P/V curves

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Intelligent Ventilation since 1983

Hysteresis and Lung Recruitment in Acute Respiratory Distress Syndrome Patients: A CT Scan Study

Chiumello D, Arnal JM, Umbrello M, Cammaroto A, Formenti P, Mistraletti G, Bolgiaghi L, Gotti M, Novotni D, Reidt S, Froio S, Coppola S
Crit Care Med. 2020 Oct;48(10):1494-1502
PMID 32897667, **http://www.ncbi.nlm.nih.gov/pubmed/32897667**

Design	Prospective observational study
Patients	25 sedated and paralyzed ARDS patients underwent a low-flow (2 cmH2O/s) inflation and deflation pressure-volume curve (5–45 cmH2O) and sustained inflation recruitment maneuver (45 cmH2O for 30 s)
Objectives	To determine the relationship between hysteresis (area enclosed by the pressure-volume curve), mechanical characteristics of the respiratory system, and lung recruitment assessed by a CT scan (computed as the difference in noninflated tissue and gas volume measured at 5 and at 45 cmH2O), in mechanically ventilated acute respiratory distress syndrome patients
Main Results	Hysteresis was correlated with respiratory system compliance computed at 5 cmH2O and the lung gas volume entering the lung during inflation of the pressure-volume curve. The hysteresis ratio (ratio between hysteresis and the product of the pressure span and the maximum volume reached) was related to both lung tissue and gas recruitment. The optimal cutoff value to predict lung tissue recruitment for the hysteresis ratio was 28%, with sensitivity and specificity of 0.75 and 0.77, respectively.
Conclusion	A significant correlation between the amount of potentially recruitable lung tissue and parameters of the PV loop, such as the hysteresis ratio or the normalized maximal distance, was observed. These indices can be used at the bedside as sufficiently accurate surrogates of lung recruitment without the need for a CT scan

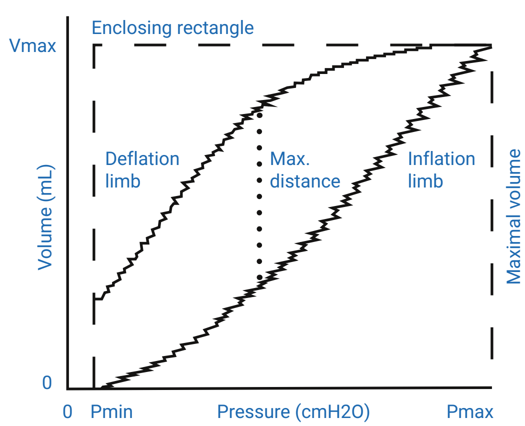

Figure 1: PV curve of a representative patient: Hysteresis is defined as the gray-shaded area between the inflation and the deflation limb; to allow for the comparison among patients with different maximal volumes, it was weighted by the enclosing rectangle (dashed line, Vmax × [Pmax–Pmin]), that is, the maximum hysteresis a patient could theoretically have, for the calculation of the hysteresis ratio. The maximal distance between the inspiratory and expiratory limb of the curve (dotted line) is weighted by the maximal volume Vmax (dashed arrow) to calculate the normalized maximal distance

Global and regional assessment of sustained inflation pressure-volume curves in patients with acute respiratory distress syndrome

Becher T, Rostalski P, Kott M, Adler A, Schädler D, Weiler N, Frerichs I
Physiol Meas. 2017 Jun;38(6):1132-1144
PMID 28339394, **http://www.ncbi.nlm.nih.gov/pubmed/28339394**

Design	Retrospective study
Patients	30 ARDS patients
Objectives	Quantify by means of EIT (electrical impedance tomography) data the amount of unrecruited lung at different clinically relevant points on the pressure-volume curve (lower inflection point, inflection point and upper inflection point) to characterize ongoing lung recruitment
Main Results	An analysis of EIT data found a high percentage of unrecruited lung at the lower inflection point, a small percentage of unrecruited lung at the inflection point and no unrecruited lung at the upper inflection point.
Conclusion	Recruitment occurs between lower and upper inflection points.

