Transpulmonary pressure measurement

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HAMILTON MEDICAL

Intelligent Ventilation since 1983

Mortality and pulmonary mechanics in relation to respiratory system and transpulmonary driving pressures in ARDS

Baedorf Kassis E, Loring SH, Talmor D
Intensive Care Med. 2016 Aug;42(8):1206-13
PMID 27318943, **http://www.ncbi.nlm.nih.gov/pubmed/27318943**

Design	EPVent substudy
Patients	56 patients from the previous EPVent study (comparisons between survivors and non-survivors according to randomized groups)
Objectives	Examine the relationships between respiratory system and transpulmonary driving pressure, pulmonary mechanics at baseline, 5 min and 24 h, and 28-day mortality
Main Results	At baseline and 5 min there was no difference in respiratory system or transpulmonary driving pressure. By 24 h, survivors had lower respiratory system and transpulmonary driving pressures and the intervention group had lower transpulmonary driving pressure.
Conclusion	Targeting positive transpulmonary pressure improved elastance and driving pressures, and may be associated with improved 28 day mortality

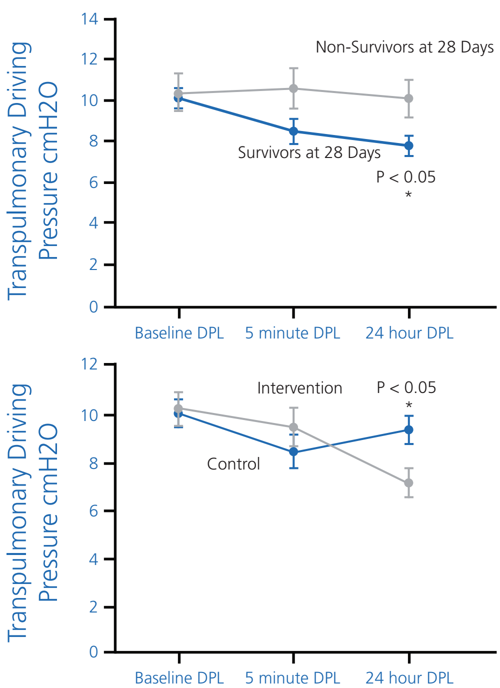

Figure 1: Survivors and patients in the intervention group had lower transpulmonary driving pressures

Mechanical ventilation guided by esophageal pressure in acute lung injury

Talmor D, Sarge T, Malhotra A, O'Donnell CR, Ritz R, Lisbon A, Novack V, Loring SH
N Engl J Med. 2008 Nov 13;359(20):2095-104
PMID 19001507, **http://www.ncbi.nlm.nih.gov/pubmed/19001507**

Design	RCT: PEEP adjusted according to measurements of Peso (esophageal pressure) to reach a positive end-expiratory Ptp (transpulmonary pressure) or according to the ARDS Network table EPVent trial
Patients	61 ALI/ARDS patients
Objectives	Compare the oxygenation, compliance, and outcomes
Main Results	PaO2/FiO2 at 72 h was 88 mmHg higher in the esophageal-pressure-guided group than in the control group. This effect was observed at 24, 48, and 72 h. Respiratory-system compliance was significantly better at 24, 48, and 72 h in the esophageal-pressure-guided group. The study reached its stopping criterion and was terminated after 61 patients had been enrolled, so the outcomes were not different between groups.
Conclusion	Target positive end expiratory Ptp improved oxygenation and compliance in ARDS patients

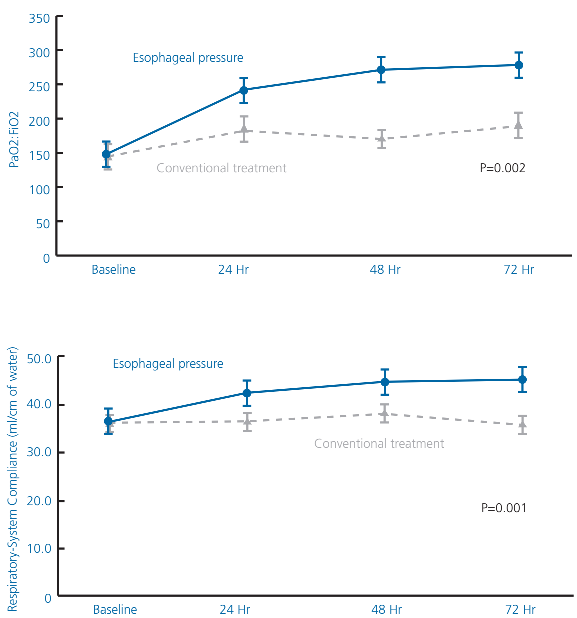

Figure 2: Target positive end expiratory Ptp increased PF ratio and Crs (compliance of respiratory system) significantly

Lung stress and strain during mechanical ventilation for acute respiratory distress syndrome

Chiumello D, Carlesso E, Cadringher P, Caironi P, Valenza F, Polli F, Tallarini F, Cozzi P, Cressoni M, Colombo A, Marini JJ, Gattinoni L

Am J Respir Crit Care Med. 2008 Aug 15;178(4):346-55
PMID 18451319, **http://www.ncbi.nlm.nih.gov/pubmed/18451319**

Design	Prospective interventional comparative study
Patients	80 ICU patients: 40 ALI/ARDS, 40 controls
Objectives	Determine whether Pplat (plateau pressure) is an adequate surrogate for stress quantitatively equal to ΔPtp (transpulmonary pressure)
Main Results	A given applied ΔPaw (airway pressure) produced largely variable stress due to the variability of the El (elastance of lung)/Ers. (elastance of respiratory system) Patients with ALI/ARDS reached higher ΔPtp than the control group.
Conclusion	Pplat was an inadequate surrogate for lung stress

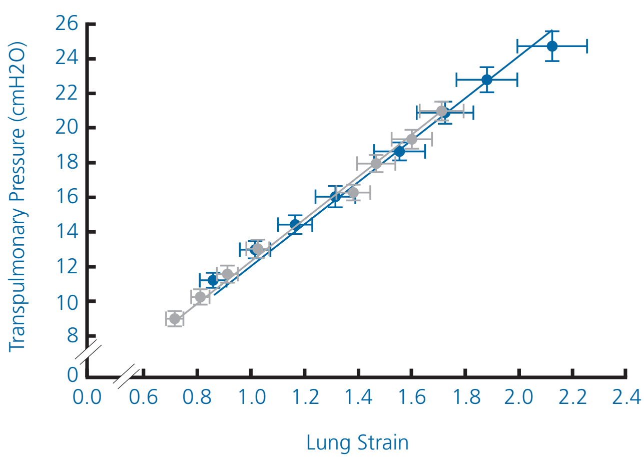

Figure 3: Stress and strain were linked by a constant proportionality factor. Knowing one, we can deduce the other.

