Positive end-expiratory pressure attenuates positional effect after thoracotomy

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Abstract:

CONTEXT: Thoracotomy is a common procedure. However, thoracotomy leads to lung atelectasis and deteriorates pulmonary gas exchange in operated side. Therefore, different positions with operated side lowermost or uppermost may lead to different gas exchange after thoracotomy. Besides, PEEP (positive end-expiratory pressure) influence lung atelectasis and should influence gas exchange.

AIMS: The purpose of this study was to determine the physiological changes in different positions after thoracotomy. In addition, we also studied the influence of PEEP to positional effects after thoracotomy.

MATERIALS AND METHODS: There were eight pigs in each group. Group I received left thoracotomy with zero end-expiratory pressure (ZEEP), and group II with PEEP; group III received right thoracotomy with ZEEP and group IV with PEEP. We changed positions to supine, LLD (left lateral decubitus) and RLD (right lateral decubitus) in random order after thoracotomy.

RESULTS: PaO_2 was decreased after thoracotomy and higher in RLD after left thoracotomy and in LLD after right thoracotomy. PaO_2 in groups II and IV was higher than in groups I and III if with the same position. In group I and III, $PaCO_2$ was increased after thoracotomy and was higher in LLD after left thoracotomy and in RLD after right thoracotomy. In groups II and IV, there were no $PaCO_2$ changes in different positions after thoracotomy. Lung compliance (C_{rs}) was decreased after thoracotomy in groups I and III and highest in RLD after left thoracotomy and in LLD after right thoracotomy. In groups II and IV, there were no changes in C_{rs} regardless of the different positions.

CONCLUSION: There were significant changes with regards to pulmonary gas exchange, hemodynamics and C_{rs} after thoracotomy. The best position was non-operated lung lowermost Applying PEEP attenuates the positional effects.

Key words:

Positive end-expiratory pressure, position, pulmonary gas exchange, thoracotomy

Thoracotomy is a common surgical procedure. The indications for thoracotomy are wide including the management of mediastinal and bronchogenic carcinoma, chest trauma, empyema, recurrent pneumothorax etc.[1-3] However, it is known that the deterioration of oxygenation is observed after thoracotomy.[4] Thoracotomy can lead to acute lung injury,[5] therefore it is worth further studying thoracotomy.

The mechanism of lung injury after thoracotomy has been previously addressed. Lung atelectasis from opening the thoracic cavity during thoracotomy is one of the important factors.[6] The pleural cavity is normally in negative pressure.[7] When it is exposed to the atmosphere during thoracotomy, the pleural cavity is filled with atmospheric air with positive pressure and the lung is deflated with atelectasis.[6,7] Atelectasis can impair arterial oxygenation and decrease compliance of respiratory system (C_{rs}).[6] Since thoracotomy results in lung atelectasis in the operated side, the condition of the bilateral lung is different. Different positions should lead to different pulmonary gas exchange. However, studies regarding positional effects after thoracotomy are quite limited. We therefore conducted this study about positional effects after thoracotomy.

Lung atelectasis impairs pulmonary gas exchange and decreases oxygenation after thoracotomy.[6] Continuous positive airway pressure is reported to be beneficial in lung atelectasis.[8,9] Consequently, positive end-expiratory pressure (PEEP) should be beneficial for lung atelectasis after thoracotomy. In a previous study, Cinnella *et al*. applied PEEP to the dependent lung during thoracic surgery and it was shown to improve oxygenation.[10] Rustomjee found PEEP can attenuate the decrease in PaO_2 after thoracotomy.[4] Therefore, PEEP is beneficial for oxygenation after thoracotomy. However, the studies about PEEP and different positions after thoracotomy are lacking.

The purpose of this study was to determine the physiological changes in different positions after thoracotomy. In addition, we also studied the influence of PEEP to positional effects after thoracotomy. We applied thoracotomy in a porcine model. We measured arterial blood gas analysis, pulmonary and systemic hemodynamics and respiratory mechanics in thoracotomized pigs in different positions with or without PEEP.

Materials and Methods

Animal preparation

The study protocol was approved by the National Science Council and Animal Review Committee of the National Defense Medical Center (Taipei, Taiwan). Anesthesia was induced via intramuscular injection of 1 mg/kg zoletil (Tiletamine:zolesepam 1:1). General anesthesia was then maintained by infusion of pentobarbital and fentanyl. The anesthetic dose was titrated to ensure optimal anesthesia for each animal — no pain response or spontaneous breathing. Once this state was attained for each animal, the dose was maintained for the duration of the procedure. A tracheotomy was performed and each animal was mechanically ventilated with a volume-control mode (Servo 300; Siemens, Solna, Sweden).

