Improving oxygenation in spontaneously breathing patients with atelectatic lung

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1. Introduction

Hypoxemic respiratory failure is one of the leading causes of the need for mechanical ventilation, in the most severe cases as the consequence of acute respiratory distress syndrome (ARDS), which still carries high risk of mortality. ARDS is a life threatening condition precipitated by disorders frequently resulting in critical care admissions like trauma, severe burns, sepsis, pancreatitis and pneumonia. All of these disorders, either causing direct (pulmonary) or indirect (extrapulmonary) tissue damage are featured by a systemic inflammatory response. The released cytokines like interleukin (IL)-1, IL-6, IL-8 and tumor necrosis factor activate neutrophils in the lung throughout the inflammatory cascade. The activated immune cells excrete injurious substances such as free oxygen radicals and proteolytic enzymes leading to alveolar endothelium and epithelium destruction. The latter pathophysiological mechanism induces impaired permeability in the lung resulting in alveolar immerging by the protein rich oedema fluid. Surfactant, which has a major role in modulating the surface tension of alveoli is also washed out. Furthermore, the surfactant production is also decreased due to the dysfunction of type II epithelial cells. As a consequence, pulmonary atelectasis develops due to alveolar collapse.

Pulmonary atelectasis is accompanied by arterial hypoxemia due to increased intrapulmonary shunt. As severe acute hypoxemia is a potential danger for all vital organs its resolution is of pivotal importance. There are several interventions, which may help improving oxygenation. In the most severe circumstances extracorporeal membrane oxygenation, high frequency oscillatory ventilation, and prone positioning have been shown to reverse persistent hypoxemia. Some of these interventions require special equipment, demand extra manpower and may be time consuming to commence.

1.1. The open lung concept

In less severe cases of acute hypoxemia, especially when this is primarily caused by atelectasis, the collapsed lung areas can be opened up with the help of transient increment in transpulmonary pressure (TP) within a short time, hence decreasing shunt fraction and improving arterial oxygenation. This procedure is called the lung recruitment manoeuvre. It can be accompanied by the titration of the “optimal” positive end-expiratory pressure (PEEP), a process which is called on a broader term as the “open lung concept” described by Lachmann in 1992.

However, it is also well known that not every lung responds for recruitment manoeuvers. Although most recruitment strategies were tested under controlled mechanical ventilation, there is also increasing evidence that maintaining spontaneous breathing during mechanical ventilation may provide numerous advantages. Applying continuous positive airway pressure (CPAP) with or without pressure support (PS) and allowing the patient to breathe spontaneously is an often used ventilation mode, both during non-invasive and invasive ventilation. Although theoretically alveolar recruitment may also have a place in these patients ventilated invasively this has only been investigated during non-invasive ventilation.

1.2. Benefits of maintaining spontaneous breathing

Maintaining spontaneous breathing on mechanical ventilation may provide several benefits. One of these advantages is the improvement of oxygenation in patients with acute lung injury by the recruitment of atelectatic lung areas in the juxtadiaphragmatic regions. Diaphragmatic contractions evoked by spontaneous breathing efforts may facilitate the recruitment of collapsed, dependent lung regions. As the collapse of alveoli is more pronounced in the dorsal regions where the muscle contraction induced diaphragm excursion is the most remarkable the redistribution of ventilation-perfusion ratio may improve oxygenation.

Beyond amelioration in gas exchange maintaining spontaneous breathing offers the prevention of cyclic alveolar atelectasis in the basal pulmonary regions. The undesirable alveolar shearing generated by the cyclic collapse and re-opening can be reduced by this advantageous phenomenon. Henceforward spontaneous breathing movements can amend the protective ventilation strategy by attenuating the mechanical distress. Reducing the inflammatory response at the level of alveoli may provide advances in the regeneration of pulmonary function.