Esophageal and transpulmonary pressures in acute respiratory failure

Talmor D, Sarge T, O'Donnell CR, Ritz R, Malhotra A, Lisbon A, Loring SH
Crit Care Med. 2006 May;34(5):1389-94
PMID 16540960, **http://www.ncbi.nlm.nih.gov/pubmed/16540960**

Design	Prospective observational study
Patients	70 patients with ARF
Objectives	Characterize influence of the chest wall on Ptp (transpulmonary pressure) at end expiration and end inspiration
Main Results	Peso (esophageal pressure) averaged 17.5 ±5.7 cmH2O at end expiration and 21.2 ±7.7 cmH2O at end inspiration. Peso was not significantly correlated with BMI. Ptp (transpulmonary pressure) was 1.5 ±6.3 cmH2O at end expiration, 21.4 ±9.3 cmH2O at end inspiration, and 18.4 ±10.2 cmH2O during a plateau, Ptp at end expiration was correlated with PEEP (p < .0001). 24% of the variance in Ptp was explained by Paw (airway pressure) (R = .243), 52% was due to variation in Peso.
Conclusion	Elevated Peso suggested that chest wall mechanical properties contribute substantially and unpredictably to the respiratory system, and therefore, Paw did not adequately predict Ptp or lung distention

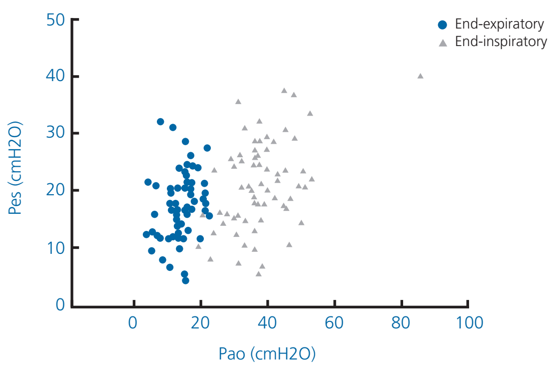

Figure 4: Paw could not predict the esophageal pressure

Recruitment maneuvers: using transpulmonary pressure to help Goldilocks

Baedorf Kassis E, Loring S, Talmor D
Intensive Care Med. 2017 Aug;43(8):1162-1163
PMID 28386726, **http://www.ncbi.nlm.nih.gov/pubmed/28386726**

Design	Post hoc analysis of EPVent study
Patients	28 patients
Objectives	Measure the change in lung elastance (EL) during recruitment: A decrease in EL (negative ΔEL) was considered evidence of recruitment and an increase in EL (positive ΔEL) evidence of overdistension
Main Results	Recruited volume was dependent on transpulmonary pressure during the maneuver and inversely dependent on ΔEL: - ΔEL was positive during recruitment in patients with peak transpulmonary pressure (PL,RM) ≥ 20 cmH2O - ΔEL was negative when PL,RM was between 10 and 20 cmH2O - ΔEL was negligible in patients with PL,RM below 10 cmH2O
Conclusion	The optimal “window” where sufficient pressure expands the lung, optimizes elastance, and avoids overdistension is between 10 and 20 cmH2O
Comment	Transpulmonary pressure helps to determine the pressure that is efficient and safe to perform a recruitment maneuver

Recruitment maneuvers and positive end-expiratory pressure titration in morbidly obese ICU patients.

Pirrone M, Fisher D, Chipman D, Imber DA, Corona J, Mietto C, Kacmarek RM, Berra L
Crit Care Med. 2016 Feb;44(2):300-7
PMID 26584196, **http://www.ncbi.nlm.nih.gov/pubmed/26584196**

Design	Prospective, crossover, nonrandomized interventional study
Patients	14 ventilated morbidly obese (body mass index > 35 kg/m2) ICU patients
Objectives	Compare PEEP set by the clinician, PEEP set according to positive end expiratory transpulmonary pressure, and PEEP associated with the least driving pressure, before and after a staircase recruitment maneuver
Main Results	Both methods identified similar optimal PEEP (21 ±4 vs 21 ±4cmH2O; p = 0.40). PEEP increased end-expiratory lung volume (Δ11 ±7mL/kg; p<0.01) and oxygenation (Δ86 ±50torr; p<0.01) and decreased elastance of the lung (Δ5±5 cmH2O/l; p<0.01). Recruitment maneuvers were effective at increasing EELV (end-expiratory lung volume) and decreasing end-inspiratory transpulmonary pressure, suggesting an improved distribution of lung aeration and reduction of overdistension. PEEP set by the clinicians (12 ±3 cmH2O) were associated with lower lung volumes, worse elastic properties of the lung, and lower oxygenation.
Conclusion	Recruitment maneuvers followed by PEEP titration improved lung volumes, respiratory system elastance, and oxygenation compared with PEEP commonly set by the clinician in morbidly obese patients

Volume delivered during recruitment maneuver predicts lung stress in acute respiratory distress syndrome

Beitler JR, Majumdar R, Hubmayr RD, Malhotra A, Thompson BT, Owens RL, Loring SH, Talmor D
Crit Care Med. 2016 Jan;44(1):91-9
PMID 26474111, **http://www.ncbi.nlm.nih.gov/pubmed/26474111**

