Intracranial pressure responsiveness to positive end-expiratory pressure is influenced by chest wall elastance: a prospective physiological study in patients with aneurysmal subarachnoid hemorrhage

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Additional File 1

Procedure of the placement of esophageal balloon catheter

We used the SmartCath-G adult nasogastric tube with an esophageal balloon (7003300, CareFusion Co., Yorba Linda, CA, USA) in this study. Patients were remained in a supine position with the head of the bed elevated to 30° during the study period. After anesthetizing the nose and oropharynx with 10% lidocaine spray, the esophageal balloon catheter was inserted through the nostril to a depth of 60 cm. The intra-gastric position of the distal part of the catheter was confirmed by aspiration of gastric juice and auscultation of air insufflations into the stomach. After confirmation of the catheter position, the balloon was inflated with 1.5 mL of air, and the proximal part of the catheter was connected to a pressure transducer. Subsequently, the catheter was slowly withdrawn, and the dynamic occlusion test was performed. An end-expiratory occlusion was performed until three to five spontaneous inspiratory efforts were made against the end-expiratory occlusion. The ratio of the change in esophageal pressure (P_{Es}) to the change in airway pressure (\Delta P_{Es}/\Delta P_{AW}) was calculated. The catheter was considered...
correctly positioned when the $\Delta P_{ES}/\Delta P_{AW}$ ratio during the occlusion test is in the range of 0.8 to 1.2 [1].

In the absence of spontaneous breathing, the positive pressure occlusion test was performed by applying manual compression on the rib cage during the end-expiratory occlusion [2, 3].

**Pressure and flow measurements**

$P_{ES}$ and $P_{AW}$ were measured by KT 100D-2 pressure transducers (KleisTEK di CosimoMicelli, Italy, range: +/- 100 cm H₂O). Flow was measured with a Fleisch pneumotachograph (Vitalograph Inc., Lenexa, KS, USA) inserted between the Y-piece of the ventilator circuit and the endotracheal tube. The volume was obtained by electrical integration of the flow signal. The Fleisch pneumotachograph and pressure transducers were connected to an ICU-Lab Pressure Box (ICU Lab, KleisTEK Engineering, Bari, Italy) by 80 cm rigid tube lines. The signals were displayed continuously and saved (ICU-Lab 2.5 Software Package, ICU Lab, KleisTEK Engineering, Bari, Italy) on a laptop for further analysis at a sample rate of 200 Hz. The pressure transducers were calibrated with a water column. The pneumotachograph was calibrated with a 1-L calibration syringe (SN: 554-2266, Hans Rudolph, Inc. Shawnee, KS, USA).

**Respiratory mechanics measurements**

An end-inspiratory occlusion and an end-expiratory occlusion were performed for 3 s. $P_{AW}$ and $P_{ES}$ during the last second of occlusion were recorded. The mean $P_{AW}$ and $P_{ES}$ during a complete cardiac cycle was measured to avoid the influence of cardiac artifacts (Figure E1).
Figure E1 Measurement of airway pressure ($P_{AW}$) and esophageal pressure ($P_{ES}$). An approximately 3-s end-inspiratory occlusion and an end-expiratory occlusion were performed. Move the cursors (the yellow and blue vertical lines) to the last and last second peaks, and the the average value between the two cursors were automatically calculated and displayed by the software.

Respiratory system elastance ($E_{RS}$) can be calculated as:

$$E_{RS} = \frac{P_{PLAT} - P_{EEP_{TOTAL}}}{V_T}$$

Where $P_{PLAT}$ and $P_{EEP_{TOTAL}}$ represent $P_{AW}$ at end-inspiratory and end-expiratory occlusion, respectively. The difference between $P_{PLAT}$ and $P_{EEP_{TOTAL}}$ was called as airway driving pressure ($\Delta P_{AW}$).

$E_{RS}$ can be differentiated into lung elastance ($E_L$) and chest wall elastance ($E_{CW}$) [4]:

$$E_{RS} = E_{CW} + E_L$$

Using the $P_{ES}$ as a surrogate for pleural pressure, $E_{CW}$ can be calculated as:

$$E_{CW} = \frac{P_{ES-EI} - P_{ES-EE}}{V_T}$$
Where $P_{ES-EI}$ and $P_{ES-EE}$ are respective $P_{ES}$ determined at end-inspiratory and end-expiratory occlusion, and the difference between $P_{ES-EI}$ and $P_{ES-EE}$ was called as chest wall driving pressure ($\Delta P_{ES}$).

$E_L$ can be calculated as:

$$E_L = \left( \frac{P_{PLAT} - P_{ES-EI}}{V_T} \right) - \left( \frac{P_{TOTAL} - P_{ES-EE}}{100} \right)$$

Where $(P_{PLAT}-P_{ES-EI})$ and $(P_{TOTAL}-P_{ES-EE})$ are the respective transpulmonary pressure at end-inspiratory and end-expiratory occlusion, and the difference of these two parameters represents the transpulmonary driving pressure ($\Delta P_L$).

$E_{RS}$, $E_{CW}$ and $E_L$ were obtained at the two tested PEEP levels.

**References**

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