Physiologic measurements

A Swan-Ganz pulmonary artery catheter was introduced into the right external jugular vein via cut-down. A 5-F thermistor-tipped catheter (Pulsiocath, Pulsion Medical Systems; Munich, Germany) was placed in the right femoral artery and connected to the PiCCO System. Cardiac output and other variables were measured with standard thermodilution technique. Ten milliliter of 0.9% saline solution at 4°C was injected into the proximal site of the Swan-Ganz catheter. The left femoral artery was cannulated for continuous arterial blood pressure monitoring and for the withdrawal of arterial blood samples. Femoral venous catheters were inserted for infusion of anesthetic drugs, maintenance fluids. Arterial blood was collected and an analysis of the blood gases was performed (Rapidlab 845 Blood Gas Analyzer; Bayer, Munich, Germany) and corrected for core temperature. Breath-by-breath C_{rs} and airway resistance (R_{aw}) were measured by a respiratory mechanics monitor (Novametrix respiratory mechanics monitor; Medical system Inc, USA).

Thoracotomy and experimental protocol

Mechanical ventilation was maintained as follows: Tidal volume = 12 mL/kg, respiratory frequency = 15 bpm, fraction of inspired oxygen (FiO_2) = 0.4. Ventilator settings were maintained constant throughout the experiment. After anesthesia induction, ventilator stabilization, and catheter introduction, baseline hemodynamic and respiratory parameters and blood gases were obtained. Left or right thoracotomy was then performed via fourth intercostal space. There were four groups (n = 8 per group) in our study: 1) Group I was left thoracotomy with zero end-expiratory pressure (ZEEP) (weight 27.9 ± 1.1 kg); 2) Group II was left thoracotomy with PEEP 5 cmH_2O (weight 26.3 ± 1.5 kg); 3) Group III was right thoracotomy with ZEEP (weight 28.9 ± 2.9 kg); 4) Group IV was right thoracotomy with PEEP 5 cmH_2O (weight 26.6 ± 2.8 kg). The animals were studied in supine, right lateral decubitus (RLD) and left lateral decubitus (LLD) positions in random order after thoracotomy. Hemodynamic and respiratory parameters and blood gases were recorded following a 30 min rest period after each change of position. At the end of the study, animals were exsanguinated after being deeply anesthetized with pentobarbital.

Statistical analysis

Statistical analysis was performed using SPSS 18 software (SPSS Inc., Chicago, IL). Results were expressed as the mean ± SD. Paired t-test was used to analyze differences before and after thoracotomy. Unpaired t-test was used to compare variables of thoracotomy with ZEEP or PEEP (group I vs. II; group III vs. IV) in the same position. Repeated analysis of variance (ANOVA) measures was used to analyze differences among the different positions (supine, RLD, LLD) after thoracotomy. When a significant difference between groups was apparent, multiple comparisons of the mean were performed using the Bonferroni test. For all tests, $P < 0.05$ was considered to be statistically significant.

Results

Gas exchanges after thoracotomy

The partial pressure of oxygen in arterial blood (PaO_2) and partial pressure of carbon dioxide in arterial blood ($PaCO_2$) are shown in Figure 1. There was significant decrease in PaO_2

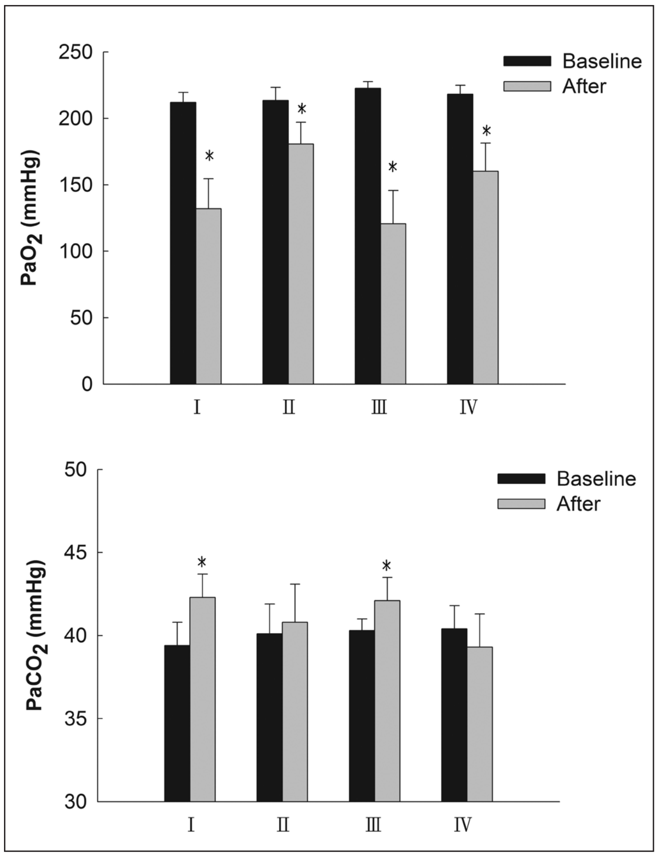

Figure 1: Gas exchange after thoracotomy

There was significant decrease in PaO2 after thoracotomy in all groups. There were also significant PaCO2 changes after thoracotomy in groups I and III (with ZEEP) but not in groups II, IV (with PEEP).