Design	EPVent substudy
Patients	42 ARDS patients
Objectives	Determine whether the volume delivered during a recruitment maneuver (VRM), consisting of sustained inflation at 40 cmH2O for 30 s, is inversely associated with lung stress and mortality in acute respiratory distress syndrome
Main Results	VRM ranged between 7.4 and 34.7 ml/kg predicted body weight. Lower VRM predicted high end-inspiratory and tidal lung stress. Low VRM was also associated with an increased risk of death.
Conclusion	Low VRM predicted high lung stress and may predict risk of death in patients with acute respiratory distress syndrome

Effect of body mass index in acute respiratory distress syndrome

Chiumello D, Colombo A, Algieri I, Mietto C, Carlesso E, Crimella F, Cressoni M, Quintel M, Gattinoni L
Br J Anaesth. 2016 Jan;116(1):113-21
PMID 26675954, **http://www.ncbi.nlm.nih.gov/pubmed/26675954**

Design	Prospective physiological study
Patients	101 ARDS patients
Objectives	Compare respiratory mechanics between normal-weight and obese ARDS patients
Main Results	Obese, overweight, and normal-weight groups presented a similar El (elastance of lung) and Ecw (elastance of chest wall) at 5 and 15 cmH2O of PEEP. Lung recruitability was not affected by the body weight. Lung gas volume was significantly lower whereas the total superimposed pressure (representing PTP to be applied at end expiration to counterbalance the increased lung weight and to keep open whatever lung units had opened at the previous inspiration) was significantly higher in the obese compared with the normal-weight group.
Conclusion	Obese ARDS patients do not present higher chest wall elastance and lung recruitability

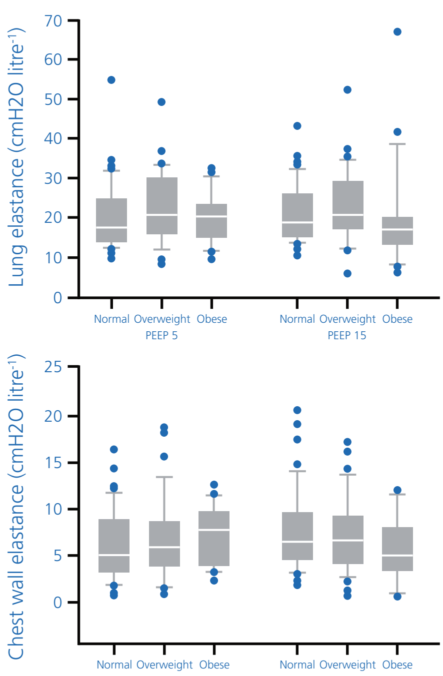

Figure 5: Results showed no difference between the weight groups with respect to lung and chest wall elastance at 2 different PEEP levels

Transpulmonary pressure and gas exchange during decremental PEEP titration in pulmonary ARDS patients

Rodriguez PO, Bonelli I, Setten M, Attie S, Madorno M, Maskin LP, Valentini R
Respir Care. 2013 May;58(5):754-63
PMID 23051849, **http://www.ncbi.nlm.nih.gov/pubmed/23051849**

Design	Prospective interventional study
Patients	11 ARDS patients
Objectives	Describe Ptp (transpulmonary pressure) and gas exchange during a decremental PEEP trial
Main Results	End-expiratory Ptp became negative in all subjects when PEEP decreased below 8.9 ± 5.2 cmH2O. PaO2 decreased when expiratory Ptp became negative ($p<0.001$).
Conclusion	Negative end-expiratory Ptp indicated high risk of alveolar collapse and explained worse oxygenation

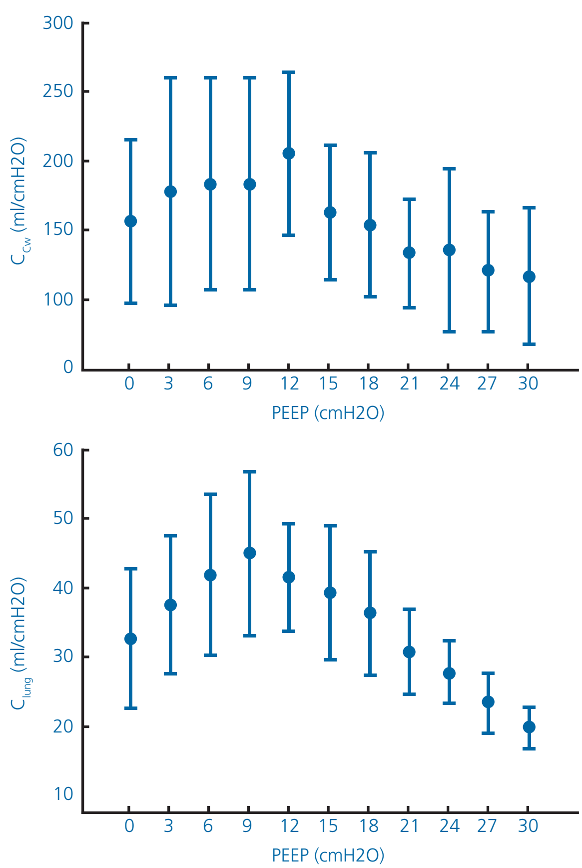

Figure 6: Cl (compliance of lung) was modified by the PEEP level while Ccw (compliance of chest wall) was not

Acute respiratory distress syndrome caused by pulmonary and extrapulmonary disease. Different syndromes?

Gattinoni L, Pelosi P, Suter PM, Pedoto A, Vercesi P, Lissoni A
Am J Respir Crit Care Med. 1998 Jul;158(1):3-11
PMID 9655699, **http://www.ncbi.nlm.nih.gov/pubmed/9655699**

Design	Prospective interventional study
Patients	21 ICU patients: 12 patients with ARDSp, 9 with ARDSexp
Objectives	Assess the possible differences in respiratory mechanics between the ARDS originating from pulmonary disease (ARDSp) and that originating from extrapulmonary disease (ARDSexp)
Main Results	At PEEP, Ers (elastance of respiratory system) and EELV (end-expiratory lung volume) were similar in both groups. El (elastance of lung) was higher in the ARDSp than in the ARDSexp (20.2 ±5.4 vs 13.8 ±5.0 cmH2O/L, p<0.05), Ecw (elastance of chest wall) was higher in the ARDSexp (12.1 ±3.8 vs 5.2 ±1.9 cmH2O/l, p<0.05). Intra abdominal pressure was higher in ARDSexp than in ARDSp (22.2 ±6.0 vs 8.5 ±2.9 cmH2O, p<0.01), and it significantly correlated with Ecw (p<0. 01). Increasing PEEP to 15 cmH2O caused an increase of Ers in ARDSp (from 25.4 ±6.2 to 31.2 ±11.3 cmH2O/l, p<0.01) and a decrease in ARDSexp (from 25.9 ±5.4 to 21.4 ±55.5 cmH2O/l, p<0.01).
Conclusion	Pulmonary-sourced ARDS and extrapulmonary-sourced ARDS differ in the effect on lung vs. chest wall compliance and the response to PEEP. Peso (esophageal pressure) measurements allow for asessment of chest wall vs. pulmonary compliance and response to PEEP.