Prolonged respiratory support, especially controlled mechanical ventilation (CMV), induces diaphragm muscle atrophy and dysfunction. The inability of diaphragm contraction precipitated by CMV leads to neural deactivation and molecular changes in the muscle cells. Maintaining spontaneous breathing is advantageous in the prevention of losing force generated by diaphragm contractility. Furthermore, reserving spontaneous breathing during mechanical ventilation offers a lower level of sedation target and improved patient-ventilator interaction. This has a major impact on respiratory weaning. The reduced requirement of sedatives attenuates the duration of respiratory support, decreases the length of stay in the intensive care unit and the overall cost of care giving.

1.3. Spontaneous breathing trial with T-piece

Weaning from mechanical ventilation is a challenging process for critical care physicians. Over the last decades many respiratory strategies were investigated to identify the most suitable method of successful weaning. Conducting spontaneous breathing trial (SBT) with T-piece to identify patients ready for extubation has been a common practice, but it may also be used as a weaning tool by alternating periods of ventilatory support and SBT on T-piece.

Ayre’s T-piece is a simple, non-rebreathing circuit first used in paediatric anaesthesia. Its potential advantages in the critical care setting are the minimal dead space, the low airway resistance and the activation of the breathing muscles. The inspired fraction of oxygen (FiO_2) can be adjusted with high flow oxygen/air mixers or by the application of a Venturi injector on the inspiratory limb. PEEP can also be applied with the help of a PEEP-valve at the end of the expiratory limb hereby establishing a high flow CPAP circuit. Comparing with mechanical ventilation disadvantages are the lack of pressure support, monitoring airway pressure and tidal volume.

Spontaneous ventilation can be facilitated by new generation of ventilators, by applying CPAP with pressure support (PS) and automatic tube compensation (ATC). The purpose of the latter is the automatic regulation of the airway pressure in proportion to the ventilator’s flow rate in order to compensate for the resistance of artificial airways. However, T-piece is applied widespread in everyday practice its effect on gas exchange has not been investigated yet.

1.4. Our aims

1. To investigate the effects of recruitment on the PaO_2/FiO_2 ratio in patients ventilated in CPAP/PS mode suffering from moderate and severe hypoxemic respiratory failure.
2. To assess recruitability in patients ventilated in CPAP/PS mode suffering from moderate and severe hypoxemic respiratory failure.
3. To investigate the effects of T-piece on gas exchange as compared to CPAP/PS and CPAP/automatic tube compensation (ATC) modes in tracheostomized patients during respiratory weaning.
4. To investigate alteration in central venous oxygen saturation ($ScvO_2$) after recruitment manoeuver in spontaneously breathing patients ventilated in CPAP/PS mode suffering from moderate and severe hypoxemic respiratory failure and throughout T-piece trial in tracheostomized patients during respiratory weaning.

2. Effects of alveolar recruitment in patients ventilated in continuous positive airway pressure/pressure support mode

2.1. Materials and methods

All mechanically ventilated patients with maintained spontaneous breathing, ventilated in CPAP/PS mode with a PEEP $\geq$ 5 cmH_2O, were enrolled in this prospective, observational study if their PaO_2/FiO_2 ratio < 300 mmHg or required an FiO_2 > 0.5, regardless of the etiology of respiratory failure. Exclusion criteria were: age < 18, pregnancy, pulmonectomy/lobectomy or spontaneous pneumothorax in past medical history, emphysematous bullae, clinically diagnosed end stage chronic obstructive pulmonary disease and vasopressor refractory hemodynamic instability.

All patients who were eligible for the study had a radial arterial and an internal jugular or subclavian central venous catheter inserted on admission to the intensive care unit as part of our standard care. Patients were sedated with continuous infusion of propofol and fentanyl reaching a Richmond Agitation Sedation Scale score of -1 to -2. Electrocardiogram, invasive blood pressure and SpO_2 were continuously monitored by Dräger Infinity Gamma XL Monitor (Telford, PA, USA). Patients were ventilated with Dräger Evita® XL respirators (Lübeck, Germany). The level of pressure support was adjusted to achieve adequate arterial pCO_2 level to maintain pH $\geq$ 7.30. Respiratory parameters, airway pressures, dynamic respiratory compliance, airway resistance, end-tidal carbon dioxide ($EtCO_2$), dead space (Vds) and dead space to exhaled tidal volume ratio (Vds/Vte) were all continuously monitored by the respirator and its own volumetric capnography.