* Comparison of baseline and after thoracotomy, $P < 0.05$

after thoracotomy in all groups (all $P < 0.001$). About $PaCO_2$, there was significant increased $PaCO_2$ (39.4 ± 1.4 mmHg to 42.3 ± 1.4 mmHg, $P = 0.001$) after left thoracotomy in group I without PEEP. In group II, there was no prominent $PaCO_2$ change after left thoracotomy with PEEP. The $PaCO_2$ changes were similar in right thoracotomy (groups III, IV).

Respiratory mechanics after thoracotomy

The respiratory mechanics are shown in Figure 2. In group I, there was significantly decreased C_{rs} after thoracotomy (19.9 ± 4.3 to 16.6 ± 4.2 $mL \bullet cmH_2O^{-1} \bullet kg^{-1}$, $P = 0.007$). However, in group II, there were no significant changes in C_{rs} after thoracotomy. The C_{rs} changes were similar in right thoracotomy (groups III, IV). However, there were increased R_{aw} after thoracotomy in all groups (all $P < 0.05$).

Pulmonary and systemic hemodynamics after thoracotomy

Systemic, pulmonary hemodynamics and extra-vascular lung water index (EVLWI) changes are shown in Figure 3. There were no significant changes in systemic hemodynamics (mean arterial pressure, MAP; cardiac index, CI; Systemic vascular resistance index, SVRI), cardiac performance (global ejection fraction, GEF) and preload parameter (global end diastolic volume index, GEDI) after thoracotomy (all $P > 0.05$). However, there were significantly increased mean pulmonary arterial pressure (MPAP), pulmonary vascular resistance index (PVRI) and EVLWI after thoracotomy in all groups (all $P < 0.05$).

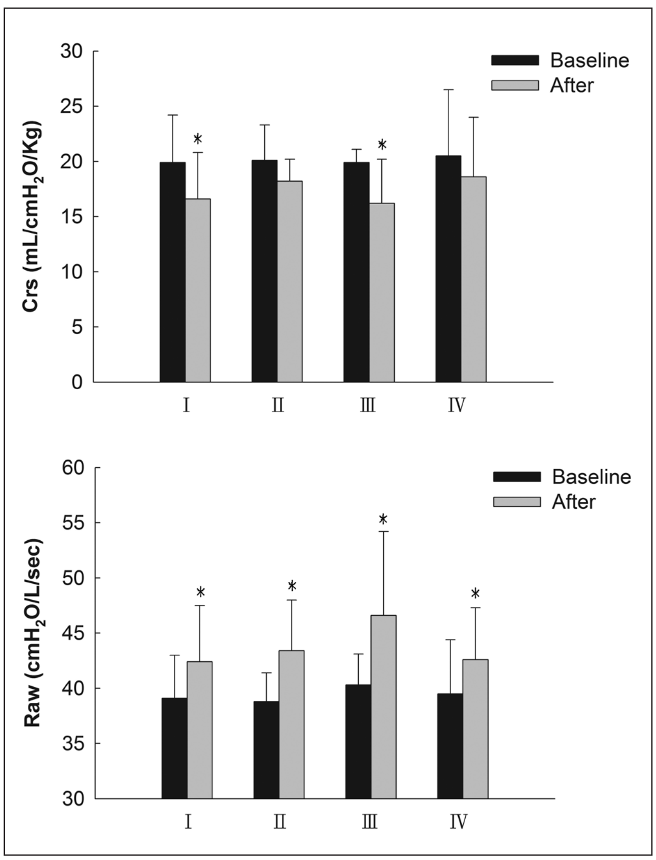

Figure 2: Respiratory mechanics after thoracotomy
In group I, there was significantly decreased Crs after thoracotomy. However, in group II, there were no significant changes in Crs after thoracotomy. The Crs changes were similar in right thoracotomy (groups III, IV). However, there were increased Raw after right or left thoracotomy in all groups.
* Comparison of baseline and after thoracotomy, $P < 0.05$

Gas exchanges in different positions after thoracotomy

The changes of PaO_2 in different positions after thoracotomy are shown in Figure 4. In group I, the PaO_2 was higher in RLD (173.7 ± 26.5 mmHg) than in supine (131.9 ± 22.7 mmHg) and LLD (132.2 ± 19.6 mmHg) ($P = 0.004$). In group II, the PaO_2 was still higher in RLD (190.2 ± 9.0 mmHg) than in supine (180.6 ± 16.4 mmHg) or LLD (161.0 ± 10.1 mmHg) ($P < 0.001$). However, the PaO_2 in group II was higher than group I in LLD and supine ($P < 0.05$ in both positions) but similar in RLD ($P > 0.05$). There were similar changes of PaO_2 in different positions after right thoracotomy in groups III and IV.

