Supplementary materials for:

The oesophageal balloon for respiratory monitoring in ventilated patients: updated clinical review and practical aspects

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Content:

Elastance-derived method to calculate end-inspiratory transpulmonary pressures

The *elastance-derived method* [1, 2] uses the tidal change in esophageal pressures (Pes, measured with circuit occlusions) to calculate the ratio between lung elastance (E_L) and respiratory system elastance (Ers); transpulmonary pressure (P_L) is then calculated as Paw x E_L/Ers. This approach assumes that changes in pleural pressure (Ppl) and Pes are similar while their absolute values may differ. The calculation has been proposed by Gattinoni [1] for static conditions in a passive patient on controlled mechanical ventilation. Both the transmural pressures and elastances of the lungs (P_L and E_L) and chest wall (Pcw – similar to Ppl, and Ecw) act in series:

$$\text{Paw} = P_L + \text{Ppl} \qquad \text{(Eq. 1)}$$

$$\text{Ers} = E_L + \text{Ecw} \qquad \text{(Eq. 2)}$$

Considering that elastance is calculated as the change in pressure divided by the change in volume (i.e., E = ΔP/ΔV), we can rewrite and combine Equations 1 and 2 as follows:

$$(\Delta P_L/\Delta V) / (\Delta \text{Paw}/\Delta V) = E_L/\text{Ers} \qquad \text{(Eq. 3)}$$

In static conditions with no volume changes, we therefore have:

$$P_L/\text{Paw} = E_L/\text{Ers} \qquad \text{(Eq. 4)}$$

Hence:

$$P_L = \text{Paw} \times E_L/\text{Ers} \qquad \text{(Eq. 5)}$$

Substituted for end-inspiratory P_L (end-inspiratory occlusion) we get:

$$P_{L,\text{end-insp}} = \text{Pplat} \times E_L/\text{Ers} \qquad \text{(Eq. 6)}$$

Because the pressures and elastances act in series, the slope of the elastance-derived relationship between P_L and Paw is defined by the E_L/Ers ratio.

Similar to this approach, the elastance-derived pleural pressure (Ppl, or Pcw) at end-inspiration (occlusion) can be calculated as:

$$\text{Ppl}_{\text{end-insp}} = \text{Pplat} \times \text{Ecw}/\text{Ers} \qquad \text{(Eq. 7)}$$

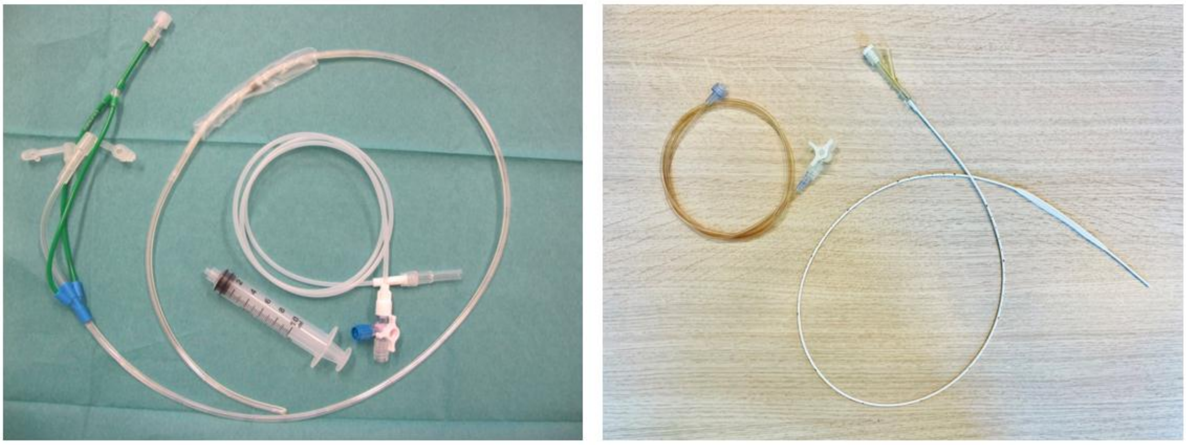
Calculations of respiratory mechanics based on Pes

Oesophageal manometry allows measuring and monitoring of static lung and chest wall compliance (C_L and Ccw) using pressure values obtained at end-inspiratory (end-insp) and end-expiratory (end-exp) occlusions and tidal volume (VT), through the following formulas:

$$C_L = VT/\Delta P_L = VT/([Pplat - Pes_{end\text{-}insp}] - [total\ PEEP - Pes_{end\text{-}exp}]) \qquad \text{(Eq. 8)}$$

$$Ccw = VT/\Delta Pcw = VT/\Delta Pes = VT/(Pes_{end\text{-}insp} - Pes_{end\text{-}exp}) \qquad \text{(Eq. 9)}$$

Alternatively, since compliance is the inverse of elastance and respiratory system pressures act in series, lung and chest wall compliance can be derived from the formula $Ers = E_L + Ecw$, or $1/Crs = 1/C_L + 1/Ccw$, with Ers and Crs the respiratory system elastance and compliance, respectively.



