217†

*P-value is significant if $p < 0.05$. †Unpaired T-test; ‡Chi-Square test; §Mann-Whitney-U test.

Table III. Subjects' data during and after treatment

Characteristics	PEEP-5 (n = 17)	PEEP-10 (n = 18)	p-value*
PIP (cmH_2O) Minute-0 Minute -20 Minute -40 Minute -60	 13.12 ± 2.49 13.12 ± 2.59 13.18 ± 2.72 13.00 ± 2.50	 12.61 ± 2.23 20.83 ± 2.17 20.61 ± 1.75 20.39 ± 1.75	 0.530† 0.000† 0.000† 0.000†
Desaturation – n (%)	0	0	
Hypotension – n (%) MAP (mmHg) Minute -0 Minute -20 Minute -40 Minute -60	0 83.67 (70 – 121) 83 (72.33- 123.33) 83 (72.33 – 114) 88.68 ± 12.50	0 83.83 (71 – 102.33) 83.66 (70 – 102.67) 85,83 (71.67 – 109) 87.46 ± 9.51	 0.960‡ 0.987‡ 0.856‡ 0.746†
PF ratio after treatment	525.94 ± 77.27	551.28 ± 72.61	0.325†
PCO_2 after treatment (mmHg)	34 (26.8 – 47.3)	31.8 (23.9 – 53.7)	0.499‡
Intubation duration (hours)	15 (5 – 36)	14 (6 – 35)	0.812†
Length of stay in ICU (days)	2 (1 – 6)	1.5 (1 – 4)	0.226‡
Pulmonary complications 7days post-operative – n (%)	0	0	
ICU readmission – n (%)	0	0	
ICU discharge condition – n (%) Alive	 17 (100%)	 18 (100%)	
Day-28 post-operative – n (%) Alive	 17 (100%)	 18 (100%)	

*P-value is significant if $p < 0.05$. †Unpaired T-test; ‡Chi-Square test

Table IV. TIV Value in the anterior and posterior part of the lungs

Timepoints	PEEP-5 (%/cmH_2O)	PEEP-10 (%/cmH_2O)	P-value*
Anterior TIV			
Minute 0	53 (46-64)	52 (45-61)	0.723†
Minute-20	52 (48-63)	50 (48-56)	0.118†
Minute-40	51 (48-58)	49 (48-52)	0.022†
Minute-60	51.06 ± 2.38	49.11 ± 0.96	0.011‡
Mean	53 (46-54)	52 (45-61)	0.002†
Posterior TIV			
Minute-0	47 (36-54)	48 (39-55)	0.732†
Minute-20	48 (37-52)	50 (44-52)	0.096†
Minute-40	49 (42-52)	51 (48-52)	0.014†
Minute-60	48.94 ± 2.38	50.89 ± 0.96	0.011‡
Mean	47 (36-54)	48 (39-55)	0.002†

*P-value is significant if $p < 0.05$. †Mann-Whitney-U test; ‡ Unpaired T-test

Table V. TIV value difference (ΔTIV) between the anterior part and posterior part of the lungs

Timepoints	PEEP-5 (%)	PEEP-10 (%)	p-value*
Minute-0	8 (2 – 28)	8 (2 – 22)	0.490
Minute-20	4 (0 – 26)	2 (0 – 12)	0.012
Minute-40	3 (0 – 16)	3 (0 – 4)	0.304
Minute-60	2 (0 – 16)	2 (0 – 4)	0.872
Mean	4 (1.5 – 21.5)	3.7 (1.0 – 9.5)	0.525

*Mann-Whitney-U test, P-value is significant if $p < 0.05$.