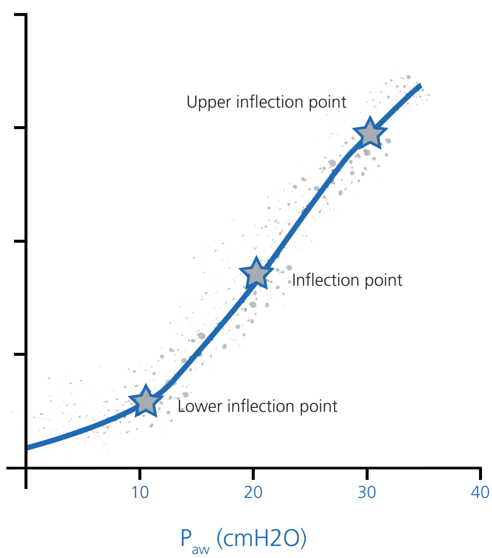

Figure 2: Figure of a pressure-volume curve inflation limb between 0 and 40 cmH2O showing lower inflection point, inflection point and upper inflection point

A new automated method versus continuous positive airway pressure method for measuring pressure-volume curves in patients with acute lung injury

Piacentini E, Wysocki M, Blanch L

Intensive Care Med. 2009 Mar;35(3):565-70

PMID 18853137 , **http://www.ncbi.nlm.nih.gov/pubmed/18853137**

Design	Prospective comparative interventional study
Patients	10 ALI/ARDS patients
Objectives	Compare PV curves obtained with the Hamilton Medical ventilators (P/V tool) with those obtained with a progressive increase in Paw (airway pressure) from 0 to 35 cmH2O
Main Results	PV curves showed a good correlation between methods with intraclass correlation coefficients > 0.75. LIP (lower inflection point), UIP (upper inflection point), PMC (point of maximum curvarture) showed a good correlation between methods with intraclass correlation coefficients of 0.98 (0.92, 0.99), 0.92 (0.69, 0.98), and 0.97 (0.86, 0.98), respectively. Bland and Altman bias and limits of agreement for LIP (0.51 ±0.95 cmH2O; -1.36 to 2.38 cmH2O), for UIP (0.53 ±1.52 cmH2O; -2.44 to 3.50 cmH2O), and for PMC (-0.62 ±0.89 cmH2O; -2.35 to 1.12 cmH2O) were clinically acceptable. No adverse effects were observed.
Conclusion	The P/V Tool was equivalent to the CPAP method for tracing static PV curves of the respiratory system

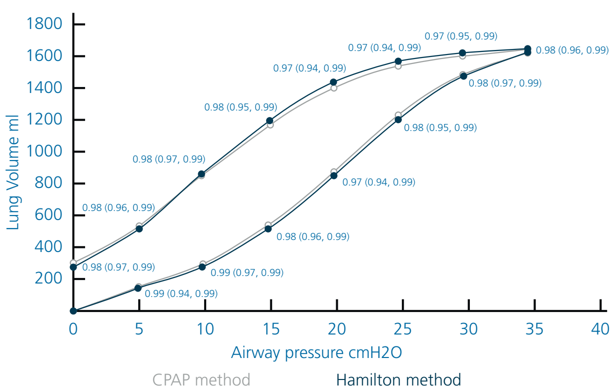

Figure 3: Comparison between P/V Tool and CPAP method; the two PV curves were surperimposed

Recruitability of the lung estimated by the pressure volume curve hysteresis in ARDS patients

Demory D, Arnal JM, Wysocki M, Donati S, Granier I, Corno G, Durand-Gasselin J
Intensive Care Med. 2008 Nov;34(11):2019-25
PMID 18575846, **http://www.ncbi.nlm.nih.gov/pubmed/18575846**