Once inclusion criteria were fulfilled respirator settings, cardio-respiratory and airway parameters were recorded at baseline. Then PEEP was increased by 5 cmH_2O and after 5 minutes measurements were repeated to investigate the effect of any PEEP-induced recruitment. For alveolar recruitment pressure support was increased to 40 cmH_2O for 40 seconds to limit the undesirable side effects of volutrauma. After which peak inspiratory pressure was reduced to the initial value as at baseline while maintaining the increased level of PEEP (by 5 cmH_2O) according to the open lung concept. Measurements were repeated immediately after recruitment then 15 and 30 minutes later with constant respirator settings as at baseline. Arterial blood gas samples were analyzed by a Roche cobas b 221 (Mannheim, Germany) blood gas system at each measurement points and central venous samples were taken at baseline and at the final time point to determine $ScvO_2$.

Primary outcome parameter was the change in oxygenation (PaO_2/FiO_2) after the recruitment manoeuver. Patients were considered as non-responders (NR) if difference of $PaO_2/FiO_2 < 20$ % and responders (R) if difference of $PaO_2/FiO_2 \geq 20$ % between baseline and following recruitment measurements.

2.2. Results

Over the study period 30 patients were enrolled, of whom 15 (50 %) patients turned out to be non-responders and 15 (50 %) responders. There was no significant difference between groups in baseline respirator settings and demographic characteristics except of age. Out of the 19 patients with admission diagnosis of cardiac origin 13 (68 %) were responders. Serious adverse effects of recruitment manoeuver like pneumothorax and worsening hemodynamic instability were not detected.

There was a non-significant decrease in PaO_2/FiO_2 from baseline to 30 minutes following recruitment in the NR-group. In the R-group PaO_2/FiO_2 significantly improved after the recruitment manoeuver as compared to baseline results and remained elevated throughout the observation period. There was significant improvement in SaO_2 among responders, while there was no significant change in the NR-group. Bicarbonate and base excess levels showed significant difference between groups at all time points. Hemodynamic parameters and $ScvO_2$ did not show any significant change over time.

There was no significant change in tidal volume, Vte indexed for predicted bodyweight, respiratory rate and minute ventilation between groups and throughout the study as compared to baseline parameters. In the NR-group dynamic compliance, a parameter indicated on the ventilator dropped non-significantly after the recruitment manoeuver but there was a significant increase in Vds/Vte following recruitment and 15 minutes later as compared to baseline in the same group. There was no other significant change in the examined respiratory and airway parameters in the NR- and R-group.

Improvement in oxygenation was detected in 74 % of all patients, and in 26 % arterial oxygenation did not improve or even deteriorated. Improvement (≥ 0) or deterioration (< 0) of dynamic compliance gave high sensitivity and specificity with a positive predictive value of 0.89 to differentiate patients with worsening as compared to those with improved PaO_2/FiO_2.

3. Effects of T-piece on arterial and central venous oxygenation in trachestomized patients as compared to continuous positive airway pressure/pressure support ventilation

3.1. Materials and methods

All patients ventilated in CPAP/PS mode via a tracheostomy tube and fulfilling the criteria of the department's weaning protocol of SBT were enrolled. Weaning criteria were defined as: SpO_2 > 94 %, respiratory rate (RR) < 35 min^{-1}, hemodynamic stability with heart rate (HR) < 100 min^{-1}, mean arterial pressure (MAP) > 60 mmHg on PEEP < 10 cmH_2O, FiO_2 < 50 % and PS ≤ 10 cmH_2O. Exclusion criteria were: pregnancy, age under 18, coexisting ventilator associated pneumonia and pulmonectomy or lobectomy in past medical history. Electrocardiogram, invasive blood pressure, SpO_2 and RR were continuously monitored by Dräger Infinity Gamma XL Monitor (Telford, PA, USA) and central venous catheters were *in situ* in all cases. Patients were ventilated by Dräger Evita® XL respirator (Lübeck, Germany) at all times.