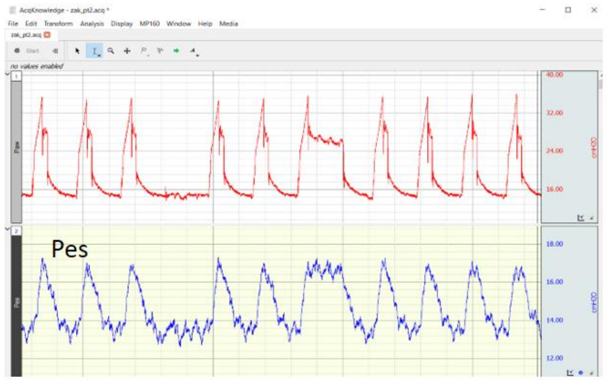
a) NutriVent b) Cooper

Supplemental figure 1. Example of commonly used oesophageal balloon catheters. a) NutriVent catheter (Sidam Group): 14 French, catheter length: 108 cm, balloon length: 10 cm, proposed initial filling volume: insert 4mL, then withdraw 1.5mL (remaining 2.5mL in balloon); b) Cooper catheter (Cooper Surgical): 5 French, catheter length: 86 cm, balloon length: 9.5 cm, proposed initial filling volume: insert 2mL, then withdraw 1.2mL (remaining 0.8mL in balloon).

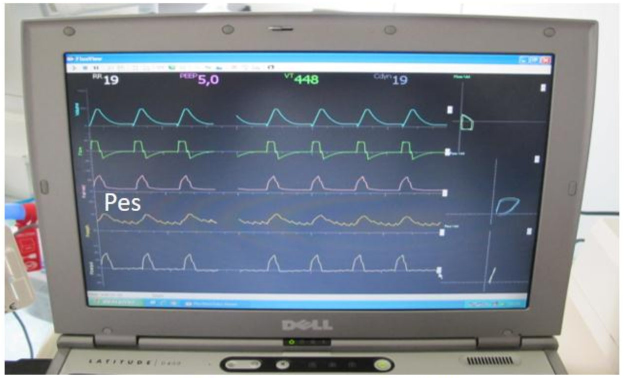
a) Servo-U ventilator (Getinge)

b) Hamilton-C6 ventilator (Hamilton)

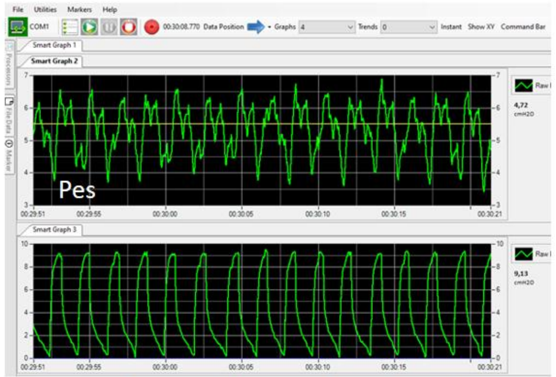
c) Engström Carestation ventilator (GE)



d) AcqKnowledge software (BIOPAC)

