IMPACT OF THE E- SIGH RECRUITMENT MANOEUVRE ON OXYGENATION AND AERATION OF THE LUNG IN PATIENTS WITH ALI/ARDS

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Abstract: Recruitment manoeuvre (RM) can be defined as a strategy to increase transient trans-pulmonary pressure. This study was aimed to evaluate the efficacy of e-sigh recruitment manoeuvre on patients with acute respiratory distress syndrome (ARDS). Thirty patients who fulfilled ARDS criteria were included in this study. They received extended sigh recruitment manoeuvre (e-sigh) consisting of positive end expiratory pressure maintained at 10 cm H2O above the lower inflection point of the pressure – volume curve for 15 minutes. We assessed the effects of these manoeuvres on: gas exchange and haemodynamic and respiratory mechanics at two time points. The patients had had a chest x-ray and thoracic computed tomography scan of the lungs after a day of the last recruitment manoeuvre, before inclusion was studied. E-sigh recruitment manoeuvre had a good impact on gas exchange and aeration of the lung and collapsed alveoli were reopened, which was objectively evaluated on x-ray and a CT scan of the lung.

Key words: ARDS, Alveolar recruitment, extended sigh, positive end expiratory pressure.

Introduction

Acute respiratory failure is manifested clinically with variable degrees of respiratory distress, an abnormal arterial blood partial pressure of oxygen or
carbon dioxide, low saturation of oxygen in arterial blood and low peripheral saturation (SpO₂). The application of mechanical ventilation in this setting can be life-saving [1]. Acute respiratory distress syndrome is characterized by acute onset of hypoxaemia PaO₂/FiO₂ < 26.7 kPa, lung inflammation with bilateral infiltrations on a frontal chest radiograph, increased vascular permeability, and pulmonary arterial wedge pressure less than 2.5 kPa (PAWP < 2.5 kPa) [2]. By definition ARDS is a lung permeability oedema, which means that the alveolar are not collapsed but filled with liquid [3]. Reduction of tidal volume, plateau pressure (Pplat) < 35 cm H₂O and adequate positive end expiratory pressure to improve oxygenation, FiO₂ < 0.5 are recommended for the ventilatory management of ARDS [4–7], as basic rules for protective ventilation. It is well known that reduction in tidal volume promotes a decrease in lung aeration [8, 9]. Several studies recommend the adjunction of recruitment manoeuvres (RM) to mechanical ventilation, to limit alveolar derecruitment induced by low tidal volume [10–12]. During ongoing management of ALI/ARDS, lung recruitment manoeuvres require a brief increase of the alveolar pressure to a level above the recommended, in order to aerate lung units filled with oedema or inflammatory cells. Recruitment is a physiological process that reopens previously gasless lung units exposed to positive pressure ventilation [13]. Until now there have been many studies evaluating the effects of recruitment manoeuvres not only on gas exchanges but on respiratory mechanics as well [14–20].

Aim of study

The aim of this study is to evaluate the effects of e-sigh recruitment manoeuvre not only on oxygenation, but on aeration of the lung as well. For that purpose chest x-ray and thoracic computed tomography scan (CT) of the lung were used as safe and objective methods for evaluation of the impact of recruitment manoeuvres on aeration of the lung. CT scan and chest x-ray were performed before recruitment manoeuvres as confirmation of diagnose and one day after the last recruitment manoeuvres. We established that the last recruitment manoeuvre would be considered the manoeuvre after which two consecutive gas analyses (the first taken at 7 h, and the last one at 19 h) would fulfill these criteria: PaO₂ > 12.9 kPa and PaO₂/FiO₂ > 40 kPa.

Materials and Methods

This study was conducted in the ICU in our hospital throughout 2011. We obtained informed consent from the patients families, as our patients were sedated during mechanically ventilation. Thirty patients who met the ARDS cri-
teria of the American-European consensus conference [2] were included in this study. Exclusion criteria were age under eighteen years, chronic respiratory insufficiency, chronic obstructive pulmonary disease, asthma, restrictive respiratory insufficiency, bronchopleural fistula, intracranial hypertension, and haemodynamic instability despite support therapy.

