Electrical impedance tomography-based analysis of ventilation-perfusion matching - Effects of different PEEP-levels after experimental pulmonary contusion.

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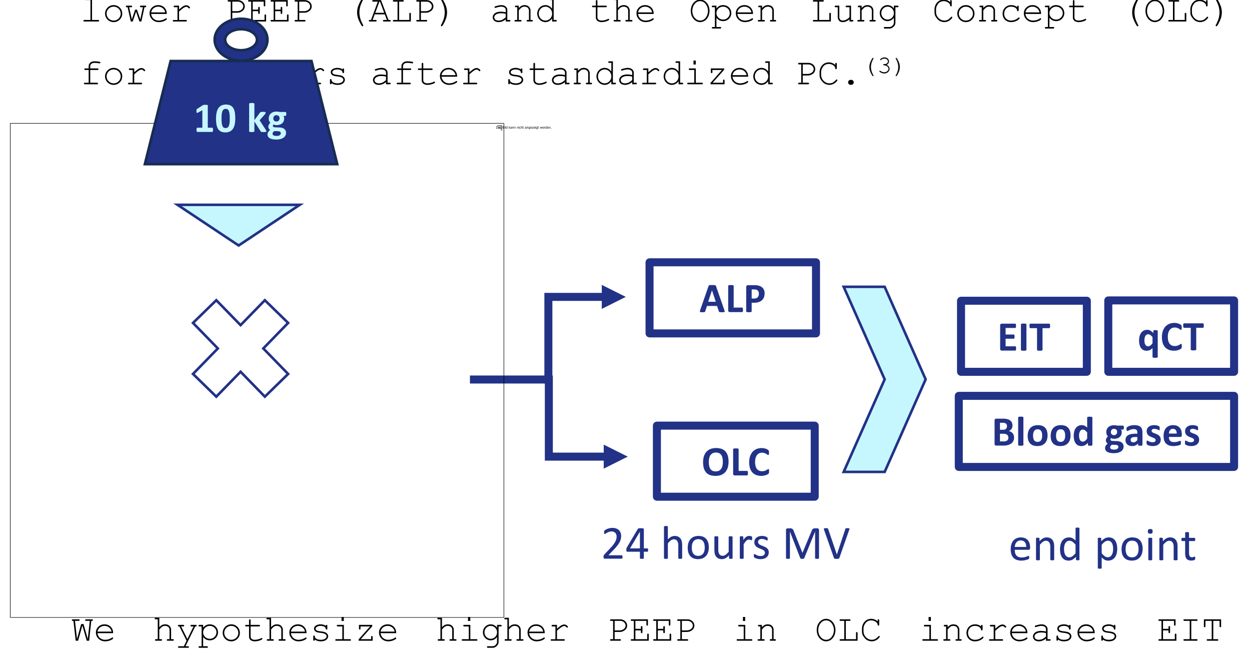
Background:

Pulmonary contusion (PC) can cause respiratory failure. [1] In contused lungs inflammation may spread to primary unaffected tissue and cause generalized edema. Increased lung weight promotes surfactant dysfunction and atelectasis formation in dependent areas. Atelectasis increase shunt fraction and impair gas exchange. Only causal therapy of severe respiratory failure is mechanical ventilation (MV). While the use low tidal volume is generally accepted, the amount of positive end-expiratory pressure (PEEP) is still a matter of debate. Adequate PEEP is able to recruit atelectatic lung areas, lower shunt and increase arterial partial pressure of oxygen (PaO_2).

Electrical impedance tomography (EIT) is a radiation free, bedside monitoring tool for lung ventilation (V). Recently interest in EIT perfusion (Q) analysis emerged. By separating ventilation and perfusion signals cardiac associated pulsatility can be detected, which is considered a surrogate for regional perfusion.[2] Presented data is an analysis of pigs ventilated with the ARDSnetwork lower PEEP (ALP) and the Open Lung Concept (OLC) for [illegible]s after standardized PC.[3]

Figure 1:



We hypothesize higher PEEP in OLC increases EIT measured V/Q match (V/Q close to 1), thereby lowers shunt and prevents hypoxemia 24 hours after PC compared to ALP.

Material and Methods:

The trial was approved by local ethics committee. EIT data, blood gases and computed tomography scans (CT) were analyzed after 24 hours of MV (Figure 1). For EIT measurements (PulmoVista 500, sample rate 20 - 50 Hz) 500 frames per animal were reconstructed and separated into ventilation and perfusion signals using frequency domain-filtering. From ventilation data mean tidal impedance change images (V_{TID}) were generated. Perfusion data was gated and averaged using end-diastolic EIT peaks and summed up along time (Q_{GATE}), with a mask threshold of 15 %.[2] In each region of interest (ROI) (ventral right (VR), ventral left (VL), dorsal right (DR), dorsal left (DL)) the proportion of active pixels was calculated in relation to total number of active pixels. Scalar division was used for V/Q values. CT was performed in end-expiratory hold. Lungs were manually segmented and analyzed using a quantitative CT approach. Arterial and mixed venous blood gases were analyzed under 100% of inspired oxygen for PaO_2 and shunt calculation. Results are presented as median (25^{th} – 75^{th}), groups were compared using Mann-Whitney-U test, significancy was assumed at $p<0.05$.