The changes of $PaCO_2$ in different positions after thoracotomy are shown in Figure 5. In group I, the $PaCO_2$ was significantly higher in LLD (46.1 ± 1.8 mmHg) than in RLD (42.1 ± 1.0 mmHg) and supine (42.3 ± 1.4 mmHg) ($P = 0.006$). In group II, there were no prominent $PaCO_2$ changes in different positions (both $P > 0.05$). The $PaCO_2$ changes were similar in right thoracotomy in groups III and IV.

Respiratory mechanics in different positions after thoracotomy

The changes of C_{rs} in different positions after thoracotomy are shown in Figure 6. In group I, C_{rs} was higher in RLD (18.4 ± 4.6 $mL \bullet cmH_2O^{-1} \bullet kg^{-1}$) than in supine (16.6 ± 4.2 $mL \bullet cmH_2O^{-1} \bullet kg^{-1}$) and LLD (16.6 ± 4.2 $mL \bullet cmH_2O^{-1} \bullet kg^{-1}$) ($P = 0.009$). However, in group II, there were no significant changes in C_{rs} in different positions ($P > 0.05$). The C_{rs} changes were similar in right thoracotomy (group III, IV). There were no significant changes of R_{aw} in different positions after thoracotomy ($P > 0.05$) (data not shown).

Pulmonary and systemic hemodynamics in different positions after thoracotomy

There were no significant changes in systemic hemodynamics (MAP, CI, SVRI), cardiac performance (GEF), preload parameter (GEDI), pulmonary hemodynamics (PVRI and MPAP) and EVLWI in different positions after thoracotomy for all groups (all $P > 0.05$) (data not shown).

Discussion

There are many important findings in our study. Lung injury is often quantified by oxygenation, C_{rs} and EVLWI.[11] Our current study demonstrated several features of lung injury after thoracotomy with poor oxygenation, lower C_{rs} and increased EVLWI. In addition, we found that different positions did lead to different pulmonary gas exchange and C_{rs} after thoracotomy. The position with thoracotomized lung uppermost had the best oxygenation and C_{rs}. Applying PEEP can lead to improved PaO_2 and C_{rs} after thoracotomy. Furthermore, PEEP can attenuate positional effects when thoracotomized lung the lowermost.

It is interesting that positional effects are different in animals with normal lung, post-pneumonectomy, and post-thoracotomy. In our previous study, PaO_2 did not change in different positions in pigs with normal lung.[12] In post-pneumonectomized pigs, the PaO_2 significantly changed in different positions with