Patients were orally intubated, sedated with 0.2–0.4 µg/kg/min and midazolam 4 mg/h, and ventilated with Evita 2 Dura ventilator (Dragger, Germany), according to the recommendation of the Consensus Conference of the American College of Chest Physicians [21]. All patients had an arterial catheter and a central venous catheter. Haemodynamic data were collected from Data Ohmeda monitors. Gas analyses were measured from blood samples taken from the arteria radialis. Partial pressure of oxygen in venous blood was measured from blood samples taken from the interior jugular vein. We used a Bd preset arterial blood collection syringe, and blood samples were analysed with an AVL 995HB blood gas analyser. Patients were ventilated by volume control ventilation with a tidal volume (Vt) 6 ml/kg and the respiratory rate was 12 respirations per minute. Positive end expiratory pressure (PEEP) and fraction of inspired oxygen (FiO₂) were set to obtain partial pressure of carbon dioxide (PaCO₂) equal to or less than 6.13 kPa. We continuously monitored compliance, tidal volume, respiratory rate, plateau pressure and peak airway pressure on the display of Evita 2 Dura ventilators (Drager, Germany). The images of pressure volume curves were obtained under quasi-static conditions during mechanical ventilation [22]. An examiner who was responsible for the collection of the data and statistical analyses was ‘blinded’ because of the protocol, before the RM, haemodynamic status of the patient was checked. Noninvasive blood pressure, pulse and electrocardiogram (ECG) were monitored on Data Ohmeda monitors. When fluid administration or vasopressors were not enough for haemodynamic stability, we did not start the recruitment manoeuvre. Patients were ventilated in zero end expiratory pressure (ZEEP) for five minutes. Compliance of the lung was recorded and lower inflection point (LIP) and upper inflection point (UIP) was established on the pressure – volume curve of the ventilator. We used a lung injury score (LIS) to assess patients for the extent of acute pulmonary damage. Patients with 0 score indicated no lung injury, lung injury score: 0,1–2.5 indicated mild to moderate lung injury and lung injury score > 2.5 indicated severe lung injuries (ARDS). After establishing the LIS, we proceeded with the recruitment manoeuvre. Extended sigh recruitment manoeuvre: We ventilated patients at zero PEEP in a volume control mode of ventilation for fifteen minutes. Then we applied positive end expiratory pressure (PEEP) 10 cmH₂O above LIP for 15 minutes. If plateau pressure was higher than upper inflection point , or higher than 35 cmH₂O, we decreased tidal volume. During the recruitment manoeuvre maximum peak pressure was limited to 50 cmH₂O. In case of severe haemodynamic instability (systolic pressure < 70 mmHg, heart rate < 50 breaths
per minute or hypoxaemia $\text{SpO}_2 < 80\%$) the recruitment manoeuvre was immediately stopped. Before recruitment manoeuvres (time point 1) and one hour after the recruitment manoeuvre (time point 2) we collected data from: 1. haemodynamic parameter: heart-rate, mean arterial pressure (MAP); 2. gas analyses taken from blood samples from a. radialis were: partial pressure of oxygen ($\text{PaO}_2$), partial pressure of carbon dioxide ($\text{PaCO}_2$), saturation of oxygen (sat $\text{O}_2$) and partial pressure of oxygen in the interior jugular vein ($\text{PvO}_2$). Partial pressure/fraction of inspired oxygen ($\text{PaO}_2/\text{FiO}_2$) ratio was mathematically established. 3. respiratory mechanics was read from the display of the ventilator: compliance, plateau pressure ($p_{-\text{plat}}$), peak airway pressure ($\text{PIP}$) and positive end expiratory pressure (PEEP). Lower inflaction point (LIP) and upper inflaction point (UIP) were read on a pressure – volume curve [23–26]. Two chest x-ray films were taken during this study. The first was before we started with the recruitment manoeuvres. We were looking for presence of intense parenchimal opacification (focal or homogeneous increase in density). The extent of these changes was scored 0 none, 1-focal, 2-diffuse. We were looking for signs of pneumothorax, pneumo-mediastinum, as an assessment of a safely-performed recruitment manoeuvre. The second chest x-ray was taken one day after the last recruitment manoeuvre. A thoracic computed tomography scan was taken before recruitment manoeuvres and one day after the last recruitment manoeuvre. The thoracic computed tomography scan procedure (CT): Lung scanning was performed in a supine position from the apex to the diaphragm by Ge Bright Speed Elite General Elektric (Ge) USA. All images were observed at a window width of 1600 Hounsfield Units (HU) and a window level of 600 HU. The exposures were taken without contrast materials. Protocol CT was performed before RM at zero PEEP and one day after the last RM when gas analysis of the patients fulfilled these criteria: $\text{PaO}_2 > 12.9 \text{ kPa and PaO}_2/\text{FiO}_2 > 40 \text{ kPa}$. During the CT scan we monitored: pulse oxymetry, electrocardiogram and blood pressure. If there was haemodinamic instability or subordinate (periferal) desaturation $\text{SpO}_2 \leq 85\%$ we stopped the procedure. Qualitative assessment of lung was performed by applying CT scan ARDS criteria: focal loss of aeration, diffuse loss of aeration. [27]