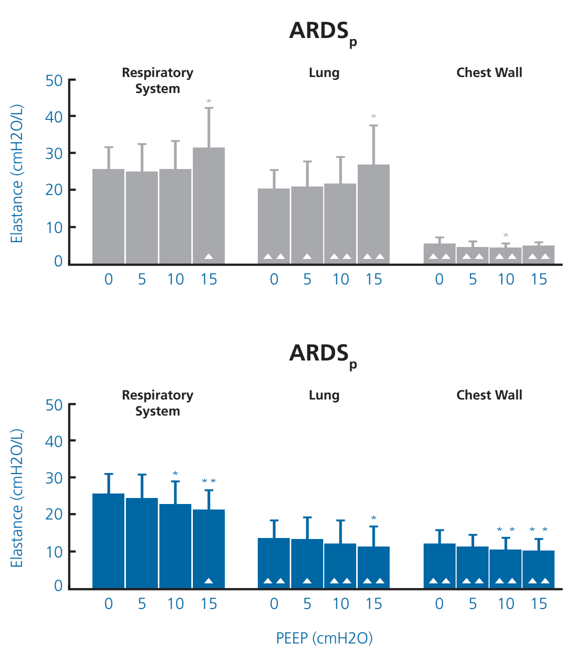

Figure 7: In pulmonary ARDS the Ers increase was due to increase of El. In extra pulmonary ARDS the Ers increase was due to increase of both Ecw and El.

Alterations of lung and chest wall mechanics in patients with acute lung injury: effects of positive end-expiratory pressure

Pelosi P, Cereda M, Foti G, Giacomini M, Pesenti A

Am J Respir Crit Care Med. 1995 Aug;152(2):531-7
PMID 7633703, **http://www.ncbi.nlm.nih.gov/pubmed/7633703**

Design	Prospective interventional comparative study
Patients	24 ICU patients: 10 ALI, 8 ARDS, 8 controls
Objectives	Evaluate the individual contribution of chest wall and lungs to respiratory system mechanics
Main Results	At ZEEP, El (elastance of lung) and Ecw (elanstance of chest wall) were increased in patients with ALI and ARDS compared with control subjects. EELV (end-expiratory lung volume) was lower in ALI subjects than in control subjects, and much lower in ARDS patients.
Conclusion	In ALI/ARDS patients, not only El but also Ecw increased

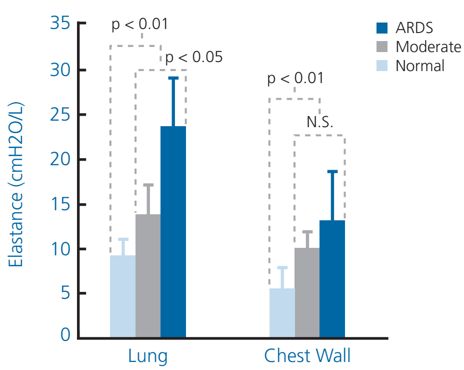

Figure 8: Elastance of both lungs and chest wall increase in ARDS

The occlusion tests and end-expiratory esophageal pressure: measurements and comparison in controlled and assisted ventilation

Chiumello D, Consonni D, Coppola S, Froio S, Crimella F, Colombo A
Ann Intensive Care. 2016 Dec;6(1):13
PMID 26868503, **http://www.ncbi.nlm.nih.gov/pubmed/26868503**

Design	Prospective physiological study
Patients	21 ICU patients
Objectives	Evaluate the effects of paralysis, two different esophageal balloon positions and two PEEP levels on the ΔPes (esophageal pressure)/ΔPaw (airway pressure) ratio measured by the positive pressure occlusion and the Baydur tests and on the end-expiratory esophageal pressure and respiratory mechanics (lung and chest wall)
Main Results	The esophageal pressure/airway pressure ratio was slightly higher (+0.11) with the positive occlusion test compared with Baydur's test. The level of PEEP and the esophageal balloon position did not affect this ratio. The esophageal pressure and airway pressure were significantly related to a correlation coefficient of r = 0.984 during the Baydur test and r = 0.909 in the positive occlusion test. End-expiratory esophageal pressure was significantly higher in sedated and paralyzed patients compared with sedated patients (+2.47 cmH2O) and when esophageal balloon was positioned in the low position (+2.26 cmH2O). The esophageal balloon position slightly influenced the lung elastance, while the PEEP reduced the chest wall elastance without affecting the lung and total respiratory system elastance.
Conclusion	Paralysis and balloon position did not clinically affect the measurement of the esophageal pressure/airway pressure ratio, however they increased the end-expiratory esophageal pressure

In vivo calibration of esophageal pressure in the mechanically ventilated patient makes measurements reliable

Mojoli F, Iotti GA, Torriglia F, Pozzi M, Volta CA, Bianzina S, Braschi A, Brochard L
Crit Care. 2016 Apr 11;20:98
PMID 27063290, **http://www.ncbi.nlm.nih.gov/pubmed/27063290**

Design	Prospective physiological study
Patients	36 patients
Objectives	Evaluate the feasibility and effectiveness of a calibration procedure consisting of optimizing balloon-filling and subtracting the pressure generated by the esophagus wall (Pew)
Main Results	VBEST (filling volume associated with the largest tidal increase of Peso) was 3.5 ±1.9 ml (range 0.5-6.0). Esophagus elastance was 1.1 ±0.5 cmH2O/ml. At filling volumes of 0.5 ml, VBEST and 4.0 ml respectively, Pew was 0.0 ±0.1, 2.0 ±1.9, and 3.0 ±1.7 cmH2O ($p<0.0001$), whereas the occlusion test was satisfactory in 22%, 98%, and 88% of cases ($p<0.0001$).
Conclusion	Under mechanical ventilation, an increase of balloon filling above the conventionally recommended low volumes warranted complete transmission swings in esophageal pressure
Comment	A simple calibration procedure allows finding the filling volume associated with the best transmission of tidal Pes change and subtracting the associated baseline artifact, thus making measurement of absolute values of Pes reliable.