Once patients fulfilled the criteria for weaning, baseline (t_0) respirator settings, cardio-respiratory parameters and arterial and central venous blood gas results were recorded while the patients were ventilated in CPAP/PS mode. Then PS was decreased to 0 cmH_2O when just ATC was applied for 15 minutes and the respiratory parameters were recorded again (t_1). ATC was set to 100 % compensation, artificial airway was marked as tracheostomy tube with the exact internal diameter. After that patients were placed on T-piece with constant FiO_2 and PEEP according to the respirator settings. FiO_2 was monitored throughout with an Ohmeda 5100 Oxygen Monitor (Madison, WI, USA) connected between the Venturi injector and the inspiratory limb of the T-piece. Repeated measurements were taken at 15 (t_2), 30 (t_3) and 60 minutes (t_4) on the T-piece trial. Vital parameters were recorded and arterial blood gas samples were analysed by a Roche cobas b 221 (Mannheim, Germany) blood gas system at each measurement points and central venous samples were taken at t_0 and t_4 to determine $ScvO_2$. The trial was interrupted if RR increased > 35 min^{-1}, SpO_2 decreased permanently under 90 %, HR > 120 min^{-1}, blood pressure > 160/90 mmHg or patient indicated shortness of breath.

3.2. Results

Over the study period 25 tracheostomized patients were enrolled. The trial was interrupted in four cases (16%) after t_2, because of pulmonary oedema, hypertension and on two occasions because of fatigue with CO_2 retention. As data was analysed on an intention-to-treat basis, we included those 4 patients who failed the T-piece trial in the final analysis.

3.2.1. CPAP/PS versus CPAP/ATC

PaO_2/FiO_2 and SaO_2 did not show any significant change on CPAP+ATC as compared to CPAP+PS mode. Tidal volume (Vte) did not decrease significantly with a significant increase in RR at the same time. There was no significant change in arterial carbon dioxide ($PaCO_2$), pH, base excess (BE), bicarbonate (HCO_3^-) and lactate. Switching from CPAP/PS to CPAP/ATC had no effect on haemodynamic parameters, as indicated by MAP and HR values.

3.2.2. CPAP/PS and CPAP/ATC versus T-piece

Regarding oxygenation, PaO_2/FiO_2 and SaO_2 showed significant improvement almost at all measurement points on T-piece trial as compared to CPAP/PS and CPAP/ATC modes except of results at t_2 as compared to t_1 when PaO_2/FiO_2 did not change significantly. There was also a significant increase in $ScvO_2$ at t_4 as compared to baseline measurements.

3.2.3. Blood gas results and haemodynamic parameters

RR and $PaCO_2$ were significantly higher at all time-points with a significant decrease in pH. There was a tendency of significantly elevated HCO_3^- levels at $t_{2\text{-}4}$ with no significant increase in BE and lactate levels showed minimal change. Regarding haemodynamic parameters MAP was significantly higher on T-piece at all time points and HR increased significantly but only by t_4 as compared to t_1.

4. Discussion

4.1. Effects of alveolar recruitment in patients ventilated in continuous positive airway pressure/pressure support mode

The most important finding of the study is that recruitment manoeuver improved oxygenation by more than 20 % in half of the patients with moderate and severe hypoxemic respiratory failure ventilated in CPAP/PS mode. We also found that patients in whom hypoxemia was due to cardiac origin seemed to benefit the most, as nearly 70% of these patients were found to be responders.

