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CASE REPORT

The effects of prone and supine position on respiratory mechanics in a patient with ARDS

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Abstract

Prone positioning is one of the few proven treatment strategies in severe acute respiratory distress syndrome (ARDS) but little is known about the change in respiratory mechanics around proning. Oesophageal pressures to estimate transpulmonary pressure (P_L) can be used to guide lung-protective mechanical ventilation in ARDS. There are two methods to estimate P_L, both probably reflecting local P_L in different zones of the lung. We present a case where prone positioning resulted in increased oxygenation and improved respiratory mechanics, suggestive of recruited lung volume and more homogeneous distribution of tidal volumes. Further studies are necessary to determine if relative P_L in the prone position really reflects the 'baby lung'.

Introduction

Acute respiratory distress syndrome (ARDS) is a life-threatening form of acute respiratory failure and accounts for 10% of ICU admissions.[1] ARDS is not a disease but a clinical syndrome caused by a pulmonary (e.g. pneumonia or massive aspiration) or systemic insult (sepsis, trauma, burns, pancreatitis). This triggers acute, diffuse, inflammatory lung injury, leading to increased alveolar capillary permeability, increased lung weight and loss of aerated lung tissue. Patients consequently suffer from hypoxaemia.[1,2] The vast majority of ARDS patients require mechanical ventilation. The main goals are to provide sufficient oxygenation and to prevent ventilator-induced lung injury. The latter is challenging since these patients present with a range of lung and chest wall elastance and variable lung inhomogeneity.

Transpulmonary pressure (P_L), the actual distending pressure of the lung, is estimated by two different methods: an absolute method using oesophageal pressure as an approximation of pleural pressure and a relative method using the relation between lung elastance and total respiratory system elastance *(formulas in table 1)*. For further reference on these measurements, a physiological and technical review was published by Akoumianaki et al.[3] Measurement of oesophageal pressure to estimate absolute P_L, has been shown to improve oxygenation and decrease elastance with a trend towards lower mortality.[4] In another study targeting relative P_L below 25 cmH_20, higher PEEP could be applied and initiation of extracorporeal membrane oxidation could be avoided.[5]

Table 1. Formulas

Absolute P_L = Paw – Pes (during inspiratory and expiratory occlusion) $\Delta Paw = P_{plateau}$ - PEEPtotal ΔP_L = absolute $P_{L,\ inspiratory}$ – absolute $P_{L,\ expiratory}$ $E_{RS} = \Delta Paw / TV$ $E_L = \Delta P_L / TV$ Relative $P_L = P_{plateau} \times E_L / E_{RS}$
Definitions of abbreviations: P_L = transpulmonary pressure, Paw = airway pressure, Pes = oesophageal pressure, $P_{plateau}$ = plateau pressure (= ; expiratory: total amount of PEEP (PEEPtotal)), E_L = lung elastance, E_{RS} = respiratory system elastance, TV = tidal volume

Unfortunately, both methods yield very different estimates of P_L.[6] Recently, Yoshida et al. showed in pigs and human cadavers that the absolute value of P_L during expiration represents the P_LL in the dependent 'atelectatic lung' and could be used to titrate PEEP, while the relative value of PL during inspiration represents the P_L in the non-dependent 'baby lung'.[7]

Prone positioning results in more homogeneous lung inflation and a more even distribution of mechanical forces throughout the injured lungs.[8] This is because recruitment of the anatomically larger lung volume in the dorsal thorax outweighs derecruitment of the smaller ventral lung regions caused by the prone position. The net effect is increased lung recruitment and oxygenation, compliance and subsequently more homogeneously distributed tidal volumes.[8] Prone positioning is, together with low tidal volume ventilation, the only intervention with moderate to high quality evidence that showed reduction in patient mortality in ARDS[1,9] and currently recommended by international ARDS practice guidelines.[10]

Very little is known about changes in respiratory mechanics during proning[11,12] and it is unknown whether relative transpulmonary pressures may be used in the prone position.