Do spontaneous and mechanical breathing have similar effects on average transpulmonary and alveolar pressure? A clinical crossover study

Bellani G, Grasselli G, Teggia-Droghi M, Mauri T, Coppadoro A, Brochard L, Pesenti A
Crit Care. 2016 Apr 28;20(1):142
PMID 27160458, **http://www.ncbi.nlm.nih.gov/pubmed/27160458**

Design	Prospective crossover study
Patients	10 patients
Objectives	Compare the change in transpulmonary pressure between 3 levels of PSV (pressure support ventilation) and CMV (controlled mechanical ventilation), estimate the influence of SB (spontaneous breathing) on alveolar pressure, and determine whether a reliable plateau pressure could be measured during PSV
Main Results	Overall ΔPtp (transpulmonary pressure) was similar between CMV and PSV, but some individual values were only loosely correlated. Spontaneous breathing acts on alveolar pressure in a similar way to PSV. Inspiratory occlusion holds performed during PSV measured Pplat (plateau pressure) comparable to with CMV.
Conclusion	ΔPtp was similar between CMV and PSV. Spontaneous breathing during mechanical ventilation can cause negative swings in alveolar pressure, a mechanism by which SB might potentially induce lung injury

Non-invasive assessment of lung elastance in patients with acute respiratory distress syndrome

Garnero A, Tuxen D, Ducros L, Demory D, Donati SY, Durand-Gasselin J, Cooper J, Hodgson C, Arnal JM
Minerva Anestesiol. 2015 Oct;81(10):1096-104
PMID 25424169, **http://www.ncbi.nlm.nih.gov/pubmed/25424169**

Design	Prsopective physiological study
Patients	26 early onset, moderate to severe ARDS patients
Objectives	Compare lung elastance assessed by a noninvasive method called lung barometry (ELLB) versus esophageal pressure method (ELPeso)
Main Results	Concordance between ELLB and ELPeso using the Bland and Altman method demonstrated bias and large limits of agreement during the increase and decrease in PEEP. There was no linear correlation between ELLB/ERS and ELPeso/ERS during the increase and decrease in PEEP.
Conclusion	The lung barometry method cannot be used instead of the esophageal pressure measurement to assess lung elastance

Positive end expiratory pressure titrated by transpulmonary pressure improved oxygenation and respiratory mechanics in acute respiratory distress syndrome patients with intra-abdominal hypertension

Yang Y, Li Y, Liu SQ, Liu L, Huang YZ, Guo FM, Qiu HB
Chin Med J. 2013;126(17):3234-9
PMID 24033942, **http://www.ncbi.nlm.nih.gov/pubmed/24033942**

Design	Prospective interventional study
Patients	15 ARDS patients: 7 with intra-abdominal hypertension (IAH, Pblad>12 cmH2O), 8 without IAH
Objectives	Determine the effet of setting PEEP with Ptp (transpulmonary pressure) and with the ARDSnet table on oxygenation and respiratory mechanics
Main Results	PEEP titrated by Ptp was higher than by the ARDSnet table in both patients with (17.3 ±2.6 cmH2O vs. 6.3 ±1.6 cmH2O) and without IAH (9.5 ±2.1 cmH2O vs. 7.8 ±1.9 cmH2O). In patients with IAH, PaO2/FiO2 was higher with PEEP titrated by Ptp than by the ARDSnet table (272 ±40 mmHg vs. 209 ±50 mmHg), Crs (compliance respiratory system) and Cl (compliance of lung) were higher with PEEP titrated by Ptp than by ARDSnet the table.
Conclusion	The use of Peso (esophageal pressure) was important in management of critically ill patients with IAH

Comparison of 2 correction methods for absolute values of esophageal pressure in subjects with acute hypoxemic respiratory failure, mechanically ventilated in the ICU

Guérin C, Richard JC

Respir Care. 2012 Dec;57(12):2045-51
PMID 23233496, **http://www.ncbi.nlm.nih.gov/pubmed/23233496**

Design	Prospective interventional study
Patients	42 patients with ALI/ARDS
Objectives	Compare 2 methods for correcting absolute Peso (esophageal pressure) value: invariant value of 5 cmH2O and the Peso obtained at relaxation volume
Main Results	The end-expiratory Ptp (transpulmonary pressure) corrected by 5 was 6 (1-8) cmH2O, and Ptp corrected by the measured Peso at relaxation volume was 2 (1-5) cmH2O ($p = 0.008$). In 28 subjects, the end-expiratory Ptp corrected by 5 was higher than Ptp corrected by the measured Peso at relaxation volume, while in 14 subjects, Ptp corrected by the measured Peso at relaxation volume was higher than Ptp corrected by 5.
Conclusion	Correcting absolute Peso by a value measured at relaxation volume was much accurate than an invariant value of 5 cmH2O

ECMO criteria for influenza A (H1N1)-associated ARDS: role of transpulmonary pressure.