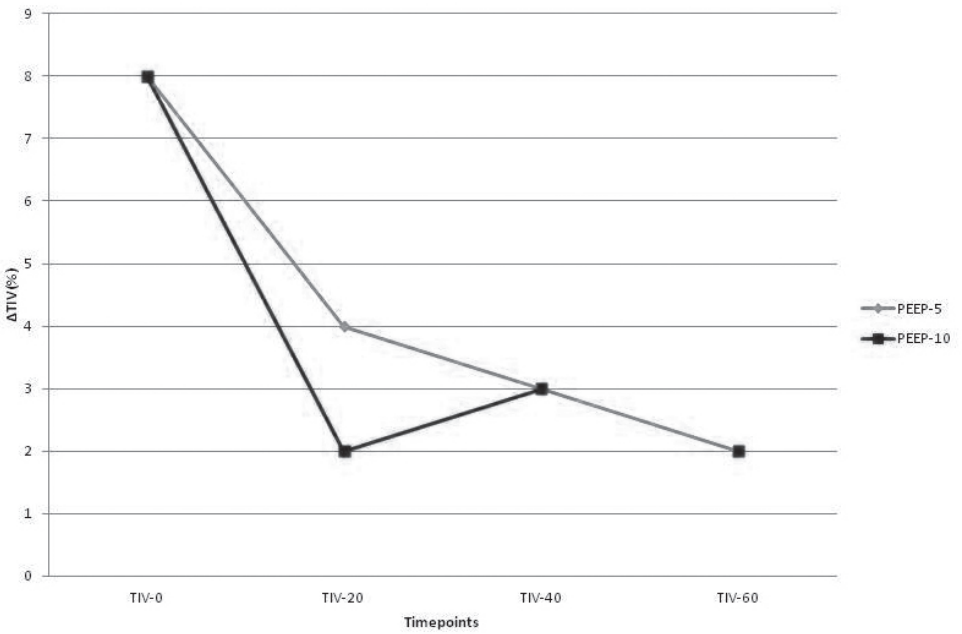

Figure 2. TIV value difference (ΔTIV) between the anterior part and posterior part of the lungs

Table VI. Global ΔEELI (gΔEELI) Value

Timepoints	PEEP-5 (impedance)	PEEP-10 (impedance)	p-value*
Minute-20	0.100 (0.010 – 0.380)	0.600 (0.200 – 0.950)	< 0.001[a]
Minute-40	0.020 (0 – 0.090)	0.055 (0.030 – 0.130)	< 0.001[a]
Minute-60	0.002 ± 0.015	0.027 ± 0.015	< 0.001[b]
Mean	0.02 (-0.03 – 0.38)	0.055 (-0.01 – 0.95)	< 0.001[a]

*P-value is significant if $p < 0.05$. †Mann-Whitney-U test; ‡Unpaired T-test.

Table VII. rΔEELI value of the anterior part and posterior part of the lungs

Timepoints	PEEP-5 (impedance)	PEEP-10 (impedance)	p-value*
rΔEELI anterior			
Minute-20	0.05 (0 – 0.18)	0.28 (0.10 – 0.47)	< 0.001
Minute-40	0.01 (0 – 0.03)	0.02 (0.01 – 0.07)	0.001
Minute-60	0 (-0.02 – 0.01)	0.01 (0 – 0.02)	< 0.001
Mean	0.01 (-0.02 – 0.18)	0.02 (-0.01 – 0.47)	< 0.001
rΔEELI posterior			
Minute-20	0.05 (0 – 0.20)	0.35 (0.10 – 0.48)	< 0.001
Minute-40	0.01 (0 – 0.06)	0.04 (0,02 – 0.09)	0.001
Minute-60	0.01 (0 – 0.03)	0.02 (0 – 0.03)	< 0.001
Mean	0.01 (-0.01 – 0.2)	0.035 (0 – 0.48)	< 0.001

*Mann-Whitney-U test, P-value is significant if $p < 0.05$.

