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Pendelluft detection using Electrical Impedance Tomography in an infant. Keep those images in mind!

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A 13-month old, 10.5kg infant with Pediatric ARDS secondary to pneumonia underwent a positive end-expiratory pressure (PEEP) decrease monitored with electrical impedance tomography (EIT, Enlight 1800, Timpel, Brazil). Under assist-control ventilation, PEEP was lowered from 13 to 5cmH_2O, 2cmH_2O every 3 min, maintaining 10cmH_2O of driving pressure. From PEEP 9cmH_2O, EIT showed progressive lung collapse. At PEEP 5cmH_2O respiratory instability was evident (Figure1). *Pendelluft* was recognized, a phenomenon characterized by the movement of air between different lung regions. Typically, dependent lung regions inflate first causing deflation of non-dependent areas at the start of inspiration. Towards the end of inspiration, the pressure gradient reverses as the diaphragm relaxes causing the "extra air" to return to nondependent lung regions (Figure2-PEEP5). Tidal volume(V_T) was kept at ~6-8mL/kg. Restoring PEEP to 11cmH_2O did not resolve *pendelluft.* Conversely, applying PEEP of 20cmH_2O for 5min and later setting PEEP to 11cmH_2O did minimize *pendelluft* (Figure2-RM+PEEP11) (Supplemental *Pendelluft* Video on-line).

Pendelluft, here described for the first time in an infant, is a potentially harmful phenomenon that emerges in the context of lung injury and increased inspiratory efforts. The negative swings in pleural pressures concentrate close to the dependent lung zones, indicating that pleural pressures are not evenly transmitted through collapsed lungs (solid-like behavior). As a consequence, local overstretch, tidal recruitment, and inflammation can occur even when set V_T is protective(1-3). Higher PEEP decreases *pendelluft* due to improved lung homogeneity (also homogenizing regional time constants), diminished respiratory drive and flattening the diaphragm (decreasing the efficiency of neuro-mechanical coupling) (2-4). *Pendelluft* detection can alert caregivers to the

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possibility of effort-dependent lung injury even with protective ventilatory settings by current standards(5).

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Figure 1. Off-line images of the positive end-expiratory pressure (PEEP) stepwise reduction. There is a shift in the lung condition from hyperdistension, mostly in non-dependent regions (light blue, on the top left) to progressive lung collapse, in dependent regions (navy blue on the top, central, and two right images), following PEEP reduction. Middle top shows the plethysmogram during acquisition, showing a more irregular respiratory amplitude once collapse is more pronounced, secondary to the patient distress. Middle bottom shows the PEEP level at each step. Bottom panel: respiratory rate increases, as respiratory distress and retractive breathing become more pronounced. Of note, in an EIT device, the plethysmogram is a waveform derived from the sum of all pixels within a given region of interest (ROI) plotted against time. It represents the amount of air that moves in and out of the lungs.

Figure 2. Airway pressure waveform, pressure limited ventilation (purple, top) and electrical impedance tomography (EIT) waveforms (lower four light-blue waveforms) synchronized with ventilator waveforms when PEEP was lowered to 5cmH_2O (PEEP5) and at PEEP11cmH_2O after a recruitment maneuver(RM) (RM+PEEP11). The EIT image was divided into four regions of interest (ROI), each covering 25% of the ventrodorsal diameter (slices 1 to 4). The four EIT waveforms (in arbitrary units: a.u.) were scaled to optimize the impedance amplitude of each slice. The patient was sedated, not paralyzed, in the supine position under assist-controlled ventilation, servo-I (Gettinge, Sweden), airway pressure gradient (above PEEP) of 10cmH_2O, RR 25/min, IT 0.7 sec, flow trigger sensibility 5. Before and during the early inflation triggered by the patient, the volume gain in the dependent region (gray bar in slices 3 and 4), was accompanied by concomitant deflation of nondependent region (gray bar in slices 1 and 2). This phenomenon of gas interchange between lung regions has been called *pendelluft*. The first dotted lines highlights the moment when positive inspiratory pressure starts. The width of the gray bar indicates the amount of delay of inflation from dependent to nondependent regions, and it was considerably reduced from PEEP5 to RM+PEEP11. The second dotted gray lines correspond to the end of the ventilator inspiratory phase. Note that, because slice 4 was less aerated at PEEP5 compared to RM+PEEP11 (EIT image on the top), the similar impedance variation at both PEEP levels (ROI 4) suggests higher strain with the lower PEEP . The black double arrows at Slice 4, proportionally much smaller in RM+PEEP11 compared to PEEP5, highlight the additional stretch caused by the concentrations of stresses in the most dependent regions, computed as the difference in local aeration from its peak value (maximal deformation) to the end-inspiratory value. Regions 3 and 4