Case history

A 63-year-old male, height 1.73 m, was seen at the emergency department in another hospital with two weeks of progressive dyspnoea, fever and muscle aches. His previous medical history was notable for angina without significant coronary artery disease. His chest radiograph showed bilateral opacities *(figure 1)* and he was severely hypoxaemic. With a differential diagnosis of pneumonia he was admitted to the ICU and subsequently intubated for respiratory failure. Empiric treatment with cefuroxime and ciprofloxacin was initiated. In the following days oxygenation worsened for which the patient was placed in a prone position and he was accepted for referral to our university hospital. All microbiology cultures remained negative.

New microbiological cultures were obtained through bronchoalveolar lavage (BAL) and computed tomography of the thorax was performed which showed increased lung densities and bilateral consolidations *(figure 2)*. To further guide lung-protective mechanical ventilation, transpulmonary pressures were measured several times on the following days: day 2, day 7 immediately after turning into the supine position for the first time because PaO_2/FiO_2 ratio had increased from 100-200 to 200-300, and after reproning because of worsened oxygenation, negative end-expiratory P_L and high end-inspiratory relative P_L *(table 2)*. Tidal volumes were 340 ml to maintain plateau pressures under 30 cmH_2O or inspiratory P_L under 25 cmH_2O. Tidal volumes and respiratory rates were kept unchanged throughout this period. While respiratory mechanics on day 2 are included in this table for completeness, the focus is on the measurements on day 7, when the patient was moved from prone to supine and back again. Prone position resulted in improved oxygenation, lung elastance and end-expiratory P_L, but an increase in absolute P_L. Lastly, as suggested by Talmor et al.,[4] PEEP was reduced from 15 to 13 cmH_2O after an end-expiratory P_L of 2.8, after which the last measurements were done.

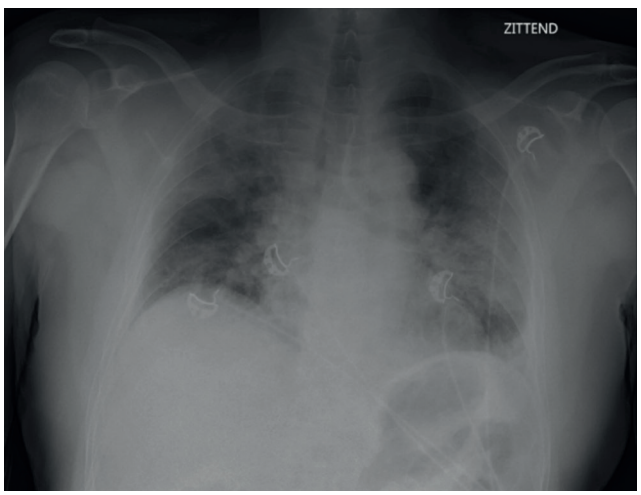

Figure 1: Chest radiograph

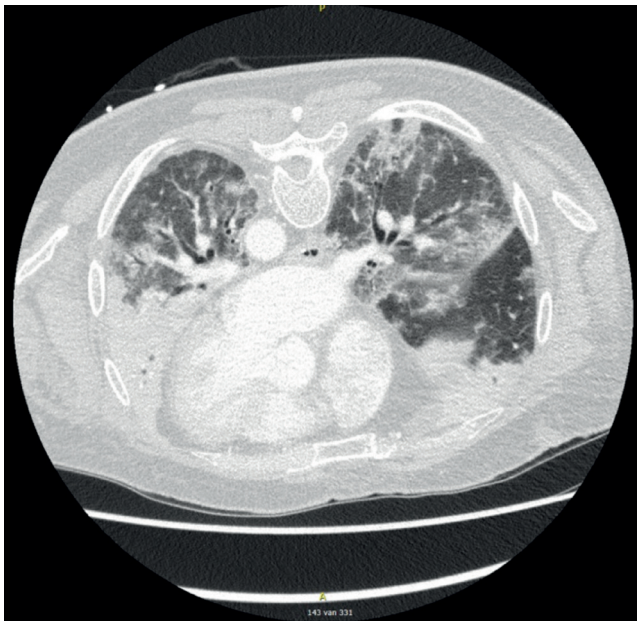

Figure 2: CT thorax in prone position

BAL cultures remained negative, and a lung biopsy was performed, which showed a typical histology of non-specific interstitial pneumonia and small arterial thrombi for which prednisone and anticoagulation were initiated. Over the