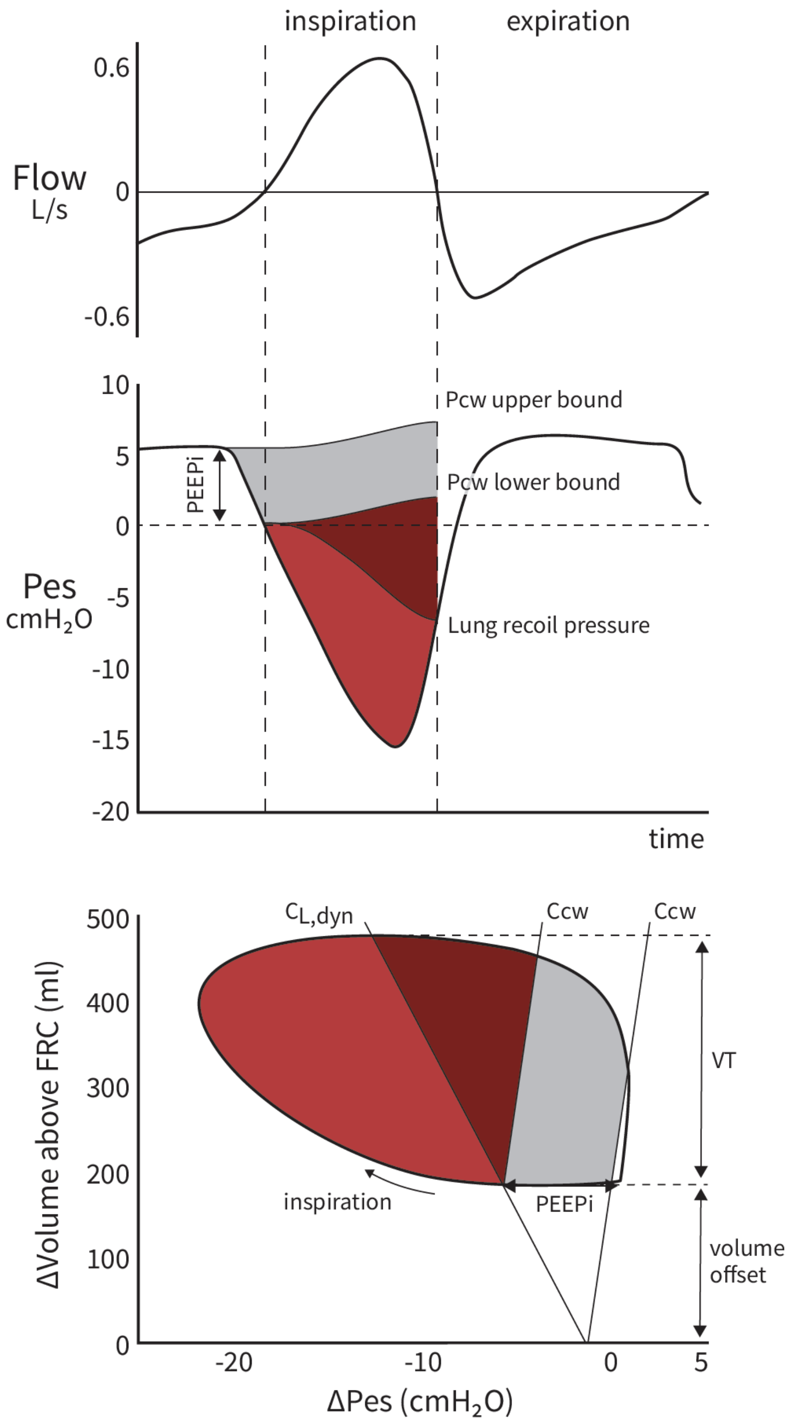


e) FluxView software (FluxMed)



e) SmartLab^{TM} software (Hans Rudolph)

Supplemental figure 2. Examples of ventilator monitors (upper) and stand-alone devices (lower) to measure Pes at the bedside (examples are during controlled mechanical ventilation): Pes directly integrated in the mechanical ventilation (Getinge (a), Hamilton (b), GE (c)) or as acquired using a stand-alone dedicated measurement setup with airway pressure and/or flow sensor integrated (BIOPAC (d), FluxMed (e), Hans Rudolph (e)). Note that other possibilities for data acquisition exist.



Supplemental figure 3. Advanced pressure-based assessment of inspiratory breathing effort during a T-piece weaning trial. Dashed lines in the flow-time and oesophageal pressure (Pes)-time curves represent moments of zero flow. **Upper:** Flow waveform. **Middle:** Esophageal pressure (Pes) waveform. The drop in Pes before the onset of inspiratory flow represents the intrinsic positive end-expiratory pressure (PEEPi). The recoil pressure of the chest wall (Pcw), estimated as 4% of the predicted vital capacity [3], is superimposed on the Pes tracing at the onset of the decrease in Pes (upper bound of Pcw) and at the onset of inspiratory flow generation (lower bound of Pcw), as well as the lung recoil pressure as derived from the dynamic lung compliance ($C_{L,dyn}$). The colored area comprises the total esophageal PTP (PTPes): the grey green area represents the PTPes attributed to PEEPi, the dark red area represents the elastic PTPes, and the light red area represents the resistive PTPes. **Lower:** Pressure-volume loop of the *changes* in Pes (ΔPes) and instantaneous lung volume (ΔVolume) during the presented breath, also known as the Campbell diagram to assess work-of-breathing (WOB). WOB is often reported in work per liter of minute ventilation (Joule/L). The chest wall compliance (Ccw) curve and $C_{L,dyn}$ curve intersect at functional residual capacity (FRC); the volume offset is due to PEEPi. The grey area represents the WOB attributed to PEEPi (i.e., there is no volume displacement during the inspiratory effort needed to overcome PEEPi), the dark red area represents the elastic WOB, and the light red area represents the resistive WOB. Note that the WOB reliably reflects the patient's work to displace a specific tidal volume (VT) when WOB is measured during a weaning trial with the patient disconnected from the ventilator (i.e., during assisted breathing the VT results from both ventilator pressurization and patient effort).

References

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2. Staffieri F, Stripoli T, De Monte V, Crovace A, Sacchi M, De Michele M, Trerotoli P, Terragni P, Ranieri VM, Grasso S. Physiological effects of an open lung ventilatory strategy titrated on elastance-derived end-inspiratory transpulmonary pressure: Study in a pig model*. *Critical Care Medicine* 2012; 40: 2124–2131.

3. Agostini E, Mead J. Statics of the Respiratory System. *Handbook of Physiology Respiration* Washington DC: American Physiological Society; 1964. p. 387–409.