Patients, according to the change in the PaO_2/FiO_2 ratio after recruitment, were divided to non-responder and responder groups. Regarding the demographic data, it is an interesting finding that patients in the NR-group were significantly younger than those in the other responder group. There were also more patients with ischemic heart disease and heart failure in the R-group, while there were only four patients with heart failure in the NR-group. One of the possible explanations is that although lung compliance decreases with age in general but success of recruitment depends on other factors like co-morbidities and it may be more successful in patients with heart disease as compared to patients with pneumonia. The beneficial effects of PEEP induced alveolar recruitment with improved compliance and oxygenation are well known phenomenon in patients with ischaemic heart disease. PEEP can also decrease intrapulmonary shunt such as hypoxic pulmonary vasoconstriction with a reduced pulmonary artery pressure among patients with heart failure. Therefore it is not the age *per se* but the accompanying higher number of patients with heart condition that caused the observed difference in the current study.

Although it is not the most accurate way to assess lung recruitment, but measuring changes in arterial oxygenation is one of the commonly used methods to detect the efficacy of recruitment. Furthermore, there is no consensus on how to define responders and non-responders based on the PaO_2/FiO_2 values which vary between 30 to 50 % in the literature. Due to the lack of well-defined values we have chosen an arbitrary threshold of difference in $PaO_2/FiO_2 \geq 20$ % to define as responders and < 20 % as non-responders following recruitment. Nevertheless, we detected an improvement of oxygenation in 74 % of all patients, and in 26 % arterial oxygenation did not improve or even deteriorated. Taking the 20 % improvement in oxygenation as a clinically significant change, 50 % of patients still responded which is similar to that of reported in recently published studies. However, it is important to note that the ratio of responders is highly dependent on the defined threshold. Our data suggests that CPAP/PS ventilation and lung recruitment may have benefits in patients suffering from moderate to severe acute lung injury especially due to acute heart failure which should be investigated further.

It is well known that not every lung responds for recruitment and unnecessary manoeuvers may lead to adverse effects. Several methods had been evaluated of which chest CT scan remains the gold standard warranting the direct visualization of the recruitable lung tissue. However, this method requires the transport of the critically ill patients to the CT scanner and exposes them to radiation. Other bed-side measurements to assess recruitability are pressure-volume curve assessment and end-expiratory lung volume/functional residual capacity ratio measurement.

An important parameter in respiratory mechanics to assess recruitability is compliance, which is determined by volume/pressure relationships. Theoretically, in recruitable patients increasing pressures will increase volume hence compliance should improve or remain unchanged. While in non-recruitable patients increased pressures during recruitment can lead to the overdistension without gaining lung volumes, hence result in a consecutive fall in respiratory compliance.

4.2. Effects of T-piece on arterial and central venous oxygenation in trachestomized patients as compared to continuous positive airway pressure/pressure support ventilation

The major finding of this study is that breathing via a T-piece improved arterial and central venous oxygenation in tracheostomized patients as compared to CPAP/PS and CPAP/ATC ventilatory modes.

In this investigation 84% of the patients completed the T-piece trial, and in 4 cases we had to interrupt the trial. Unfortunately we cannot compare our failure rate directly with international results as according to our best knowledge there is no literature data on the effect of T-piece on gas exchange and weaning in tracheostomized patients. In general, failure rate after SBT is reported around 26-42% within the first 60 minutes, which was only 16% in our study.

Regarding the effects of T-piece trial on gas exchange, in a recent clinical study on intubated patients it was found that PaO_2 did not change significantly as compared to PS ventilation, which is in contrast with our findings of improved oxygenation on T-piece.