**Statistical analysis**

All data are expressed as mean and standard deviation. Baseline clinical and ventilator data are compared by student t-test for parametric data and Mann-Whitney U test for nonparametric data, and the Kolmogorov Smirnov test was used for verification of normal distribution of quantative data. The statistical significance level was fixed at 0,05.
Results

Patients’ characteristics are shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Patients’ characteristics</th>
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<tbody>
<tr>
<td><strong>Variable</strong></td>
</tr>
<tr>
<td>Age (year)</td>
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<tr>
<td>Gender (M/F)</td>
</tr>
<tr>
<td>LIS</td>
</tr>
<tr>
<td>Primary illness</td>
</tr>
<tr>
<td>Sepsis</td>
</tr>
<tr>
<td>Pancreatitis</td>
</tr>
<tr>
<td>Chest trauma</td>
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<tr>
<td>Pneumonia</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD. (p < 0.05) e- sigh = extended sigh, M = male, F = female, LIS = lung injury score

The average age of our study was 48.6 years; there were 17 male patients and 13 women. Lung injury scale higher than 2.0 ± 1.8 indicated that our patients had either acute lung injury (ALI) or acute respiratory distress syndrome (ARDS). Primary illness that caused ARDS was: sepsis in 11 patients, pancreatitis in 10 patients, chest trauma in 5 patients and pneumonia in 4 patients.

There is a significant difference in PaO₂, oxygen saturation (Sat O₂) before the recruitment manoeuvres and after recruitment manoeuvres (p = 0.0000). There is a statistically significant difference in PaO₂/FiO₂ before and after the recruitment manoeuvre. The lowest mean value of PaCO₂ in the e- sigh group was achieved after the recruitment manoeuvre. There are no statistical differences in PaCO₂ before and after the e-sigh recruitment manoeuvre. Although there is an improvement in partial pressure of oxygen in venous blood (PvO₂), there are not statistical differences before and after the recruitment manoeuvre.

According to the post hoc Turkey HSD, e- sigh recruitment manoeuvre had a positive impact on PaO₂, PaO₂/FiO₂, O₂, saturation of oxygen in arterial blood manoeuvres (p = 0.000). Table 2.

Haemodynamic changes: There are no differences in heart rate and mean arterial blood pressure five minutes before the recruitment and sixty minutes after the recruitment. Respiratory mechanics: Highest values of compliance are achieved during the recruitment manoeuvre in both groups. There was greater improvement in compliance during the e-sigh recruitment manoeuvre.