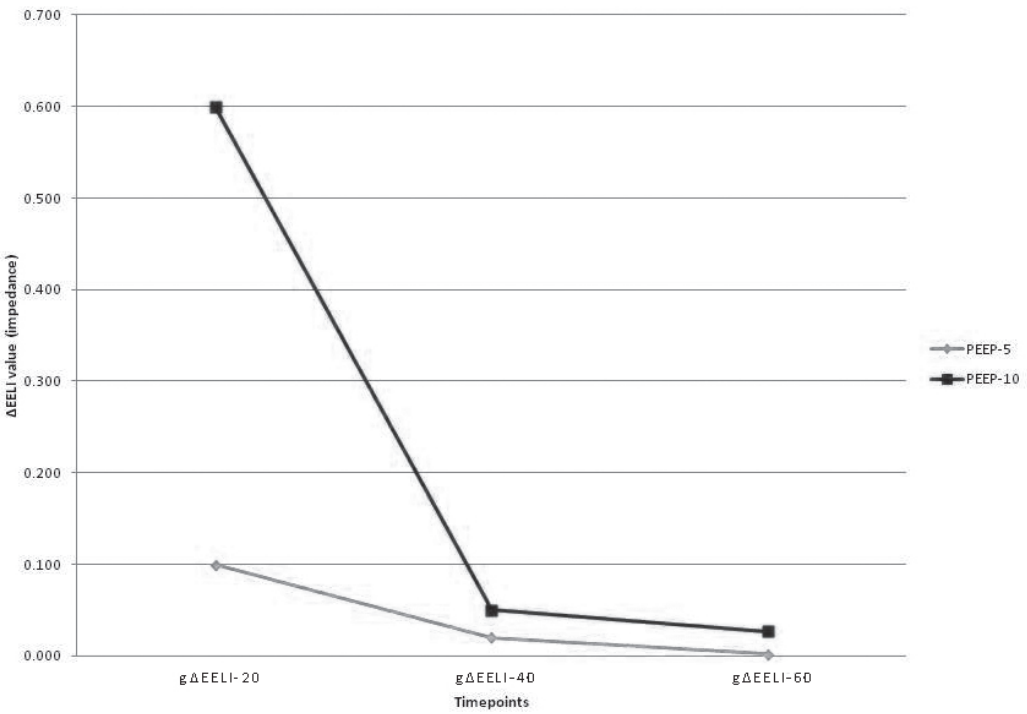

Figure 3. Global ΔEELI (gΔEELI) Value

Table VIII. RC Value in the anterior and posterior part of the lungs

Timepoints	PEEP-5 (%/cmH_2O)	PEEP-10 (%/cmH_2O)	P-value*
RC anterior			
Minute-0	6.40 (4.08-15.33)	7.00 (4.60-15.00)	0.613
Minute-20	6.30 (4.17-16.00)	4.90 (3.40-8.17)	< 0.001
Minute-40	6.00 (3.77-17.00)	4.80 (1.20-6.86)	< 0.001
Minute-60	6.25 (4.08-16.33)	4.90 (3.43-6.86)	< 0.001
Mean	6.25 (3.77-17.00)	5.09 (1.2-15.00)	<0.001
RC posterior			
Minute-0	5.20 (3.27-18)	6.35 (3.25-13.00)	0.386
Minute-20	6.38 (3.70-17.33)	4.67 (3.27-8.5)	0.032
Minute-40	6.25 (3.92-16.33)	4.85 (3.64-7.43)	0.077
Minute-60	6.25 (4.20-17.00)	5.05 (3.64-7.63)	0.029
Mean	6.25 (3.27-18)	5.1 (3.25-13)	0.078

*Mann-Whitney-U test, P-value is significant if $p < 0.05$.

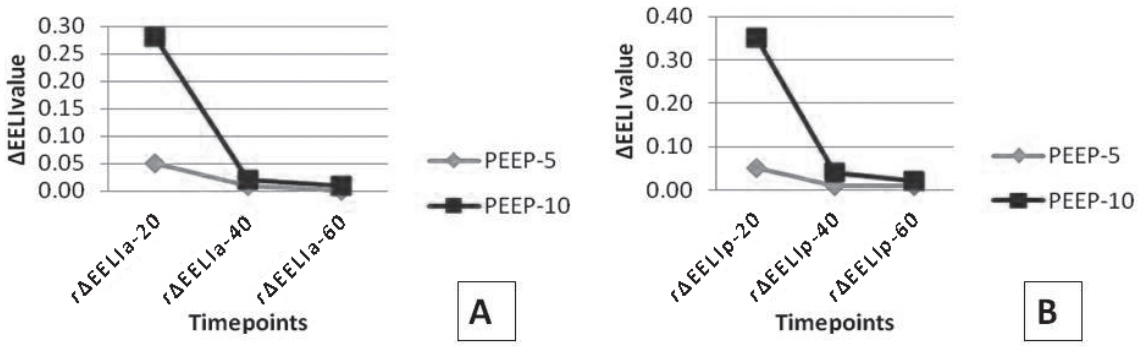

Figure 4. Regional rΔEELI value

Table IX. RC Value Changes (ΔRC) in the anterior and posterior part of the lungs compared to CR Minute-0

Timepoints	PEEP-5 (%/cmH_2O)	PEEP-10 (%/cmH_2O)	P-value*
ΔRC anterior			
Minute-20	0 {(-2) – 1.8)}	-2.2 {(-7.1) – 0.01}	< 0.001
Minute-40	-0.25 {(-2.08) – 1.67}	-2.72 {(-8.14) – (-0.6)}	< 0.001
Minute-60 Mean	-0.3 {(-2.25) – 2.00} -0.1 {(-2.25) – 2.00}	-2.41 {(-8.14) – (-0.15)} -2.6 {(-8,14) – 0.01}	< 0.001 < 0.001
ΔRC posterior			
Minute-20	0.1 {(-1.57) – 1.53}	-1.49 {(-7.9) – 0.75}	< 0.001
Minute-40	0.25 {(-1.67) – 1.53}	-1.71 {(-7.22) – 1.65}	< 0.001
Minute-60 Mean	0.5 {(-1.86) – 1.62} 0.25 {(-1.86) – 1.62}	-1.64 {(-7.9) – 1.85} -7.9 {(-7.9) – 1.85}	0.001 < 0.001

*Mann-Whitney-U test, P-value is significant if $p < 0.05$.