Design	Prospective interventional study
Patients	26 ARDS patients
Objectives	Estimate potential lung recruitability by hysteresis of quasi-static PV curve
Main Results	A positive linear correlation was found between hysteresis (calculated as the ratio of the area enclosed by the limbs of the PV curve, from 0 to 40 cmH2O, divided by the predicted body weight), and recruited volume (measured by integration of the flow required to maintain the pressure at 40 cmH2O for 10 s divided by predicted body weight); and between the linear Crs (compliance of respiratory system) measured on the inflation limb and the volume recruited.
Conclusion	Hysteresis of the PV curve could assess the recruitability of the lung at the bedside

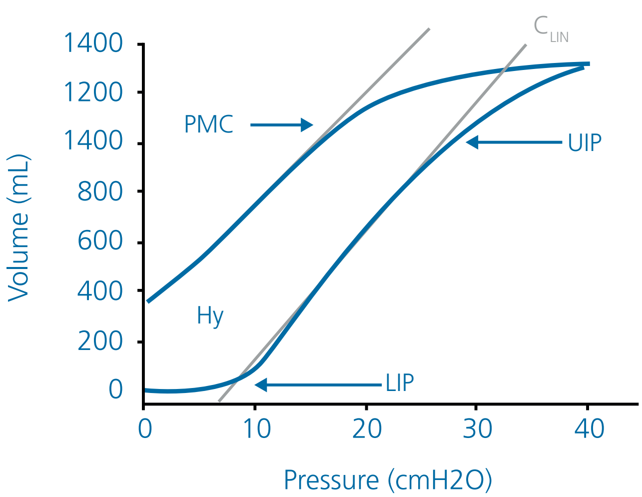

Figure 4: Example of LIP, UIP, PMC, Cdyn and hysteresis

Inspiratory vs. expiratory pressure-volume curves to set end-expiratory pressure in acute lung injury

Albaiceta GM, Luyando LH, Parra D, Menendez R, Calvo J, Pedreira PR, Taboada F
Intensive Care Med. 2005 Oct;31(10):1370-8
PMID 16091965, **http://www.ncbi.nlm.nih.gov/pubmed/16091965**

Design	Prospective interventional study
Patients	8 ALI patients VC Vt 6 ml/kg
Objectives	Study the effects of two levels of PEEP, 2 cmH2O above LIP (lower inflection point) and equal to the PMC (point of maximum curvarture) of the PV curve, in gas exchange, respiratory mechanics, and lung aeration
Main Results	PEEP 2 cmH2O above LIP was 15.5 ±3.1 cmH2O and a PEEP equal to PMC was 23.5 ±4.1 cmH2O. PEEP according to the PMC was related to an improvement in oxygenation, an increase in normally aerated lung volumes, a decrease in nonaerated lung volumes, and greater alveolar stability. There was also an increase in PaCO2, Paw (airway pressure), and hyperaerated lung volume.
Conclusion	PEEP according to PMC recruited some parts and overdistended others parts of lungs

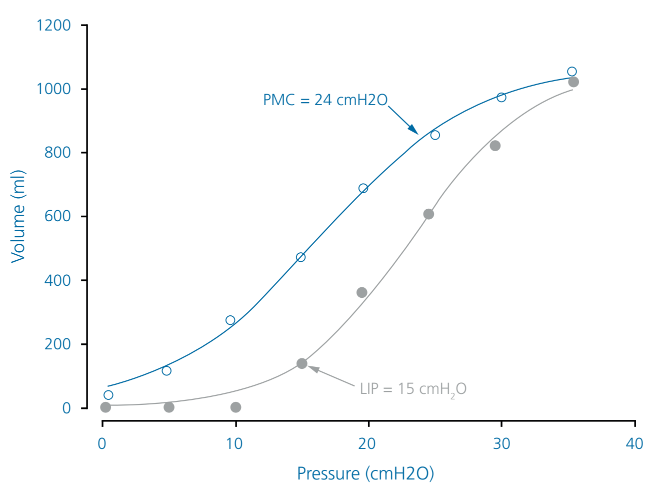

Figure 5: Example of LIP and PMC

A scanographic assessment of pulmonary morphology in acute lung injury. Significance of the lower inflection point detected on the lung pressure-volume curve