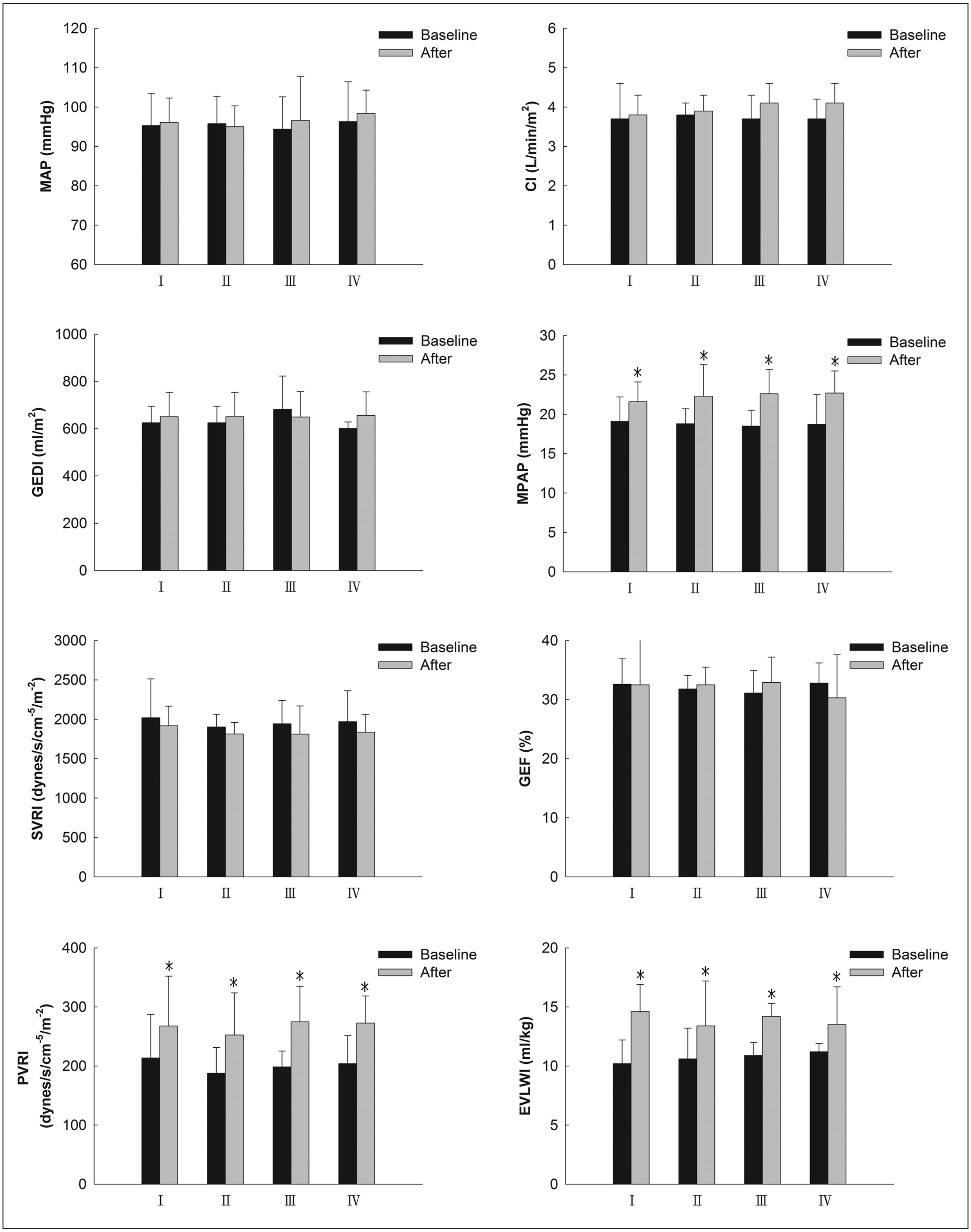

Figure 3: Systemic, pulmonary hemodynamics and extra-vascular lung water index after thoracotomy

There were no significant changes in systemic hemodynamics (MAP, CI, SVRI), cardiac performance (GEF) and preload parameter (GEDI) after thoracotomy. There were significantly increased MPAP, PVRI and EVLWI after thoracotomy in all groups.