There are several mechanisms which could explain this significant increase in arterial oxygenation. First, the activation of breathing muscles without the interference of the ventilator may have a significant impact. Mechanical ventilation, controlled as well as PS modes, induce diaphragm dysfunction. In patients who fulfill the “ready to be weaned” criteria, breathing via a T-piece may be beneficial as compared to several ventilation modes, in which the patient has to trigger the ventilator by either flow or pressure. During T-piece trials respiratory muscle movements may promote immediate alveolar recruitment with a prompt benefit on gas exchange. It has also been shown in a recent article that different arrangements of the T-piece system can affect PaO_2. Second, when a long inspiratory corrugated tube was inserted between the Venturi injector and the T-piece as an inspiratory limb, just like in our investigation, it resulted in significantly improved arterial oxygenation as compared to assembling the Venturi injector directly to the T-piece. Finally, the PEEP valve might have had some effect on the observed changes. Increased PEEP level is associated with alveolar recruitment and improved arterial oxygenation. As we did not measure the actual PEEP level on T-piece, one cannot exclude its effect on the results.

In the current study we measured significantly higher $ScvO_2$ values on T-piece as compared to CPAP/PS and CPAP/ATC ventilation. Increased $ScvO_2$ can be the result of increased oxygen delivery (cardiac output, CO and arterial oxygen content, CaO_2) and/or when oxygen consumption is decreased. Unfortunately we are unable to give an exact explanation for this phenomenon as we did not measure CO and work of breathing (WOB).

4.3. Haemodynamic effects of lung recruitment manoeuvres

The anatomical proximity of the lungs and heart within the chest means that transiently increased intrathoracic pressures have major effect on systemic cardiovascular function. Undesired side effects of the recruitment process mainly arise from the increased airway pressures which can cause overdistension of alveoli in well ventilated lung areas, marked increase in ventilation-perfusion mismatch, barotrauma, pneumothorax and new air leak around an existing chest tube. These effects may be even more pronounced in patients with ARDS in whom hemodynamic instability is a common feature. It has strong pathophysiological rationale supported by clinical data that routine ICU monitoring, such as invasive blood pressure and central venous pressure monitoring may not be adequate to follow hemodynamic changes encountered during lung recruitment.

4.3.1. Effects on right heart and pulmonary circulation

Distending lung volume evoked by applied raised airway pressure leads to an increase in TP. TP can be estimated from the difference between alveolar and intrathoracic pressures. The transmission of TP to the pleural space impedes venous return and the filling of the right ventricle. Meanwhile, the increased TP is transposed to vessels interlacing the lung tissue hereby elevating pulmonary vascular resistance (PVR) and right ventricular afterload.

4.3.2. Ventricular interdependence

It is important to note that the end-diastolic right ventricular volume has a direct effect on the left ventricle, which holds true *vica versa*. This is called the ventricular diastolic interdependence. The two chambers are coupled within a common pericardial sac and share joint intraventricular septa as a traverse wall. Thus, their volumes are limited by the pericardium, hence any change in the right ventricular end-diastolic volume has an effect on the left ventricular end-diastolic volume.

4.3.3. Effects on left heart and systemic circulation

The cardiopulmonary system is described by Pinsky as a pressure chamber inside a pressure chamber. Any increment in the intrathoracic pressure increases the right atrial pressure, decreases the venous return and the transmural left ventricular systolic pressure hence attenuating the left ventricular ejection fraction. If haemodynamic changes are solely monitored by mean arterial pressure (MAP) during lung recruitment manoeuvre one can theoretically miss relevant alterations in the systemic circulation. Recent investigations concluded that simple haemodynamic parameters like MAP or heart rate did not show any significant change during and after various recruitment interventions. However, applying advanced invasive haemodynamic monitoring, relevant changes in the systemic circulation can be observed.