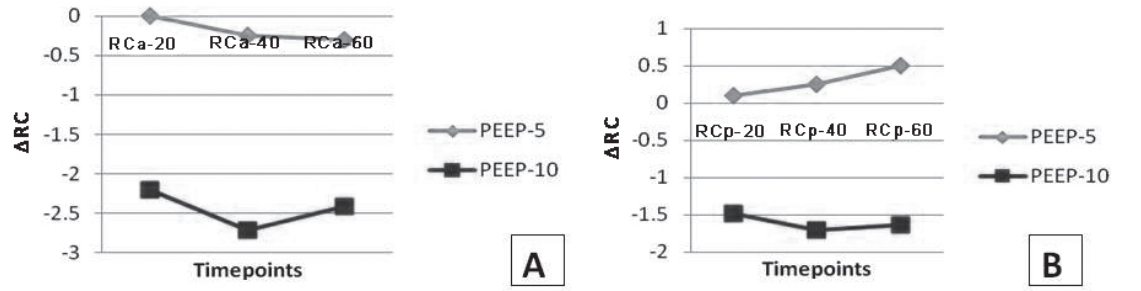

Figure 5. RC Value Changes/Difference (ΔRC)

Discussion

Several settings for mechanical ventilation e.g. tidal volume, oxygen fraction, respiratory rate and PEEP were studied to find optimal settings for alveoli recruitment, maintaining thus so called open lung status but at the same time avoiding overstretch of alveoli as much as possible [9].

EIT appears to be practical bedside non-invasive and real-time imaging modality for measuring regional and global lung ventilation along with compliance in mechanically ventilated patients helpful in setting in

open lung strategy thus preventing atelectasis. EIT in terms of ventilation distribution imaging seems to be as good as CT-scan exam.

This study compares the influence of lower PEEP-5 and higher PEEP-10 on the global and regional ventilation distribution in postoperative patients undergoing mechanical ventilation in surgical ICU monitored with EIT (PulmoVista 500®) by assessing Tidal Impedance Variation (TIV), End Expiratory Lung Impedance (EELI) and Regional Compliance (RC) from first minutes, and up to 60 minutes. Because of the long--term stability of the EIT signal which has a variation within range of 1.5-6.1% it seems to be very reliable tool for this very purpose [10].

Ventilation distribution is influenced by factors like preexisting pathological condition of the lungs, BMI, body position, pain induced by mechanical ventilation, type and length of surgery, sedation level, ventilator settings and mode of mechanical ventilation. The inclusion and exclusion criteria into the study were selected to eliminate as much as possible abovementioned factors and thus obtaining roughly homogenous pool of subjects.

Intraoperative conditions (ventilator settings, fluid therapy, vasoactive drugs) varied among subjects and may have influenced subject's lungs ventilation status during the study itself. However, there were no statistical differences in intraoperative baseline tidal volume, PEEP, PaO_2/FiO_2 ratio, administration of fluid, blood transfusion and vasoactive drugs between the two groups. In postoperative period similar ventilator settings (except for PEEP level) and sedation protocol were set to even further eliminate factors confounding ventilation distribution and hence study outcome.

Based on the parameters assessed by EIT monitoring, a good ventilation distribution was recognized when there was a homogeneity between lung regions (anterior/ventral and posterior/dorsal) represented by Tidal Impedance Variation difference (ΔTIV) < 7%. Open lung status was recognized when: a) the administration of higher PEEP value created larger TIV supposedly due to larger lung volume after alveolar recruitment; b) when increasing EELI (global and regional) was proportional to increasing PEEP supposedly due to larger lung volume after alveolar recruitment. Lung distention was evaluated using Regional Dynamic Compliance Change (ΔRC) in the anterior and posterior parts of the lungs.