Results:

After 24 hours of MV (ALP, n=9; OLC, n=8) OLC had significantly higher PEEP. ALP animals had significantly lower PaO_2 compared to OLC. Shunt fraction and quantitative CT measured non-aerated lung mass (CT Mnon) was significantly higher in ALP. (see table 1)

Table 1:

	ALP	OLC	p-value
PEEP (cmH_2O)	8 (8 - 10)	21 (20 - 22)	p<0.001
PaO_2 (mmHg)	78 (73 - 111)	499 (430 - 523)	p<0.001
Shunt (%)	28 (27 – 32)	10 (7 - 16)	p<0.001
CT Mnon (%)	59 (48 - 65)	7 (3 - 15)	p<0.001

Figure 2:

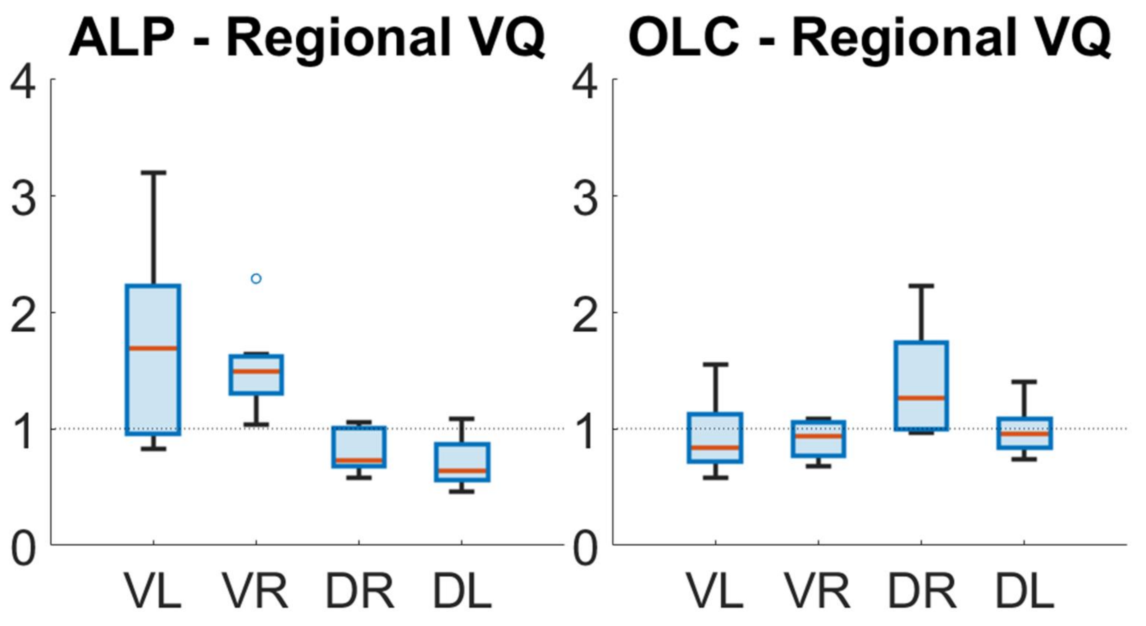


Figure 2 shows increased ventilation with lower pulsatility in ventral ROIs (V/Q>1) and less ventilation yet more pulsatility in dorsal ROIs (V/Q<1) in ALP animals . Regional V/Q for OLC has closer medians to V/Q=1.

Figure 3:

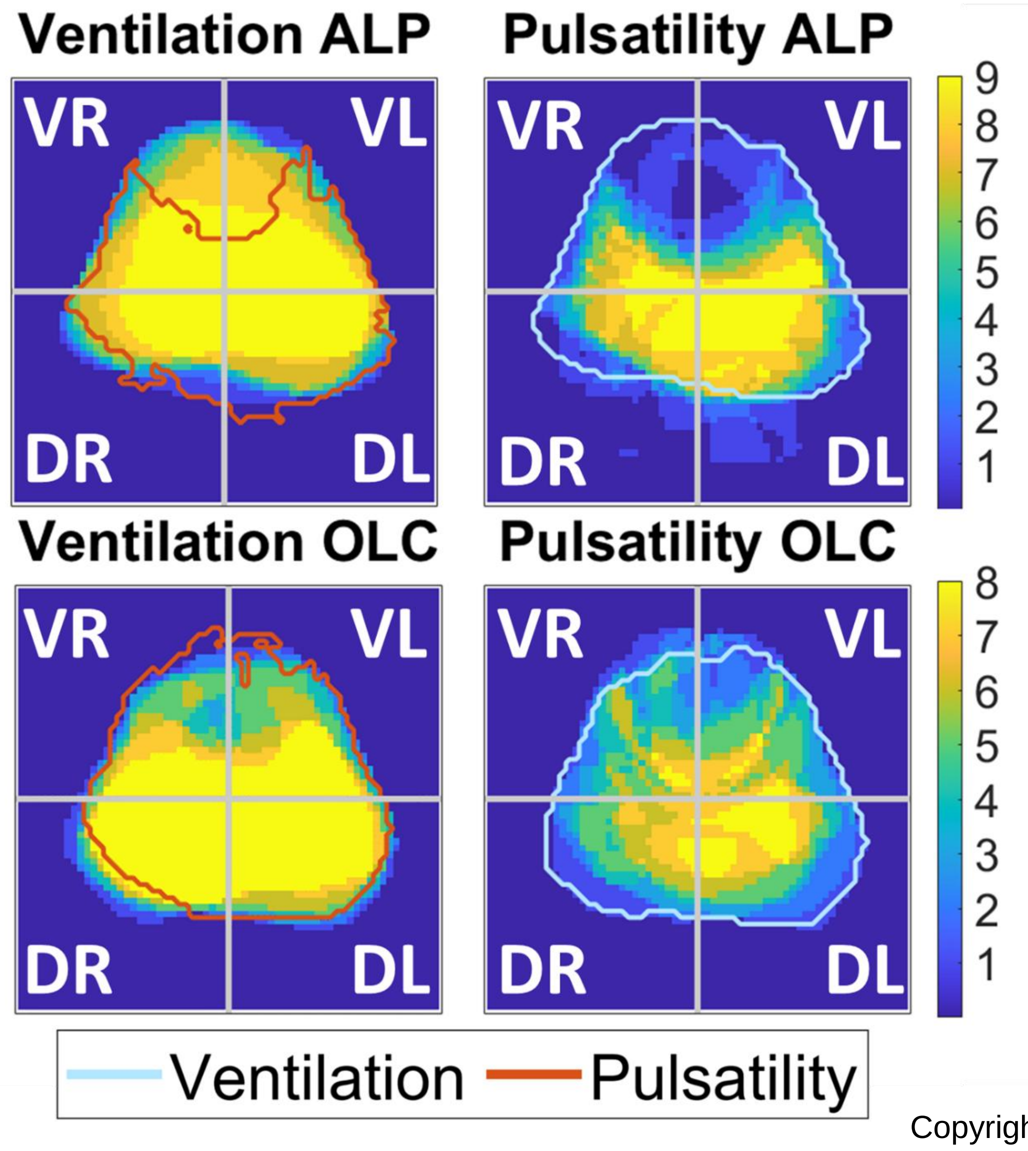


Figure 3 shows overlapped ventilation and pulsatility images of all animals per group. Dark/blue regions indicate little activity, bright/yellow pixels are active areas. In ALP ventilation is located ventral for most animals, while pulsatility is predominantly in dorsal ROIs. Additionally, a ventilation defect located DR can be seen in ALP, where the trauma was induced. On the other hand, OLC is able to ventilate dorsal ROIs and show a homogeneous distribution of pulsatility in ventral and dorsal ROIs.

Conclusion:

Ventilation with high PEEP in OLC homogenized EIT detected V/Q, reduced CT Mnon and lowered shunt. Ventilation with low PEEP promoted V/Q>1 in ventral ROIs and V/Q<1 in dorsal ROIs after PC. This can be interpreted as ventral dead space ventilation and dorsal shunt. We are aware that EIT pulsatility reflects pulsatile change blood volume rather than pulmonary blood flow, which can be affected by many factors.[5] However, EIT V/Q results are mirrored by clinically relevant parameters (shunt, PaO_2, CT Mnon) in our study. Further analyses will follow to compare our results to a hypertonic saline bolus, which is considered the gold standard in EIT perfusion analysis.

We conclude that EIT derived pulsatility analysis might be sufficient to evaluate PEEP setting in MV for V/Q match following PC.

References:

1) Fulton et. al, The progressive nature of pulmonary contusion, Surgery, 1970

2) Frerichs et. al, Assessment of changes in distribution of lung perfusion by EIT, Respiration 2009

3) Landeck et. al, High PEEP ventilation mitigates the progression from unilateral PC to ARDS, J Trauma 2024

4) Adler et. Al, GREIT: a unified approach to 2D linear EIT reconstruction of lung images, Physiol Meas 2009

5) Borges et. al, Regional lung perfusion