4.3.3.1. Cardiac output and left ventricular end-diastolic volume

The increased availability of sophisticated continuous CO monitoring using pulse pressure analysis like pulse contour cardiac output (PiCCO^{TM}), lithium dilution cardiac output (LiDCO^{TM}) or FloTrac^{TM}/Vigileo^{TM} techniques and Doppler cardiac output devices enabled the clinicians to follow alterations in the systemic haemodynamics during each cardiac cycle. Utilising these advanced monitoring techniques, profound and significant decrease in CO was observed during lung recruitment manoeuvres. This decline in left ventricular performance can be explained by interconnected fluctuations within the “chamber in the chamber” system discussed previously. Increased intrathoracic pressure, decreased right ventricular filling, increased right ventricular outflow impedance with leftward intraventricular septal shift are all precipitating reduced CO. However, rapid recovery of the baseline CO was described when the effects were measured in a temporal study, so the depression is only transient correlating with the temporarily increased TP.

4.3.3.2. Alterations in heart rate

Along with stroke volume, heart rate is the other determinant of CO. Through the recruitment manoeuvre one may expect the development of reflex tachycardia along the drop in CO. Many investigations failed to observe such an increase in heart rate, principally no significant alteration of pulse rate was found. However, in a recent investigation significant reduction in heart rate was suspected as the major component of the declining CO during the sigh manoeuvre. One of the explanations is that the inflated lung tissue can activate vagal tone causing bradycardia. Another assumption is that the sigh manoeuvre may precipitate a similar pattern in intrathoracic pressure as the Valsalva manoeuvre, hence producing reduction in heart rate.

5. Conclusions

1. Alveolar recruitment manoeuver can improve oxygenation in patients suffering from moderate and severe acute hypoxemic respiratory failure and ventilated in CPAP/PS mode as indicated by the significant improvement in oxygenation after recruitment in 74% of all patients.

2. The decrease in dynamic compliance as displayed on the ventilator after the recruitment manoeuver proved to be a simple bed-side indicator of failure in improving oxygenation in spontaneously breathing patients.

3. Ayre's T-piece significantly improves arterial oxygenation as compared to CPAP/PS and CPAP/ATC ventilation.

4. Ayre's T-piece resulted in significantly higher $ScvO_2$ as compared to CPAP/PS and CPAP/ATC ventilation. Our results suggest a potential role of T-piece trials during respiratory weaning in tracheostomized patients.

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Full paper publications related to the thesis

I. **Lovas A**, Molnár Z. T-piece improves arterial and central venous oxygenation in trachestomized patients as compared to continuous positive airway pressure/pressure support ventilation. *Minerva Anestesiol* 2013;79(5):492-497.

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II. **Lovas A**, Németh MF, Trásy D, Molnár Z. Lung recruitment can improve oxygenation in patients ventilated in continuous positive airway pressure/pressure support mode. *Front Med (Lausanne)* 2015;2:25. doi: 10.3389/fmed.2015.00025

IF: pending

III. **Lovas A**, Szakmány T. Haemodynamic effects of lung recruitment manoeuvres. *Biomed Res Int* 2015;Article ID 478970. doi:10.1155/2015/478970

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Book chapters related to the thesis

IV. **Lovas A**. Alveolustoborzás *in* Molnár Z, Bede A (szerk.). A lélegeztetés gyakorlata. *Medicina Könyvkiadó Zrt*., Budapest, 2015:133-146.

V. **Lovas A**. Leszoktatás gépi lélegeztetésről *in* Molnár Z, Bede A (szerk.). A lélegeztetés gyakorlata. *Medicina Könyvkiadó Zrt*., Budapest, 2015:175-195.

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VI. **Lovas A**, Kószó R, Molnár Z. T-piece improves arterial and central venous oxygenation in tracheostomized patients as compared to pressure support (PS) ventilation. *Intensive Care Med* 2012;38 Supplement 1:S149-50.

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XI. **Lovas A**. Leszoktatás: gép vagy ember vezérelje? SZINT, Szeged, 2015. november 12.-13.

XII. **Lovas A**. Mechanical ventilation in patients with COPD. 2nd SOS Team Days, Subotica-Palic, Serbia, 24-26 September 2015

XIII. **Lovas A**. Hemodynamic effects of lung recruitment. Third Congress of Intensive Care Medicine, Belgrade, Serbia, 26-28 November 2015