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Table 2

**Physiological and ventilator variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before RM</th>
<th>After RM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haemodynamic</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>MAP (mmHg)</td>
<td>107,9 ± 15,8</td>
<td>105,9 ± 15,6</td>
<td>0,21</td>
</tr>
<tr>
<td>HR (breaths per minute)</td>
<td>100,7 ± 19,1</td>
<td>97,2 ± 19,6</td>
<td>0,30</td>
</tr>
<tr>
<td>Arterial blood gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PvO2 (kPa)</td>
<td>4,9 ± 1,0</td>
<td>5,2 ± 0,9</td>
<td>0,09</td>
</tr>
<tr>
<td>PaO2 (kPa)</td>
<td>9,1 ± 2,1</td>
<td>14,8 ± 1,8</td>
<td>0,00*</td>
</tr>
<tr>
<td>PaCO2 (kPa)</td>
<td>5,9 ± 1,1</td>
<td>6,9 ± 6,6</td>
<td>0,48</td>
</tr>
<tr>
<td>Sat O2 (%)</td>
<td>84,9 ± 7,2</td>
<td>93,7 ± 2,6</td>
<td>0,00*</td>
</tr>
<tr>
<td>PaO2/FiO2 (kPa)</td>
<td>20,3 ± 5,0</td>
<td>41,7 ± 6,9</td>
<td>0,00*</td>
</tr>
<tr>
<td>Ventilator settings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIP (cmH2O)</td>
<td>37,1 ± 3,6</td>
<td>45,8 ± 2,3</td>
<td>0,00*</td>
</tr>
<tr>
<td>P-plat (cmH2O)</td>
<td>29,9 ± 2,3</td>
<td>37,0 ± 1,8</td>
<td>0,59</td>
</tr>
<tr>
<td>PEEP (cmH2O)</td>
<td>13,9 ± 1,4</td>
<td>20,9 ± 1,5</td>
<td>0,00*</td>
</tr>
<tr>
<td>VT (ml)</td>
<td>457,4 ± 48,0</td>
<td>363,8 ± 54,4</td>
<td>0,00*</td>
</tr>
<tr>
<td>C (ml/cmH2O)</td>
<td>29,3 ± 2,9</td>
<td>41,3 ± 3,44</td>
<td>0,00*</td>
</tr>
</tbody>
</table>

MAP – mean arterial pressure, HR – heart rate; PvO2 – partial pressure of oxygen in blood sample from interior jugular vein; PaO2 – partial pressure of oxygen in arterial blood; PaCO2 – partial pressure of carbon-dioxide in arterial blood, Sat O2 – saturation of oxygen in arterial blood, PaO2/FiO2 – partial pressure of oxygen in arterial blood/fraction of inspired oxygen; PIP peak inspirational pressure; plat – plateau pressure, PEEP – positive end expiratory pressure, VT – tidal volume – Compliance

* indicated p < 0.05

There were 29 patients on the CT scan before the e-sigh recruitment manoeuvre with diffuse changes of the lung and one patient with focal changes of the lung, according to ARDS criteria. We noticed that after the e-sigh recruitment manoeuvre the aeration in patients with diffuse changes of the lung was considerably improved (96.7%). In patients with focal changes the improvement was 26.7%. We concluded that the recruitment manoeuvre is more effective in patients with ARDS who have diffuse changes than in patients with focal changes.

**Discussion**

The e-sigh recruitment manoeuvre led to improved oxygenating. After the e-sigh recruitment manoeuvre partial pressure of oxygen (PaO2) and oxygen saturation (sat O2) in arterial blood showed improvement. Partial pressure of
oxygen in the interior of the jugular vein (PvO₂) was also improved but there were no statistical differences before and after the recruitment manoeuvre. Compliance of the lung was also improved during the e-sigh recruitment manoeuvre. Adverse events, such as haemodynamic instability and desaturation, common during the recruitment manoeuvre, were not statistically significant in our study. Many authors [11, 17, 19] have shown that e-sigh is a safe and efficient method for an improvement in oxygenation. Lim et al. [16] used e-sigh as recruitment manoeuvres. He gradually reduced tidal volumes from 8 to 2 ml/kg and increased PEEP from 10 to 25 cmH₂O. This was a successful manoeuvre, oxygenation was increased and patients were haemodynamically stable. Constantin et al. [26] compared two recruitment manoeuvres, e-sigh with PEEP 10 cm H₂O above LIP for 15 minutes and CPAP 40 cmH₂O for 40 seconds. Both manoeuvres improved oxygenation but CPAP was associated with haemodynamic instability. Khaled M Mahmoud and Amany S Ammar [27] also proved that extended sigh was more effective in the oxygenation of patients than CPAP. The study of Pellosi [28] showed that conventional e-sigh improved oxygenation but the effect of improvement was limited to until the discontinuation. Lapinsky et al. [15] applied inflation manoeuvre using 45 cmH₂O or the peak pressure at the tidal volume or a tidal volume of 12ml/kg which was lower. The manoeuvre was applied for 20 seconds. Improvement in oxygenation occurred in 10 minutes. Neither barotrauma nor complications were recorded. Five patients (or a fifth patient) developed hypotension and mild oxygen desaturation.