Vieira SR, Puybasset L, Lu Q, Richecoeur J, Cluzel P, Coriat P, Rouby JJ

Am J Respir Crit Care Med. 1999 May;159(5 Pt 1):1612-23
PMID 10228135, **http://www.ncbi.nlm.nih.gov/pubmed/10228135**

Design	Prospective comparative interventional study
Patients	ALI patients: 8 with LIP (lower inflection point), 6 without LIP
Objectives	Assess lung morphology according to the presence or the absence of a LIP on the lung PV curve and compare the effects of PEEP. CT scans were performed at ZEEP and two levels of PEEP: PEEP1 = LIP + 2 cmH2O and PEEP2 = LIP + 7 cmH2O, or PEEP1 = 10 cmH2O and PEEP2 = 15 cmH2O in the absence of an LIP
Main Results	In ZEEP, total lung volume, volume of gas, and volume of tissue were similar in both groups; the percentage of normally aerated lung was lower (24 ±22% vs 55 ±12%, $p < 0.05$) and the percentage of poorly aerated lung was greater (40 ±12% vs 23 ±8%, $p < 0.05$) in patients with LIP than in patients without LIP. Crs (compliance of respiratory system) and Cl (compliance of lung) were lower in patients with LIP. In both groups, PEEP induced an alveolar recruitment that was associated with lung overdistension only in patients without LIP.
Conclusion	The presence or absence of LIP on the PV curve was associated with potential lung recruitability. In patients without LIP, normally aerated lung areas coexisted with nonaerated lung areas and increasing PEEP resulted in lung overdistension rather than in additional alveolar recruitment. In patients with LIP, air and tissue were more homogeneously distributed within the lungs, and increasing PEEP resulted in additional alveolar recruitment without lung overdistention

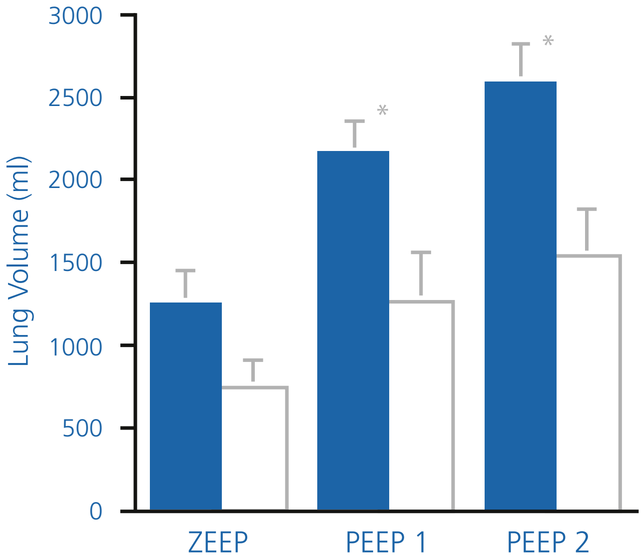

Figure 6: Patients with LIP had more aerated tissue than patients without LIP: lung density histograms Tomographic lung scan cuts at ZEEP, PEEP1, PEEP2

Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome

Amato MB, Barbas CS, Medeiros DM, Magaldi RB, Schettino GP, Lorenzi-Filho G, Kairalla RA, Deheinzelin D, Munoz C, Oliveira R, Takagaki TY, Carvalho CR
N Engl J Med. 1998 Feb 5;338(6):347-54
PMID 9449727, **http://www.ncbi.nlm.nih.gov/pubmed/9449727**