* Comparison of baseline and after thoracotomy, $P < 0.05$

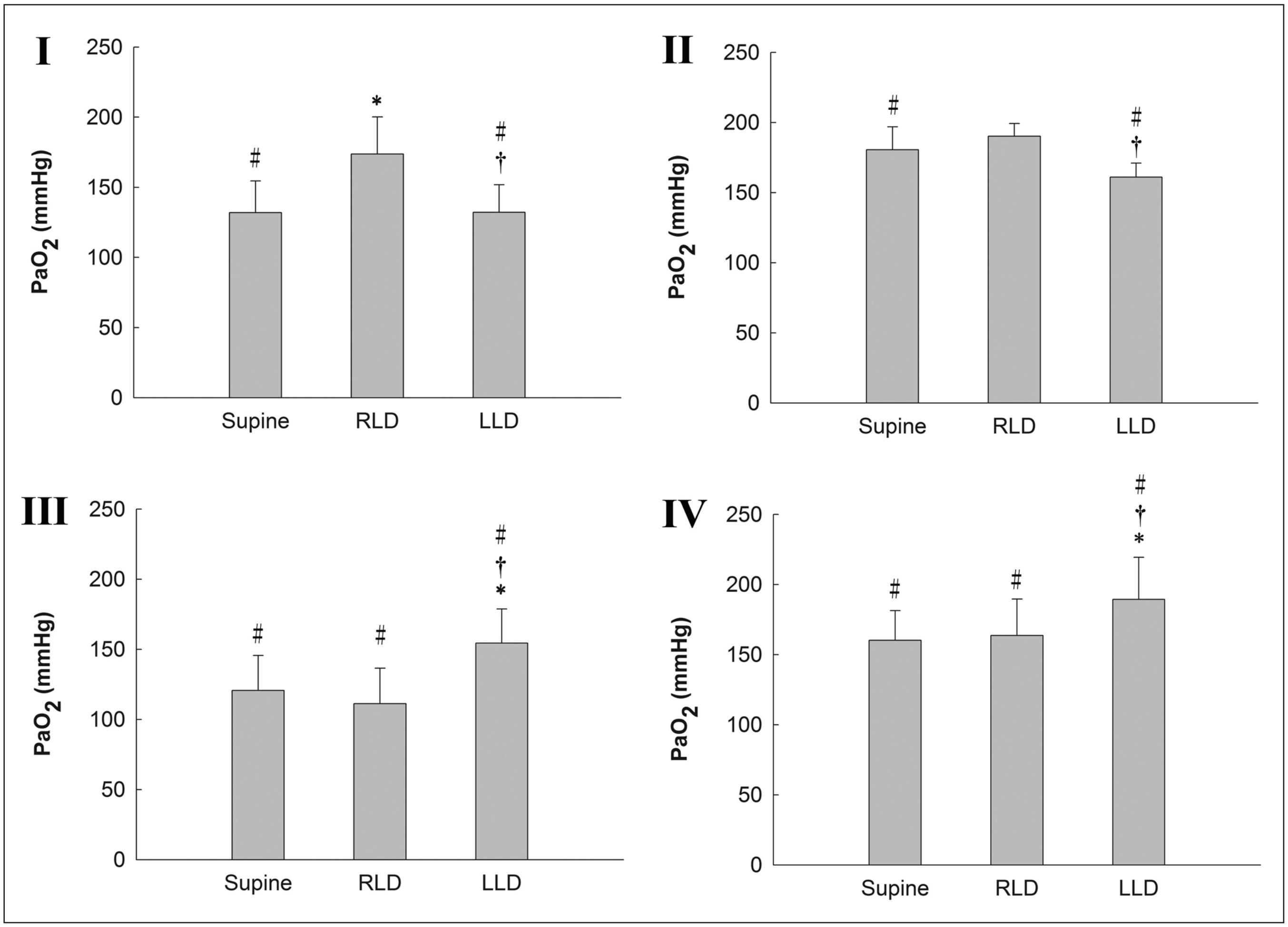

Figure 4: Changes of PaO_2 in different positions after thoracotomy
In group I, the PaO2 was higher in RLD than in supine and LLD after left thoracotomy. In group II, the PaO2 was still higher in RLD than in supine or LLD. However, the PaO2 in group II was higher than group I in LLD and supine. There were similar changes of PaO2 in different positions after right thoracotomy (III and IV).
* Significantly different from control, $P < 0.05$; †Significantly different from RLD, $P < 0.05$; #Comparison of the same positions between groups I vs. II and groups III vs. IV, $P < 0.05$

the best PaO_2 in the position with remained lung uppermost (operated side lowermost).[12,13] However, in the current study, the best PaO_2 in post-thoracotomized pigs is the position with thoracotomized lung uppermost (operated side uppermost). Therefore, the best position after thoracotomy and pneumonectomy is the opposite side. Inappropriate positions after thoracotomy and pneumonectomy will further lead to decreased PaO_2.

In different positions, many factors determine pulmonary gas exchanges, such as gravity,[14] intrinsic vascular or bronchial structures,[15] hypoxic pulmonary vasoconstriction,[16] and shifting of mediastinal and abdominal structures.[17] Post-pneumonectomy with one-lung ventilation (OLV) deteriorates pulmonary gas exchange.[12,13] Besides, OLV after pneumonectomy leads the remained lung more susceptible to circumferential compression by mediastinal and abdominal contents. Therefore, in the position with remained lung lowermost, prominent circumferential organs compression occurs and further deteriorates pulmonary gas exchange.[17] However, these anatomic and physiological changes are different between post-pneumonectomy and post-thoracotomy. After thoracotomy, there is still two-lung ventilation. The deteriorated pulmonary gas exchange after thoracotomy is due to lung atelectasis of the surgical side. In post-thoracotomized pigs, there is redistribution of ventilation and perfusion between the two lungs in different positions. In the position with thoracotomized lung lowermost, the perfusion will shift to dependent thoracotomized lung as a result of gravity. The ventilation-perfusion mismatching then aggravates and leads to poor pulmonary gas exchange. When turning the animal to the position of healthy lung lowermost, the perfusion will shift to the normal dependent lung. The ventilation-perfusion mismatching is then improved and this leads to improved pulmonary gas exchange.

Previous studies found that thoracotomy decreases C_{rs},[18,19] which is consistent with our findings. However, we further found that C_{rs} also changed with different positions after thoracotomy. In groups I and III with ZEEP, the best C_{rs} was in the position with thoracotomized lung uppermost. This result is compatible with one previous study, which showed that a lateral position is associated with a small increase of C_{rs}.[20] It is interesting to address this finding. After thoracotomy, lung atelectasis occurs in the thoracotomized