Table 2. Respiratory mechanics in the presented patient

	Day 2 Prone	Day 7 Supine	Day 7 Prone	Day 7 Prone
Ventilator setting				
Respiratory rate	28	28	28	28
Tidal volume	340	340	340	340
PEEP (cmH_20)	15	15	15	13
FiO_2 (%)	45	55	40	40
PaO_2 (mmHg)	68			
SpO_2	95-97	93	94	94
Pressures in cmH_2O				
Paw end-expiratory occlusion	16	16,1	15,7	13,5
Pes end-expiratory occlusion	10,013,5	19,8	12,9	11,8
Paw end-inspiratory occlusion	30,6	31,3	30,3	27,6
Pes end-inspiratory occlusion	17,3	21,8	26,216,2	15,1
P_L, end-expiratory	2,5	-3,7	2,8	1,7
P_L, end-inspiratory absolute	13,3	9,5	14,1	12,5
P_L, end-inspiratory relativ	22,7	27,2	23,5	21,0
Elastances in cmH_2O/L				
E_{RS}	38,3	44,6	42,9	41,5
E_{CW}	9,9	5,9	9,7	9,8
E_L	28,4	38,8	33,2	31,5

Definitions of abbreviations: Paw = airway pressure, Pes = oesophageal pressure, P_L = transpulmonary pressure, E_{RS} = respiratory system elastance, E_{CW} = chest wall elastance, E_L = lung elastance

next week oxygenation slowly improved. Recovery was complicated by ICU acquired weakness, colonic ischaemia (which spontaneously recovered) and delirium. Percutaneous tracheotomy was performed to facilitate weaning from mechanical ventilation. After a total of six weeks he was transferred back to the referring hospital for the remainder of his recovery.

Discussion

ARDS management remains largely supportive based on the principles of lung-protective mechanical ventilation.[1] Prone position is one of the few proven treatment strategies in severe ARDS but little is known about the change in respiratory mechanics around proning and vice versa.

We present a patient with severe ARDS in whom prone positioning resulted in an increase in oxygenation, a decrease in lung elastance and an increase in chest wall elastance. Also inspiratory relative P_L decreased but absolute P_L increased. End-expiratory P_L increased, as was found by Kumaresan et al.[13] Improved oxygenation and decreased lung elastance suggests recruited lung volume and a more homogeneous distribution of tidal volumes.[12] The two methods of measuring absolute and relative transpulmonary pressures give conflicting results as was previously noted by Gulati et al.[6] Furthermore, since relative inspiratory P_L is probably only representative of lung stress in the nondependent 'baby lung' in the supine position, it may not be reliable in our patient in prone position.[7]

In a recent study including 41 patients, Riad et al. also showed increases in absolute inspiratory and expiratory transpulmonary pressure, but contrary to our findings lung elastance did not change. Relative P_L was not determined.[11] The fact that our measurements were performed approximately one hour after placing the patient in the prone position might have allowed time for lung recruitment and concurrent decreased lung elastance as opposed to Riad who performed the measurements during the procedure of prone positioning. Different observations in patients can also be explained by marked heterogeneity in ARDS patients and it underlines the importance of measuring respiratory mechanics to guide individual treatment.

The increased chest wall elastance in the prone position is explained by the firm bed preventing the more compliant ventral chest wall from expanding as easily as in supine position.[8]

According to Yoshida et al. expiratory absolute P_L reflects pressure in the middle to dorsal lung (lung regions close to the oesophageal balloon) and inspiratory relative P_L is representative for the nondependent 'baby lung'.[7] With this in mind, we set PEEP targeting expiratory absolute P_L >0 cmH_2O to prevent atelectasis and target inspiratory relative P_L <20-25 cmH_2O to prevent barotrauma, targets as previously recommended for these goals.

Conclusion

Oesophageal pressures to estimate transpulmonary pressure can be used to guide lung-protective mechanical ventilation in ARDS. Two methods estimating P_L exist, both probably reflecting local P_L in different zones of the lung. The presented case showed that prone positioning resulted in increased oxygenation, a decrease in lung elastance and relative P_L but increased absolute P_L, suggestive of recruited lung volume and more homogeneous distribution of tidal volumes. Further studies are necessary to determine if relative P_L in prone position really reflects the 'baby lung'.

Disclosures

All authors declare no conflict of interest. No funding or financial support was received.

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