Design	Multi-Center RCT Protective versus Conventional ventilation
Patients	53 ARDS patients
Objectives	Compare outcomes Protective ventilation: Total PEEP 2 cmH2O above LIP (lower inflection point) on the static PV curve (16 cmH2O if there was no LIP), a Vt < 6 ml/Kg PBW (predicted body weight), driving pressures < 20 cmH2O above PEEP, permissive hypercapnia, and preferential use of pressure-limited ventilatory modes Conventional ventilation: lowest PEEP for acceptable oxygenation, Vt = 12 ml/Kg PBW and normal PCO2
Main Results	After 28 days, death = 38% in protective-ventilation group vs 71% in the conventional-ventilation group. The rates of weaning from mechanical ventilation were 66% in the protective-ventilation group and 29% in the conventional-ventilation group. The rates of barotrauma were 7% and 42%, respectively, despite the use of higher PEEP and mean Paw (airway pressure) in the protective-ventilation group.
Conclusion	As compared with conventional ventilation, the protective strategy (including PEEP set with LIP) was associated with improved survival at 28 days, a higher rate of weaning from mechanical ventilation, and a lower rate of barotrauma

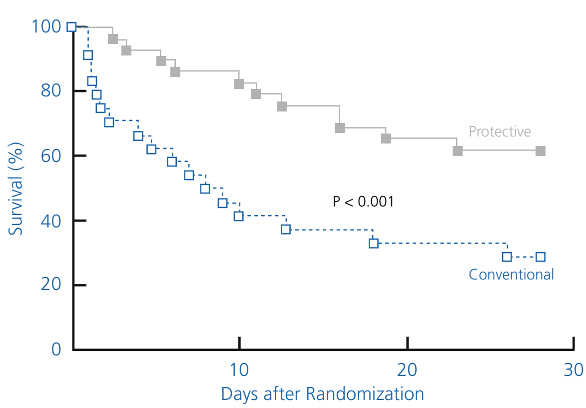

Figure 7: Survival was higher with protective ventilation, including PEEP set with LIP rather than with conventional ventilation

Total respiratory pressure-volume curves in the adult respiratory distress syndrome

Matamis D, Lemaire F, Harf A, Brun-Buisson C, Ansquer JC, Atlan G
Chest. 1984 Jul;86(1):58-66
PMID 6734293, **http://www.ncbi.nlm.nih.gov/pubmed/6734293**

Design	Prospective interventional study
Patients	19 ARDS patients
Objectives	Assess the value of measuring compliance
Main Results	Group 1: Normal Crs (compliance of respiratory system) measured during deflation, little hysteresis, and no inflection in the ascending limb corresponded with a nearly normal chest x-ray film and to recovery. Group 2: Normal Crs during deflation, increased hysteresis, and presence of an inflection corresponded with the initial stage of the syndrome and to pure alveolar opacities on the chest x-ray film. Group 3: Dcreased Crs during deflation, marked hysteresis, and presence of an inflection was seen later in the course of the syndrome and corresponds with mixed alveolar and interstitial opacities. Group 4: Reduced Crs during deflation, no increased hysteresis, and no inflection corresponded with end-stage of ARDS and a predominant interstitial pattern on the chest x-ray film.
Conclusion	PV curve was correlated with the ARDS stage. In normal lung or at early stage little hysteresis and no LIP (lower inflection point). Hysteresis increased and LIP appeared at the initial stage. Hysteresis was important and clear LIP during oedematous stage. No hysteresis and no inflection during the interstitial stage

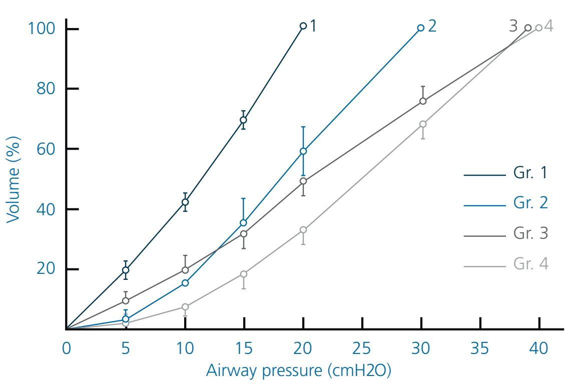

Figure 8: Example of ascending limb for each group Group 1: no LIP Group 2: presence of a LIP Group 3: presence of a LIP Group 4: no LIP, decreased Crs

Measurement of alveolar derecruitment in patients with acute lung injury: computerized tomography versus pressure-volume curve