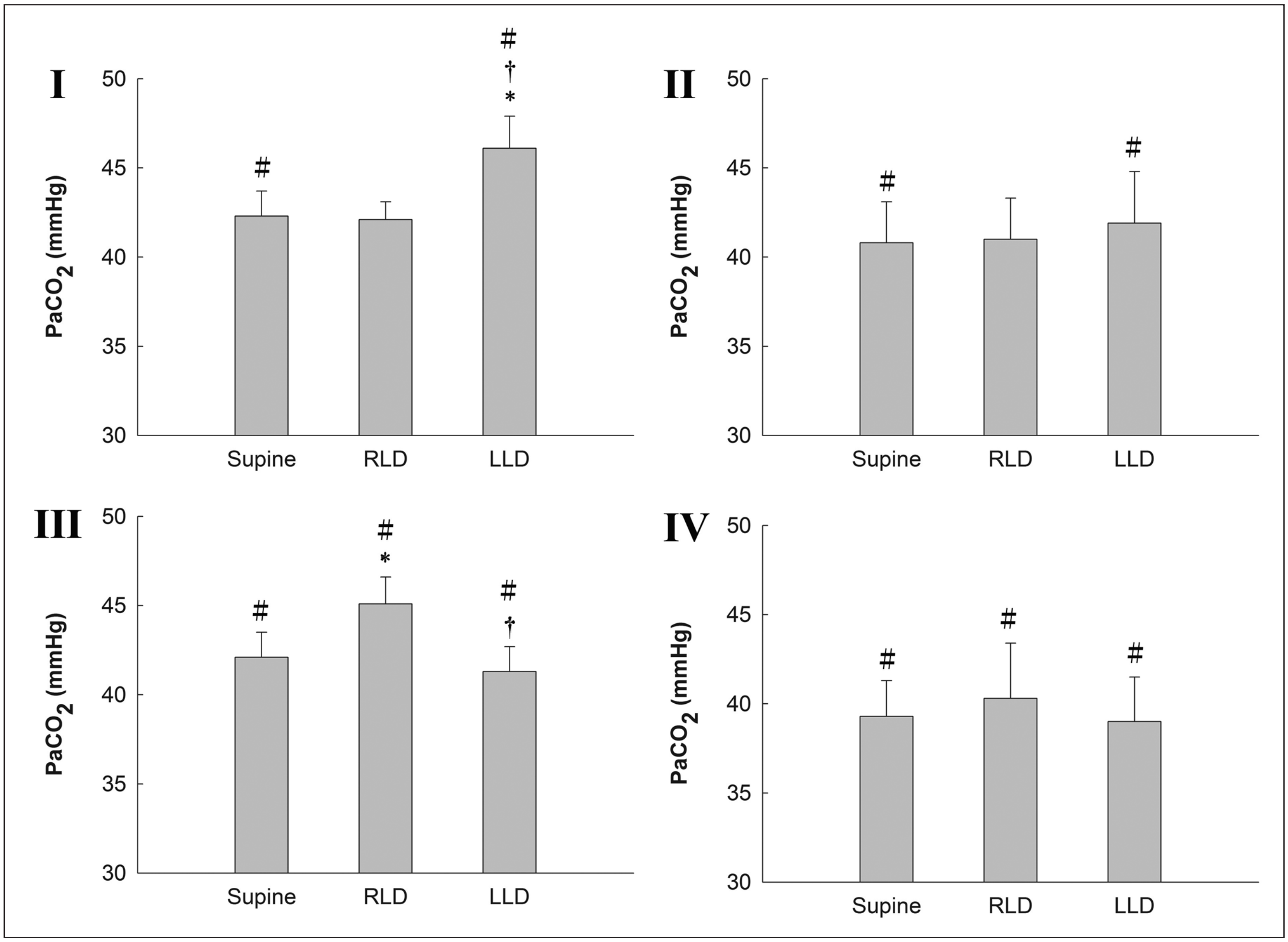

Figure 5: Changes of $PaCO_2$ in different positions after thoracotomy
In group I, the PaCO2 was significantly higher in LLD than in RLD and supine. In group II, there were no prominent PaCO2 changes in different positions. The PaCO2 changes were similar in right thoracotomy (groups III and IV).
*Significantly different from control, $P < 0.05$; †Significantly different from RLD, $P < 0.05$; #Comparison of the same positions between groups I vs. II and groups III vs. IV, $P < 0.05$

side and leads to lower C_{rs}.[21] However, turning the subjects to the lateral position with thoracotomized lung uppermost resulted in more ventilation to the upper lung. This will "recruit' the atelectatic area of thoracotomized lung and result in increased C_{rs}. This effect is like the prone position in ARDS.[22] Therefore, the C_{rs} is higher in this position. When turning subjects to the supine or lateral position with thoracotomized lowermost, pressure applies to the airway will result in unequal ventilation with more ventilation going to the normal lung. Lung atelectasis of thoracotomized lung is further aggravated in these positions.

However, the positional effect for C_{rs} is not prominent when applying PEEP in our groups II and IV. In the previous studies, PEEP along has been shown to be effective regarding the re-expansion of previously collapsed areas.[23,24] Since PEEP already re-expanded some lung atelectasis, the recruit effect is not prominent when turning to thoracotomized lung uppermost. Therefore, applying PEEP can attenuate positional effects after thoracotomy. There are a limited number of studies about position and lung atelectasis. Klingstedt *et al*. assessed atelectasis by computerized tomography.[25] They found that atelectatic areas could be reduced by PEEP.[25] Since PEEP can reduce lung atelectasis in the thoracotomized lung, the positional effects on pulmonary gas exchange and C_{rs} are then attenuated. In our study, PEEP with 5 cmH_2O was enough to restore oxygenation and attenuate positional effects without interfering with the hemodynamics after thoracotomy.

Limitations of study

Although, we found that different positions lead to different pulmonary gas exchanges after thoracotomy and that PEEP can attenuate the positional effects, our study was performed using an animal porcine model. It is still necessary to confirm these findings in human subjects.