Grasso S, Terragni P, Birocco A, Urbino R, Del Sorbo L, Filippini C, Mascia L, Pesenti A, Zangrillo A, Gattinoni L, Ranieri VM

Intensive Care Med. 2012 Mar;38(3):395-403
PMID 22323077, **http://www.ncbi.nlm.nih.gov/pubmed/22323077**

Design	Prospective interventional study
Patients	14 patients with influenza AH1N1-associated ARDS referred for ECMO
Objectives	Assess whether partitioning the Ers (elastance of respiratory system) between El (elastance of lung) and Ecw (elastance of chest wall) in order to target values of end-inspiratory Ptp (transpulmonary pressure) close to its upper physiological limit (25 cmH2O) may optimize oxygenation
Main Results	In 7 patients, end-inspiratory Ptp was 27.2 ±1.2 cmH2O; all of these patients underwent ECMO. In the other 7 patients, end-inspiratory Ptp was 16.6 ±2.9 cmH2O, increasing PEEP (from 17.9 ±1.2 to 22.3 ±1.4 cmH2O) to approach the upper physiological limit of end-inspiratory Ptp = 25.3 ±1.7 cmH2O improved oxygenation, allowing patients to be treated without ECMO. There were obese patients in both groups.
Conclusion	Abnormalities of chest wall mechanics may be present in some patients with influenza AH1N1-associated ARDS, so analyzing the lung and chest wall mechanics avoided ECMO.

Esophageal pressures in acute lung injury: do they represent artifact or useful information about transpulmonary pressure, chest wall mechanics, and lung stress?

Loring SH, O'Donnell CR, Behazin N, Malhotra A, Sarge T, Ritz R, Novack V, Talmor D
J Appl Physiol. 2010 Mar;108(3):515-22
PMID 20019160, **http://www.ncbi.nlm.nih.gov/pubmed/20019160**

Design	Parallel to EPVent physiological study
Patients	48 patients from EPVent
Objectives	Assess the credibility of Peso (esophageal pressure) by comparison with simultaneously measured gastric (Pga) and bladder pressures (Pblad)
Main Results	End-expiratory Pes, Pga, and Pblad averaged 18.6 ±4.7, 18.4 ±5.6, and 19.3 ±7.8 cmH2O, respectively. End-expiratory Pes was correlated with Pga and Pblad and was unrelated to Ccw (compliance of chest wall). Ptp was -2.8 ±4.9 cmH2O at end expiration and 8.3 ±6.2 cmH2O at end inspiration. Lung stress measured as end-inspiratory transpulmonary pressure was much less than stress inferred from the Pplat (plateau pressure), Cl (compliance of lung), and Ccw by 9.6 cmH2O.
Conclusion	Stress calculated with ΔPtp provides an incomplete measure because it avoids prestress. Peso provided meaningful information.

Influence of lung and chest wall compliances on transmission of airway pressure to the pleural space in critically ill patients

Jardin F, Genevray B, Brun-Ney D, Bourdarias JP
Chest. 1985 Nov;88(5):653-8
PMID 3902386, **http://www.ncbi.nlm.nih.gov/pubmed/3902386**

Design	Prospective interventional comparative study
Patients	19 patients with ARF, 3 groups: Crs (compliance of respiratory system) > 45, Crs between 45 and 30, Crs < 30 ml/cmH2O
Objectives	Evaluate the transmission of Paw to the pleural space at end expiration and end inspiration, at three levels of PEEP
Main Results	In patients with Crs > 45 ml/cmH2O, 37% of Paw (airway pressure) was transmitted to the pleural space, Cl (compliance of lung) = 100.3 ±17.2 ml/cmH2O. With Crs between 45 and 30 ml/cmH2O, 32% of Paw was transmitted to the pleural space, Cl = 45.0 ±6.3 ml/cmH2O. With Crs < 30 ml/cmH2O, 24% of Paw (airway pressure) was transmitted to the pleural space, Cl = 28.6 ±8.9 ml/cmH2O.
Conclusion	An increase in lung stiffness decreased transmission of airway pressure to the pleural space

A simple method for assessing the validity of the esophageal balloon technique

Baydur A, Behrakis PK, Zin WA, Jaeger M, Milic-Emili J. Am Rev Respir Dis
1982 Nov;126(5):788-91
PMID 7149443, **http://www.ncbi.nlm.nih.gov/pubmed/7149443**

Design	Prospective interventional physiological study
Patients	10 subjects
Objectives	Determine the validity of the conventional esophageal balloon technique as a measure of pleural pressure by occluding the airways at end expiration and measuring the ratio of changes in Peso (esophageal pressure) and mouth pressure during the ensuing spontaneous occluded inspiratory efforts
Main Results	ΔPes/ΔPmouth values were close to unity in sitting and lateral positions. In supine positions, positioning the balloon to different levels in the esophagus allowed for finding a locus where the ΔPes/ΔPmouth ratio was close to unity.
Conclusion	Positioning the balloon according to the "occlusion test" procedure validated measurements of pleural pressure

Pulmonary, chest wall, and lung-thorax elastances in acute respiratory failure

Katz JA, Zinn SE, Ozanne GM, Fairley HB
Chest. 1981 Sep;80(3):304-11
PMID 6944170, **http://www.ncbi.nlm.nih.gov/pubmed/6944170**

Design	Prospective interventional study
Patients	15 patients with ARF
Objectives	Determine whether Ers (elastance of respiratory system) reflected El (elastance of lung), Ecw (elastance of chest wall), or both
Main Results	Ers was 27.9 ±2.6 cmH2O/l, chest wall accounted for 34 ±2%. Changes in Ers correlated only with changes in El (r = 0.96; p<0.001) and not with Ecw, except for 3 patients where changes in Ers were due to changes in Ecw.
Conclusion	Peso (esophageal pressure) mesurement was important to determine whether increase in Ers was due to an increase in El or Ecw

Topography of esophageal pressure as a function of posture in man

Milic-Emili J, Mead J, Turner JM
J Appl Physiol. 1964 Mar;19:212-6
PMID 14155284, **http://www.ncbi.nlm.nih.gov/pubmed/14155284**

Design	Prospective interventional physiological study
Patients	7 healthy subjects
Objectives	Determine topography of esophageal pressure at various lung volumes, in various positions
Main Results	The upper-third pressures reflected external and mouth pressures, and changed with head posture. The lower-third pressures varied point by point and with position. The middle-third pressures were uniform.
Conclusion	Peso (esophageal pressure) obtained in the middle-third of esopagus more closely reflected pleural pressure

Value and limitations of transpulmonary pressure calculations during intra-abdominal hypertension