Lu Q, Constantin JM, Nieszkowska A, Elman M, Vieira S, Rouby JJ
Crit Care. 2006 Jun;10(3):R95
PMID 16792793, **http://www.ncbi.nlm.nih.gov/pubmed/16792793**

Design	Prospective interventional study
Patients	19 ALI/ARDS patients
Objectives	Compare PEEP-induced lung derecruitment assessed by a PV curve and CT scan methods for assessing alveolar derecruitment after the removal of PEEP
Main Results	Alveolar derecruitments between PEEP of 15 cmH2O and ZEEP measured by the CT and PV curve methods were not different (373 ±250 and 345 ±208 ml ($p = 0.14$), respectively). Measurements by both methods were tightly correlated ($R = 0.82$, $p < 0.0001$). The derecruited volume measured by the PV curve method had a bias of -14 ml and limits of agreement of between -158 and +130 ml in comparison with the average derecruited volume of the CT and PV curve methods, according to the Bland and Altman method.
Conclusion	Alveolar derecruitment measured by the CT scan and PV curve were tightly correlated but with large limits of agreement

A high positive end-expiratory pressure, low tidal volume ventilatory strategy improves outcome in persistent acute respiratory distress syndrome: a randomized, controlled trial

Villar J, Kacmarek RM, Pérez-Méndez L, Aguirre-Jaime A
Crit Care Med. 2006 May;34(5):1311-8
PMID 16557151 , **http://www.ncbi.nlm.nih.gov/pubmed/16557151**

Design	Multi-Center RCT standard ventilation versus lowVt/PEEP set with LIP (lower inflection point)
Patients	103 ARDS patients
Objectives	Compared outcome of standard ventilation: Vt = 9-11 ml/kg PBW (predicted body weight), PEEP ≥ 5 cmH2O, FiO2 to SpO2 > 90%, PO2 = 70-100 mmHg LowVt/PEEP set with LIP : Vt = 5-8 ml/kg, PEEP = LIP + 2 cmH2O, FiO2 to SpO2 > 90%, PO2 = 70-100 mmHg
Main Results	ICU mortality (53.3% vs. 32%), hospital mortality (55.5% vs. 34%), and ventilator-free days at day 28 (6.02 ±7.95 vs. 10.90 ±9.45) all favored LowVt/PEEP set with LIP.
Conclusion	Mechanical ventilation strategy with a PEEP set above UIP (upper inflection point) and a low Vt has a beneficial impact on outcomes

Pressure-volume curve variations after a recruitment manoeuvre in acute lung injury/ARDS patients: implications for the understanding of the inflection points of the curve

Pestaña D, Hernández-Gancedo C, Royo C, Pérez-Chrzanowska H, Criado A
Eur J Anaesthesiol. 2005 Mar;22(3):175-80
PMID 15852989, **http://www.ncbi.nlm.nih.gov/pubmed/15852989**

Design	Prospective interventional study
Patients	35 postoperative patients with ALI/ARDS
Objectives	Study the variations of the PV curve after recruitment maneuver (RM): 2 PV curves separated by an RM (40 cmH2O)
Main Results	73 procedures. LIP (lower inflection point) and PMC (point of maximum curvarture) did not change after the RM. A UIP (upper inflection point) was observed in 18 curves before the RM and disappeared in 9 procedures after the RM.
Conclusion	UIP depended on the previous recruitment

Tomographic study of the inflection points of the pressure-volume curve in acute lung injury

Albaiceta GM, Taboada F, Parra D, Luyando LH, Calvo J, Menendez R, Otero J
Am J Respir Crit Care Med. 2004 Nov 15;170(10):1066-72
PMID 15317670, **http://www.ncbi.nlm.nih.gov/pubmed/15317670**

Design	Prospective interventional study
Patients	7 pulmonary ARDS patients and 5 extrapulmonary ADRS patients
Objectives	Assess changes in lung parenchyma by CT scan at different inflection points
Main Results	Increases in normally aerated lung and recruitment (decrease in nonaerated lung) were parallel and continuous during inflation. Loss of aeration and derecruitment were only significant at pressures below the PMC (point of maximum curvarture) on the deflation. This point was related to a higher amount of normally aerated tissue and a lower amount of nonaerated tissue when compared with the LIP (lower inflection point). Aeration at the inflection point was similar in lung injury from pulmonary or extrapulmonary origin.
Conclusion	This study supports the use of the deflation limb and PMC of the PV curve as a level of PEEP that achieves the two objectives of a “lung-protective ventilation”, of the highest amount of normally aerated tissue for ventilation and the lowest derecruitment during end-expiration.