Conclusion

Our current study found that thoracotomy will lead to lung injury with deterioration of oxygenation, lung C_{rs} and EVLW. After thoracotomy, different positions lead to different pulmonary gas exchange with the poorest oxygenation in the position with thoracotomized lung lowermost. Applying PEEP after thoracotomy can improve oxygenation, lung C_{rs} and EVLW.

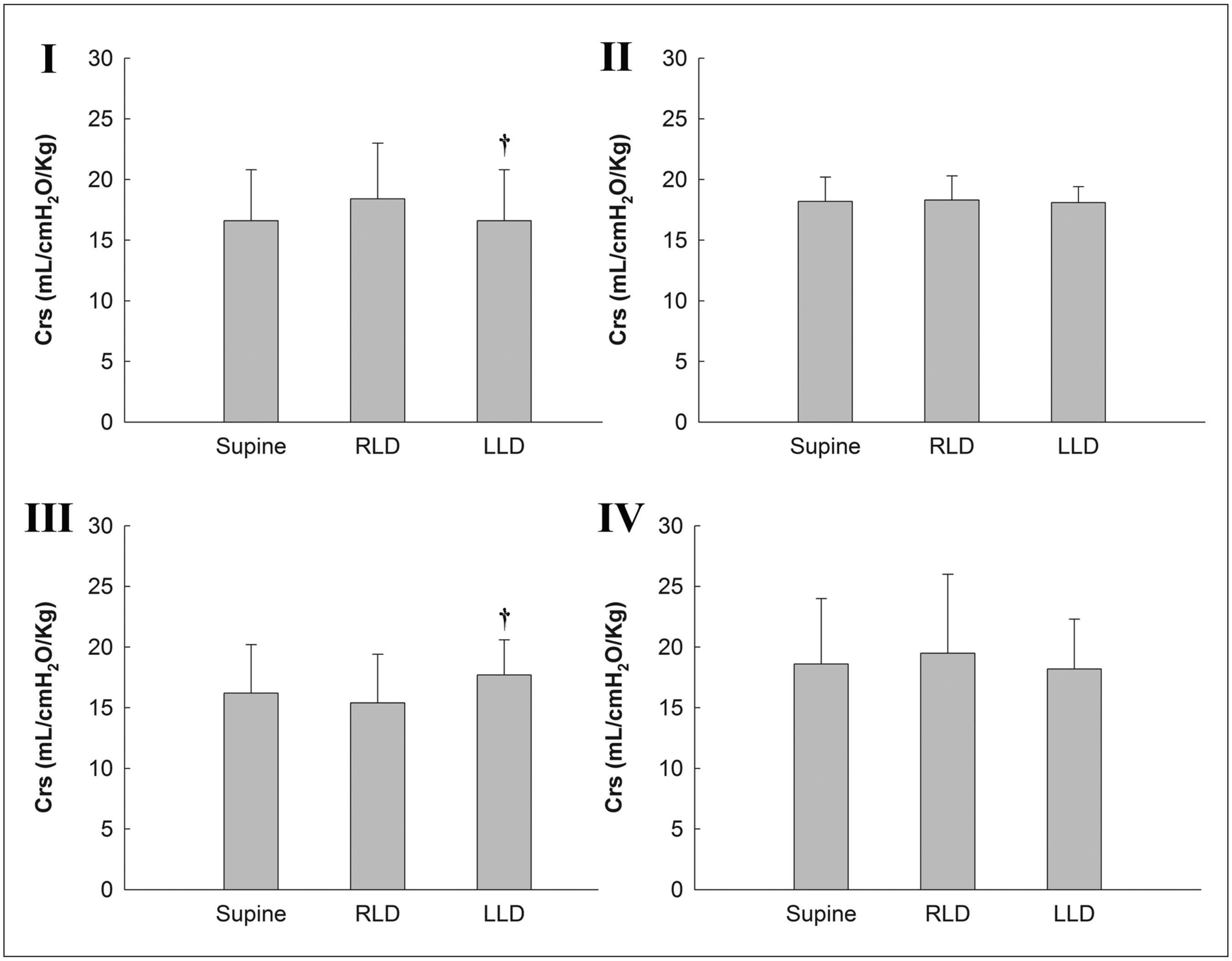

Figure 6: Changes of respiratory system compliance in different positions after thoracotomy
In group I, there were significant higher Crs in RLD than in supine and LLD. However, in group II, there were no significant changes in Crs in different positions. The Crs changes were similar in right thoracotomy (groups III, IV).
*Significantly different from control, $P < 0.05$; †Significantly different from RLD, $P < 0.05$; #Comparison of the same positions between groups I vs. II and groups III vs. IV, $P < 0.05$

Furthermore, applying PEEP can attenuate the positional effects when in positions with thoracotomized lung lowermost.

Competing interests

The authors have no financial or other potential conflicts of interest.

Acknowledgments

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