Cortes-Puentes GA, Gard KE, Adams AB, Faltesek KA, Anderson CP, Dries DJ, Marini JJ
Crit Care Med. 2013 Aug;41(8):1870-7
PMID 23863222, **http://www.ncbi.nlm.nih.gov/pubmed/23863222**

Design	Animal study
Patients	11 pigs
Objectives	Describe the effects of increased intra-abdominal pressure (IAP from 0 to 25 mmHg) on Peso (esophageal pressure), Ptp (transpulmonary pressure), and functional residual capacity (FRC), at two levels of PEEP (1 and 10 cmH2O)
Main Results	FRC was reduced by increasing IAP at both levels of PEEP, without changes of end-expiratory Peso. When IAP became higher than 5 mmHg, Pplat increased linearly by 50% of the applied IAP, with same changes in Peso. With constant Vt, negligible changes occurred in Ptp (pressure plateau). Increasing IAP reduced Ccw (compliance of chest wall), but in this case, increasing PEEP improved Ccw.
Conclusion	Lung collapse caused by increasing IAP was improved by increasing PEEP

Pleural pressure and optimal positive end-expiratory pressure based on esophageal pressure versus chest wall elastance: incompatible results

Gulati G, Novero A, Loring SH, Talmor D
Crit Care Med. 2013 Aug;41(8):1951-7
PMID 23863227, **http://www.ncbi.nlm.nih.gov/pubmed/23863227**

Design	Retrospective study
Patients	64 ARDS patients managed with Peso (esophageal pressure)
Objectives	Compare Peso and Ecw (elastance of chest wall) for estimated pleural pressure and set PEEP
Main Results	Pleural pressures estimated by Peso and Ecw were different and discordant during end-expiratory occlusion and end-inspiratory occlusion. PEEP recommended by the two methods for each patient were discordant and uncorrelated.
Conclusion	The strategies of targeting an end-expiratory Peso-based Ptp (transpulmonary pressure) =0 cmH2O and targeting an end-inspiratory Ecw (elastance of chest wall)-based Ptp=26 cmH2O cannot be interchangeable. Ecw and Ers (elastance of respiratory system) varied unpredictably with changes in PEEP

Volume-related and volume-independent effects of posture on esophageal and transpulmonary pressures in healthy subjects

Washko GR, O'Donnell CR, Loring SH
J Appl Physiol. 2006 Mar;100(3):753-8
PMID 16306256, **http://www.ncbi.nlm.nih.gov/pubmed/16306256**

Design	Prospective interventional physiological study
Patients	10 healthy subjects
Objectives	Determine the variability of postural effects on Peso (esophageal pressure), in relaxation volume and total lung capacity
Main Results	Ptp (transpulmonary pressure) at relaxation volume averaged 3.7 (SD 2.0) cmH2O upright and -3.3 (SD 3.2) cmH2O supine. Approximately 58% of the decrease in Ptp between the upright and supine postures was due to a corresponding decrease in relaxation volume. The remaining 2.9 cmH2O difference is consistent with reported values of a presumed postural artifact.
Conclusion	Adding 3 cmH2O was necessary to correct estimated Ptp for the effect of lying supine but considering the range of Ptp in ARF patients, the need to correct Ptp is debatable

Recruitment and derecruitment during acute respiratory failure: an experimental study

Pelosi P, Goldner M, McKibben A, Adams A, Eccher G, Caironi P, Losappio S, Gattinoni L, Marini JJ
Am J Respir Crit Care Med. 2001 Jul;164(1):122-30
PMID 11435250, **http://www.ncbi.nlm.nih.gov/pubmed/11435250**

Design	Animal study
Patients	6 dogs with oleic acid respiratory failure
Objectives	Compare pleural pressure and Peso (esophageal pressure) in upper nondependent, middle, and dependent lung regions
Main Results	There was a good Bland and Alltman correlation between pleural pressure and Peso in non-dependent, middle, and dependent regions. Significant differences were found between absolute values, but changes of pleural pressure were similar with changes of Peso in response to increasing Paw (airway pressure).
Conclusion	Variation in Peso was a reasonable estimate of variation of pleural pressure

Validation of esophageal pressure occlusion test after paralysis

Lanteri CJ, Kano S, Sly PD
Pediatr Pulmonol. 1994 Jan;17(1):56-62
PMID 8108177, **http://www.ncbi.nlm.nih.gov/pubmed/8108177**

Design	Animal study
Patients	16 puppies
Objectives	Evaluate occlusion test for paralyzed subject by occluding airway and applied pressure to the abdomen or ribs and observation of positive swings in both Peso (esophageal pressure) and Paw (airway pressure)
Main Results	In traditional occlusion tests, ΔPeso was within 10% of ΔPaw. In positive pressure occlusion tests using abdominal pressure performed after paralysis, ΔPeso was within 10% of ΔPaw. In positive pressure occlusion tests using rib pressure, ΔPeso was within 10% of ΔPaw.
Conclusion	Accurate occlusion tests were possible in paralyzed subjects by abdominal or rib pressure during airway occlusion

Lung mechanics in sitting and horizontal body positions

Behrakis PK, Baydur A, Jaeger MJ, Milic-Emili J
Chest. 1983 Apr;83(4):643-6
PMID 6831953, **http://www.ncbi.nlm.nih.gov/pubmed/6831953**

Design	Prospective interventional physiological study
Patients	10 healthy subjects
Objectives	Mesure Cl (compliance of lung) in different positions
Main Results	Cl was 210 in sitting, 190 in lateral, and 160 ml/cmH2O in supine positions. The change was significant ($p<0.01$) between the sitting and supine positions.
Conclusion	Peso (esophageal pressure) measurement was better in a sitting position. In ICU patients, the head of the bed should be greater than 45° measurement.