Early patterns of static pressure-volume loops in ARDS and their relations with PEEP-induced recruitment

Vieillard-Baron A, Prin S, Chergui K, Page B, Beauchet A, Jardin F
Intensive Care Med. 2003 Nov;29(11):1929-35
PMID 12923622, **http://www.ncbi.nlm.nih.gov/pubmed/12923622**

Design	Prospective interventional study
Patients	54 ARDS patients
Objectives	Evaluate recruitment obtained at a constant elastic pressure of 20 cmH2O by superimposing the PV curve at ZEEP and at PEEP
Main Results	2 different types of loops: in type 1 (38 cases), the inflation limb was characterized by an inflection zone resulting from an improvement in Crs (compliance of respiratory system); in type 2, the inflation limb was virtually linear, Crs remained low (26 ±9 cmH2O). Use of a low PEEP (6 ±2 cmH2O) produced recruitment in type 1 patients (74 ±53 ml), which was marginally improved by a higher (12 ±2 cmH2O) PEEP (89 ±54 ml). In type 2, recruitment produced by PEEP was lower (48 ±26 ml).
Conclusion	In ARDS patients with reduced Crs, recruitment obtained by PEEP was limited. PEEP application produced recruitment in pulmonary ARDS, which was mainly obtained with a low PEEP, determined as “neutralizing” PEEP measured with ZEEP.

Alveolar derecruitment at decremental positive end-expiratory pressure levels in acute lung injury: comparison with the lower inflection point, oxygenation, and compliance

Maggiore SM, Jonson B, Richard JC, Jaber S, Lemaire F, Brochard L

Am J Respir Crit Care Med. 2001 Sep 1;164(5):795-801
PMID 11549535, **http://www.ncbi.nlm.nih.gov/pubmed/11549535**

Design	Prospective interventional study
Patients	16 ALI patients
Objectives	Determine alveolar closing pressures by calculating alveolar derecruitment induced by decreasing PEEP
Main Results	Derecruitment occurred at each PEEP decrement; derecruited volume was not correlated with LIP (lower inflection point). Linear Crs (compliance of respiratory system) at ZEEP was correlated to derecruited volume at PEEP 15 cmH2O.
Conclusion	Crs above LIP reflected the amount of recruitable lung. Alveolar closure in ALI occurs over a wide range of pressure. LIP is a poor predictor of alveolar closure.

Best compliance during a decremental, but not incremental, positive end-expiratory pressure trial is related to open-lung positive end-expiratory pressure: a mathematical model of acute respiratory distress syndrome lungs

Hickling KG
Am J Respir Crit Care Med. 2001 Jan;163(1):69-78
PMID 11208628, **http://www.ncbi.nlm.nih.gov/pubmed/11208628**

Design	Simulation study
Patients	Lung model
Objectives	Determine during incremental and decremental PEEP trial whether the maximum mean tidal slope occurs at open-lung PEEP, and if this relationship varies with Vt and respiratory mechanics
Main Results	During incremental PEEP, the PEEP providing the maximum mean tidal PV slope did not coincide with the open lung PEEP, and varied greatly with varying Vt and "lung mechanics." Incremental PEEP with a low Vt did not prevent alveolar collapse. During decremental PEEP with a low Vt, maximum mean tidal PV slope occurred with PEEP = 2-3.5 cmH2O below open-lung PEEP, unless closing pressure was high. The maximum mean tidal PV slope was always higher and the variation in PV slope with PEEP was greater during decremental PEEP.
Conclusion	The maximum PV slope during a decremental PEEP trial with a low Vt was a useful method to determine open-lung PEEP

The pressure-volume curve is greatly modified by recruitment. A mathematical model of ARDS lungs.

