26th International Conference on Biomedical Applications of Electrical Impedance Tomography (EIT 2026), Sheffield, UK

We need good measures of pendelluft so EIT can guide care

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Abstract: EIT provides the only bedside way to examine pendelluft. However, EIT measures of pendelluft are inconsistent. We discuss the importance of standardized EIT measures and clarification of unsolved questions.

1 Introduction

Pendelluft is the movement of air between lung regions, occurring due to intra-tidal changes in local time constants (e.g. airway opening pressures), and pressure gradients resulting from inspiratory or expiratory effort. In effort-related pendelluft, often a decrease in ventral impedance is seen concurrent with an increase in dorsal impedance at the start of inspiration, suggesting air redistribution, likely due to a predominantly dorsal negative pleural pressure swing resulting from diaphragm contraction.

Pendelluft has been associated with worse outcomes, but causality and interlinked mechanisms are not understood. Potential mechanisms include increased “dead space” due to internal movement of air, high local lung stress contributing to both worse outcomes and pendelluft, and/or high effort as a common cause of e.g. fatigue and pendelluft.

Importantly, it is unclear whether pendelluft is a sign of potential lung injury, or independently causes or aggravates it. We must better understand these mechanisms before clinical studies and implementation of EIT during spontaneous breathing and assisted ventilation. Provided that EIT is the only practical technology to detect and monitor pendelluft, we should first agree on how to quantify pendelluft with EIT and which features to report.

2 EIT-based pendelluft measures

Several methods for quantification of respiratory effort-related pendelluft have been published. To note, EIT cannot directly measure air flows between regions, but flows can be inferred from changes in regional volumes.

Waveform based methods

- Difference between amplitude (total impedance change in a pixel) and tidal impedance variation (using global timing) as a fraction of the tidal impedance variation. [1]
- Difference between amplitude and tidal impedance variation as a fraction of the amplitude. [2]
- Difference between amplitude and tidal impedance variation of four regions summed. [3]

Regional volume shift

- Difference in normalized impedance change between ventral and dorsal regions during inspiration. [4]

Reverse impedance change (RIC)

- Impedance change in the opposite direction (RIC) as a fraction of the amplitude plus RIC. [5]

Unfortunately, there is little consistency between these calculations. It is also not clear whether these capture (all) relevant features of pendelluft.

To explore how delay and waveform shape affect measures, we simulated the results in figure 1. This illustrates that measuring pendelluft based on delay may overestimate pendelluft, while only considering waveforms may underestimate pendelluft due to interference from the delay in ventral inflation.

Other potentially relevant features have, to our knowledge, not yet been studied, including inspiratory and expiratory pressure distribution throughout the thorax; regional airway opening and closing pressures, regional dynamic resistance and compliance, and regional inflammatory status.

3 Discussion

EIT is a potentially groundbreaking technology for the identification and management of pendelluft. However, currently proposed measures can over- or underestimate pendelluft. We recommend strong definitions, work to understand the limitations of proposed measures, and robust calculations.

References

1. Sang L et al (2020) Ann Transl Med 8:1216–1216
2. Menga LS et al (2023) Am J Respir Crit Care Med 207:1310–1323
3. Coppadoro A et al (2020) Ann Intensive Care 10:39
4. Cornejo RA et al (2022) Sci Rep 12:20233
5. Adler A et al (2024) Physiol Meas 45:10NT01

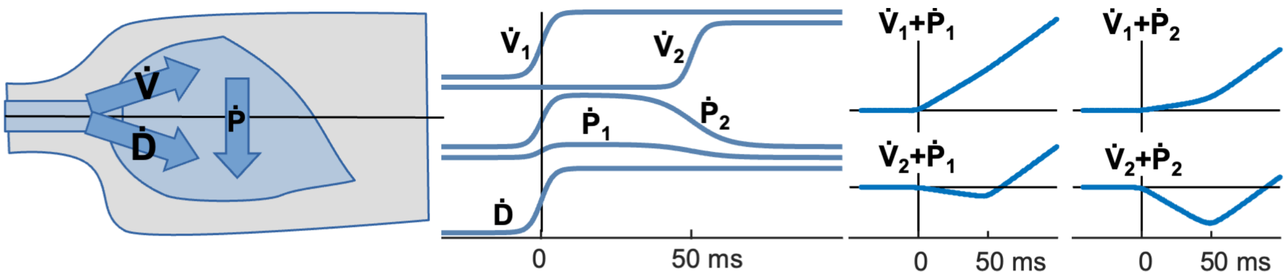

Figure 1: Illustration of pendelluft at the beginning of a breath, using two lung regions and three identifiable flows. (Left) Ventral ($\dot{V}$). Dorsal ($\dot{D}$) and Pendelluft ($\dot{P}$) flows in(to) the lungs. (Center) Prompt ($\dot{V}_1$) and delayed ($\dot{V}_2$) ventral flow and two levels of $\dot{P}$. (Right) ventral impedance over time. A delayed inflation does not mean (significant) pendelluft per se ($\dot{V}_1$+P2 vs. $\dot{V}_2$+P1). Differences in waveform amplitude do not relate directly to the amount of pendelluft ($\dot{V}_1+\dot{P}_2$ vs. $\dot{V}_2+\dot{P}_2$).