Additional files

Esophageal and transpulmonary pressure in the clinical setting: meaning, usefulness and perspectives

Mauri T, Yoshida T, Bellani G, Goligher EC, Carteaux G, Rittayamai N, Mojoli F, Chiumello D, Piquilloud L, Grasso S, Jubran A, Laghi F, Magder S, Pesenti A, Loring S, Gattinoni L, Talmor D, Blanch L, Amato M, Chen L, Brochard L, Mancebo J; PLeUral pressure working Group (PLUG—Acute Respiratory Failure section of the European Society of Intensive Care Medicine).
Intensive Care Med. 2016 Sep;42(9):1360-73
PMID 27334266, **http://www.ncbi.nlm.nih.gov/pubmed/27334266**

Design	Review conducted by PLUG (PLeUral pressure working Group)
Objectives	Review of the relevant technical, physiological and clinical details that support the clinical utility of esophageal pressure
Conclusion	Esophageal pressure monitoring provides unique bedside measures for a better understanding of the pathophysiology of acute respiratory failure patients. Including esophageal pressure monitoring in the intensivist's clinical armamentarium may enhance treatment to improve clinical outcomes

The application of esophageal pressure measurement in patients with respiratory failure

Akoumianaki E(1), Maggiore SM, Valenza F, Bellani G, Jubran A, Loring SH, Pelosi P, Talmor D, Grasso S, Chiumello D, Guérin C, Patroniti N, Ranieri VM, Gattinoni L, Nava S, Terragni PP, Pesenti A, Tobin M, Mancebo J, Brochard L.
Am J Respir Crit Care Med. 2014 Mar 1;189(5):520-31
PMID 24467647, **http://www.ncbi.nlm.nih.gov/pubmed/24467647**

Design	International experts conference "Plug"
Patients	ICU patients during passive and active ventilation
Objectives	Summarize current Peso (esophageal pressure) knowledge and describe clinical application in mechanically ventilated patients.
Main Results	Peso is helpful in setting Pinsp and PEEP in ARDS patients, in studying patient ventilator synchrony, and in understanding weaning failure
Conclusion	Physiological knowledge, description of the technique, clinical indications

Transpulmonary pressure: the importance of precise definitions and limiting assumptions

Loring SH, Topulos GP, Hubmayr RD
Am J Respir Crit Care Med. 2016 Dec 15;194(12):1452-57
PMID 27606837, **http://www.ncbi.nlm.nih.gov/pubmed/27606837**

Design	Review
Conclusion	Explains the various physiological terms to define the physical state of the lungs, the chest wall, and the integrated respiratory system, and stresses the need for consistency when using them

The promises and problems of transpulmonary pressure measurements in acute respiratory distress syndrome

Sahetya SK, Brower RG
Curr Opin Crit Care. 2016 Feb;22(1):7-13
PMID 26627536, **http://www.ncbi.nlm.nih.gov/pubmed/26627536**

Design	Review
Conclusion	Limitations of transpulmonary pressure measurements

Measurement of esophageal pressure at bedside: pros and cons

Brochard L
Curr Opin Crit Care. 2014 Feb;20(1):39-46
PMID 24300619, **http://www.ncbi.nlm.nih.gov/pubmed/24300619**

Design	Review
Conclusion	Advantages and limitations of using esophageal pressure in intensive care

Two steps forward in bedside monitoring of lung mechanics: transpulmonary pressure and lung volume

Cortese GA, Marini JJ
Crit Care 2013 March;19;17(2):219
PMID 23509867, **http://www.ncbi.nlm.nih.gov/pubmed/23509867**

Design	Review, Expert opinion
Patients	na
Objectives	Review the management rationale and technical background for monitoring TP pressure and FRC
Main Results	"It seems clear that these newly available tools, used separately and/or together, have potential to improve delivery of respiratory care by characterizing the response to interventions or to the course of disease."
Conclusion	Athough not perfect, estimations of Ptp (transpulmonary pressure) are of more help in elucidating the interactions between patient characteristics, disease conditions, and ventilator settings than are pulmonary mechanics based on airway pressure alone

Goal-directed mechanical ventilation: are we aiming at the right goals? A proposal for an alternative approach aiming at optimal lung compliance, guided by esophageal pressure in acute respiratory failure

Soroksky A, Esquinas A
Crit Care Res Pract. 2012;2012:597932
PMID 23019524, **http://www.ncbi.nlm.nih.gov/pubmed/23019524**

Design	Review
Conclusion	Explain the use of Peso (esophageal pressure)

Esophageal pressure: benefit and limitations

Hedenstierna G
Minerva Anestesiol. 2012 Aug;78(8):959-66
PMID 22699701, **http://www.ncbi.nlm.nih.gov/pubmed/22699701**

Design	Expert Opinion
Conclusion	Highlights Peso (esophageal pressure) limitations

Targeting transpulmonary pressure to prevent ventilator induced lung injury

Sarge T, Talmor D
Minerva Anestesiol. 2009 May;75(5):293-9
PMID 19412147, **http://www.ncbi.nlm.nih.gov/pubmed/19412147**

Design	Review
Conclusion	Customize the ventilator settings for ARDS patients

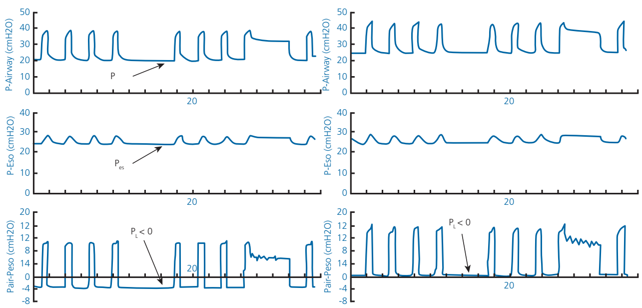

Figure 9: Increasing PEEP leaded positivation of the end expiratory Ptp

Esophageal and gastric pressure measurements.

Benditt JO, Proctor HJ, Woolson R.
Respir Care. 2005 Jan;50(1):68-75
PMID 15636646, **http://www.ncbi.nlm.nih.gov/pubmed/15636646**

Design	Review
Patients	na
Objectives	Review the historical background, physiology, placement techniques, and potential clinical applications of esophageal and gastric pressure measurements.

Respiratory mechanics in mechanically ventilated patients

Hess DR

Respir Care. 2014 Nov;59(11):1773-94

PMID 25336536, **http://www.ncbi.nlm.nih.gov/pubmed/25336536**

Design	Review
Conclusion	Explains esophageal pressure measurement in ventilated patients

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