At the beginning of the trial (minute-0) both groups received PEEP-5. In our study, there was no difference at the minute-0 in TIV values between both groups. Higher TIV values in the anterior parts of lungs was observed at minute 20-40-60 in both groups meaning the ventilation was shifted to the non--dependent lung, and the ventilation of posterior part or the dependent lung was reduced (Table IV) [11]. In supine position, patients with mechanical ventilation have a higher ventilation distribution to the anterior parts, especially in controlled or intermittent positive pressure under sedation or muscle relaxant [8].

The ΔTIV (TIV difference between anterior and posterior part of the lungs) was measured to evaluate homogeneity of these parts in terms of ventilation, with less than 7% difference in TIV difference (ΔTIV) showing homogenous ventilation [12]. The ΔTIV 8% difference at the baseline in our study represented non-homogeneity within the two regions and we think it may have been caused by some collapsed alveoli (Table V, Figure 2). There are collapsed alveoli in atelectasis and other lung pathology as well such as pneumothorax, lung edema and pleural effusion, COPD, ILD [11]. Exclusion criteria before the study and post-operative examinations excluded above mentioned lung pathology in our subjects, so it can be drawn by exclusion from baseline/initial TIV difference (ΔTIV) > 8% that there was some postoperative atelectasis in our subjects.

Analysis of rTIV and gTIV values in PEEP-5 and PEEP-10 showed statistically significant difference ($p < 0.05$) in measurement taken at minute 20 of the study. The ΔTIV changed after higher PEEP administration in the PEEP-10 group at minute-20 (Table V). There was a significant difference in TIV values at minute-20 where PEEP-10 had a more homogenous ventilation distribution than PEEP-5 which was not observed in other time points and can be interpreted as PEEP-10 achieving ventilation homogeneity faster than PEEP-5. These results were consistent with Blankman's study concluding that TIV values in lower PEEP was higher in the anterior lung, and titrating PEEP up will increase TIV values in the posterior lung [9]. PEEP-5 had a slower opening of collapsed lungs than PEEP-10 and PEEP-5 caught up with PEEP-10's pace after more than 20 minutes. At minute-40 and 60, the median of both groups had ΔTIV < 7%.

TIV difference (ΔTIV) between the anterior and posterior parts showed no significant difference between both group at every time point taken. The

decreasing ΔTIV over time suggests more homogenous ventilation in anterior and posterior parts of the lungs, although the results were not significantly different between PEEP-5 and PEEP-10.

The redistribution of ventilation downwards may have been caused by the transition of controlled ventilation to assisted ventilation since all the patients only received sedation without muscle relaxant and with time showed some respiratory drive on their own. The redistribution is consistent with that seen in the assisted ventilation mode causing a continuous displacement of the anterior (ventral) non-dependent ventilation towards the posterior (dorsal) parts of the lung [8].

PEEP-5 had a slower opening of collapsed lungs than PEEP-10 and PEEP-5 caught up with PEEP-10's pace after more than 20 minutes. There was a significant difference on the TIV values at minute-20 where PEEP-10 had a more homogenous ventilation distribution than PEEP-5 which was not observed in other time points and can be interpreted as PEEP-10 achieving ventilation homogeneity faster than PEEP-5.

The administration of higher PEEP in the initial phase of ventilator use in post-operative patients was more effective and faster in creating homogenous ventilation distribution. In PEEP-5 group, at minute-40 and 60, there was one subject with ΔTIV more than 7% between the anterior and posterior part, meaning that the homogenous condition in the particular subject was not complete after 1 hour of observation. Further observation showed no differences in lung complications, intubation duration and length of hospital stay of this individual_compared to other subjects, which could be explained by his good pre-operative heart and lungs condition [13].

The second parameter taken was the End-Expiratory Lung Impedance (EELI) regional and global showing impedance changes in lungs as a whole or in lung regions (anterior and posterior respectively) due to PEEP administration. At the start of measurements, both groups had global ΔEELI (gΔEELI) and regional ΔEELI (rΔEELI) =0 at minute-0. The global (gΔEELI) values showed statistically significant difference at every measured time point between PEEP-5 group and PEEP-10 group (Table VI, Figure 3).

EELI difference (ΔEELI) either regional (rΔEELI) or global (gΔEELI) is representing changes in lungs' end-expiratory impedance over the study time. rΔEELI and gΔEELI were calculated by measuring the difference between respective EELI at the time points 20-40-60 and EELI at minute-0 as a baseline. Positive ΔEELI difference (ΔEELI) means that atelectasis is diminished and collapsed alveoli are filled with air. Global EELI difference (gΔEELI) was the total change of EELI in all lungs regions, while regional (rΔEELI) measured EELI in anterior or posterior parts of the lungs [12]. Global EELI difference (gΔEELI) were positive and significantly higher in PEEP-10 at every time point, with the largest value at minute-20 in PEEP-10 group. The mean gΔEELI was also significantly higher in PEEP-10 group (Table VI). These results are consistent with the study showing increasing ΔEELI are in step with higher PEEP [10].