**Conclusion**

Our study proved that e-sigh recruitment manoeuvre improved oxygenation and aeration of the lung due to reopened collapsed alveoli. There was no haemodynamic instability during this manoeuvre. E-sigh RM had a good impact on the respiratory mechanism as well. We confirmed with x-ray and CT scan, as objective methods for verification of lung condition, that e-sigh is a method of choice in the treatment of patients with acute respiratory distress syndrome.

Conflict of interest: not declared.

**References**


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Abbreviations:

ALI – acute lung injury
ARDS – acute respiratory distress syndrome
RM – recruitment manoeuvre
PEEP – positive end expiratory pressure
E-sigh – extended sigh
LIS – lung injury score
X-ray – conventional radiography
CT scan – computerized tomography
PaO2 – partial pressure of oxygen in arterial blood
PvO2 – partial pressure of oxygen in venous blood
PaCO2 – partial pressure of carbon dioxide in arterial blood
FiO2 – fraction of inspired oxygen ratio
PaO2/FiO2 – partial pressure of oxygen in arterial blood/fraction of inspired oxygen ratio
TV – tidal volume
LIP – lower inflation point
UIP – upper inflation point
Pplat – plateau pressure
PIP – peak airway pressure
C – compliance
CPAP – continues positive airway pressure
Sat O2 – saturation of oxygen in arterial blood
PAWP – pulmonary arterial wedge pressure
MAP – mean arterial pressure
SpO2 – peripheral saturation
ECG – electrocardiogram
ZEEP – zero end expiratory pressure

Резиме

ВЛИЈАНИЕ НА АЛВЕОЛАРНОТО ПРОДУВУВАЊЕ
СО ПРОДОЛЖЈЕНА ВОЗДИШКА ВРЗ ГАСНАТА РАЗМЕНА И АЕРАЦИЈАТА НА БЕЛИТЕ ДРОБОВИ КАЈ ПАЦИЕНТИ
СО АЛИ/РДС

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Апстракт: Основна стратегија на маневрите на алвеоларно продувување (PM) е транзиторното зголемување на транспулмоналнот притисок. Целта на оваа студија е евалуација на ефикасноста на алвеоларното продувување со

продолжена воздишка кај пациенти со акутна повреда на белите дробови (АЛИ) и пациенти со акутен респираторен дистрес синдром (АРДС).

Майтеријали и методи: Трисет пациенти кои ги исполнува АРДС критерумите беа вклучени во оваа студија. Кај нив се направи алвеоларно продувување со продолжена воздишка кое се состои од апликација на позитивен ендекспираторен притисок на 10 см H2O над долната точка на надувување од волумен/притисок кривата, во временска длабочина од 15 минути. Ги испитуваме ефектите на овој тип на алвеоларно продувување врз гасната размена, хемодинамските и респираторните параметри во две временски точки (пред и по алвеоларното продувување). На пациентите им се направи рендгенска снимка и компјутеризирана томографија на белите дробови, пред да се започне со алвеоларното продувување и еден ден по последното алвеоларното продувување.

Заклучок: Алвеоларното продувување ја подобрува гасната размена, аерацијата на белите дробови и повторно ги отвора колабираните алвеоли што објективно се евалуира со рендгенографија и компјутеризирана томографија на белите дробови.

Ключни зборови: Акутен респираторен дистрес синдром (АРДС), алвеоларно продувување, продолжена воздишка, позитивен ендекспираторен притисок (ПЕЕП).

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