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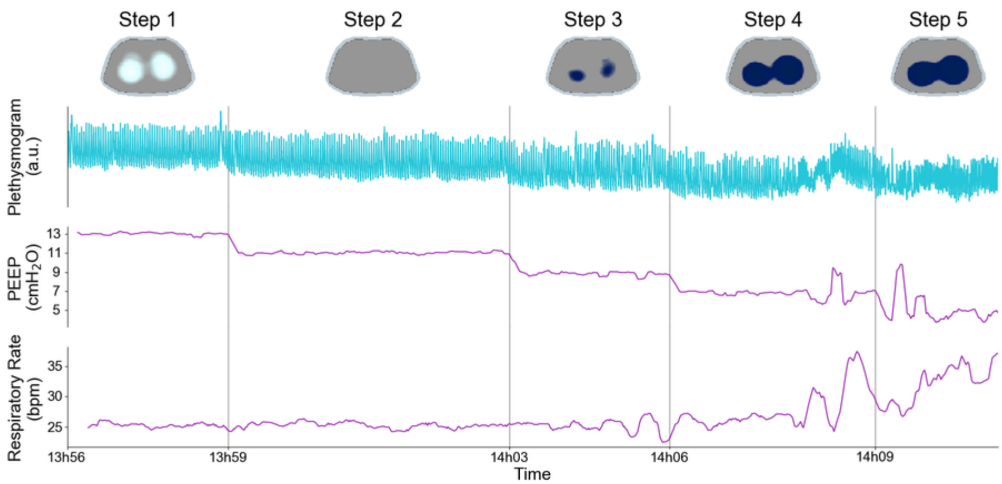
deflation during the ventilatory inspiratory phase indicates diaphragmatic relaxation, allowing the estimation of this additional stretch (double arrows). RR. respiratory rate; IT. inspiratory time; PEEP. positive end-expiratory pressure.



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38x19mm (600 x 600 DPI)

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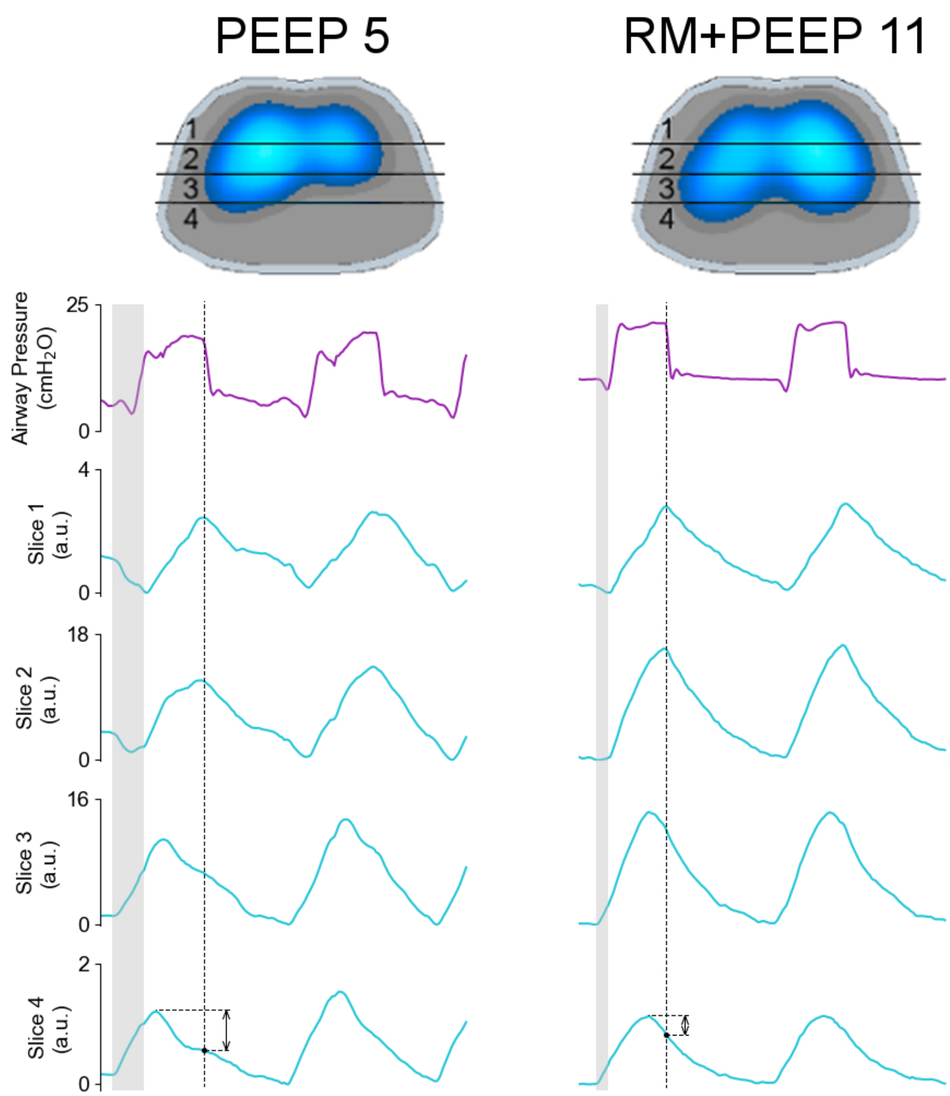

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77x90mm (300 x 300 DPI)

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Online Supplemental Video (accessible from this issue's table of content online at www.atsjournals.org):

During assisted ventilation, when lung collapse was more pronounced at PEEP of 5cm$H_2$0, clearly the dependent lung fills earlier than the non-dependent lung. This occurs secondary to *pendelluft*, a phenomenon that describes the air movement from anterior to dorsal portions of the lungs. This results from the more negative pressure generated in the dorsal lungs regions, secondary to the diaphragmatic shape, leading to potential local overstretch, even when low tidal volumes are used. Higher PEEP values decrease this *pendelluft* likely due to a combination of decreasing respiratory drive and increasing end-expiratory lung volume, thus flattening the diaphragm. The two different lung filling patterns are displayed side-by-side at the supplemental movies, comparing PEEP 5cm$H_2$0 to PEEP 11cm$H_2$0 after a previous transient PEEP increment to 20cm$H_2$0. Note, mainly at the left lung at PEEP5, the movement of gas depicted with the use of EIT.