There was significant difference of rΔEELI values for anterior and posterior part of the lungs between both groups at every measured time point (Table VII and Figure 4). Regional EELI difference (rΔEELI) shows statistically significant higher values in PEEP-10 ($p < 0.05$) at every time point, especially in the posterior part (Table VII). These results are consistent with the assisted mode ventilation produced shift in ventilation from anterior to posterior lung regions and higher PEEP resulting in shifting the ventilation to more posterior lung regions in supine position [8]. There was a negative rΔEELI in the anterior parts observed in PEEP-5 group patient at minutes-60, which showed the impedance in the anterior lungs at minute-60 was smaller than at minute-40, which can be interpreted as atelectasis from de-recruitment of some alveoli with time (Table VII).

In our study, both global and regional EELI show significant differences between both groups, consistent with EELI increase with higher PEEP. The positive ΔEELI values declined during the study over time within the same PEEP group, and these declines may have resulted from loss of muscle tone due to the use of sedations in our patients. Positive ΔEELI alone may have increased without recruitment of more collapsed alveoli but with further inflation of already open alveoli. PEEP-induced changes in ΔEELI can represent recruitment-derecruitmet and inflation-deflation of already ventilated lungs in our patients. Higher PEEP contributes to better alveoli opening and recruitment, however ΔEELI alone was not sufficient to define the optimal PEEP setting.

Regional Dynamic Compliance Change (RC) was calculated by dividing regional TIV values by the difference between PIP and PEEP. RC represents lungs' dynamic compliance due to ventilator pressure changes

[9,11]. Regional Dynamic Compliance difference (ΔRC) is representing changes in lungs' dynamic compliance over the study time. It was calculated by measuring the difference between RC at the time points 20-40-60 and RC at minute-0 as a baseline. RC values in PEEP-5 group were higher than in PEEP-10 particularly in the anterior parts of the lungs (Table VIII). There was a significant RC difference (ΔRC) in both anterior and posterior parts of the lung at every time points between the groups, but ΔRC in the PEEP-10 group was more negative than in PEEP-5 group (Table IX, Figure 5). Negative ΔRC in the PEEP-10 (group receiving higher PEEP) means that RC values at the time points were lower than at minute-0. It seems to indicate that too high PEEP was applied and may have lowered RC. Decreasing RC with increasing PEEP points to over-stretched less compliant alveoli, but on the other hand decreasing RC with lowering PEEP shows collapsed alveoli requiring high critical opening pressure. The decrease in RC values (more negative ΔRC) was in line with the increase of Peak Inspiratory Pressure (PIP) in the PEEP-10 group.

In conclusion, the anterior and posterior parts of the lungs were rather overstretched by the higher PEEP (PEEP-10), while at the lower PEEP-5 the alveoli of the anterior parts were slightly overinflated and of the posterior part were recruited. The overdistended lung with low RC produced by PEEP-10 is more difficult to ventilate and only with higher PIP and it was seen in reduced RC in our subjects from PEEP-10 group. Further research should confirm the decreasing EELI with time study as a sign of recurrent atelectasis that is attributed to oversedation in some subjects; decreasing TIV difference with time study as a sign of downward shift in ventilation that is attributed to return of spontaneous ventilation and application of fixed hybrid PEEP initially higher to open the lungs quickly and then switch to lower PEEP that still prevent atelectasis.

Conclusion

Distribution of ventilation using EIT imaging between both groups was only significantly different at minute-20 in all measured parameters, but did not differ statistically within the first hour of postoperative mechanical ventilation. Lung impedance changes and dynamic compliance changes between PEEP 10 cmH_2O and PEEP 5 cmH_2O were significantly different at both anterior and posterior part of lung. Higher PEEP influenced regional ventilation, mainly in posterior parts of the lungs. PEEP 5 cmH_2O can be applied to prevent post-operative atelectasis, whereas PEEP 10 cmH_2O can cause over distention especially in anterior parts of the lungs.

Funding/Support

The study was supported by Department of Anaesthesiology and Intensive Care, Faculty of Medicine, University of Indonesia.

Conflict of interest
None

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