Hickling KG

Am J Respir Crit Care Med. 1998 Jul;158(1):194-202

PMID 9655729, **http://www.ncbi.nlm.nih.gov/pubmed/9655729**

Design	Simulation study
Patients	Lung model
Objectives	Evaluate the effect of varying alveolar threshold opening pressures, PEEP, and Pinsp on the static PV curve, using a mathematical model of the ARDS lungs, with simulated gravitational superimposed pressure
Main Results	LIP (lower inflection point) was affected by superimposed pressure and threshold opening pressures and did not accurately indicate the PEEP required to prevent end-expiratory collapse. Reinflation of collapsed lung units (recruitment) continued on the linear portion of the PV curve, above LIP, which had a slope at any volume greater than the total compliance of aerated alveoli. As recruitment decreased, the reduced PV slope could produce UIP (upper inflection point) at 20 to 30 cmH2O. UIP caused by alveolar overdistension could be modified or eliminated by recruitment with a high threshold opening pressure. With constant Pinsp as PEEP increased and threshold a opening pressure range of 5 to 60 cmH2O, PEEP to prevent end-expiratory collapse was indicated by a minimum PV slope above 20 cmH2O, minimum hysteresis, and maximum volume at 20 cmH2O.
Conclusion	No aspect of the PV curve adequately predicted optimum ventilator settings. Setting PEEP according to LIP and Pplat according to UIP were inaccurate in this model

Impact of positive end-expiratory pressure on chest wall and lung pressure-volume curve in acute respiratory failure

Mergoni M, Martelli A, Volpi A, Primavera S, Zuccoli P, Rossi A
Am J Respir Crit Care Med. 1997 Sep;156(3 Pt 1):846-54
PMID 9310003, **http://www.ncbi.nlm.nih.gov/pubmed/9310003**

Design	Prospective interventional study
Patients	13 patients with ARF
Objectives	Investigate whether chest-wall mechanics could affect the total respiratory system PV curve
Main Results	With ZEEP, an LIP (lower inflection point) on the respiratory system PV curve was observed in all patients (7.5 ±3.9 cmH2O); in 2 patients a LIP was detected only on the lung PV curve (8.6 and 8.7 cmH2O), whereas in 7 patients a LIP was observed only on the chest wall PV curve (3.4 ±1.1 cmH2O). In 4 patients, a LIP was detected on both lung and chest wall PV curves (8.5 ±3.4 and 2.2 ±1.0 cmH2O, respectively). The LIP was eliminated by PEEP. At high levels of PEEP, a UIP (upper inflection point) appeared on respiratory system and lung PV curves (11.7 ±4.9 cmH2O and 8.9 ±4.2 cmH2O above PEEP, respectively)
Conclusion	The disappearance of LIP observed with PEEP suggested that lungs were recruited. The pressure of a UIP apparition suggested alveolar overdistension at high levels of PEEP.

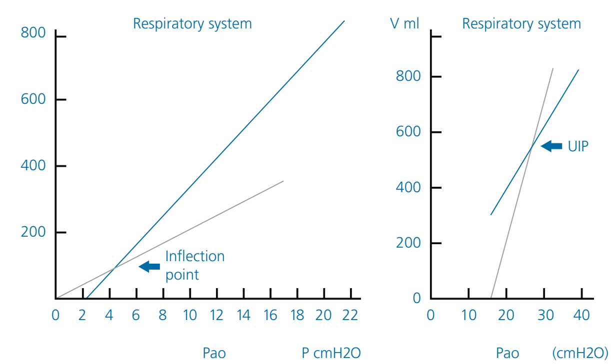

Figure 9: Example of LIP and UIP

Pressure-volume curves with and without muscle paralysis in acute respiratory distress syndrome

Decailliot F, Demoule A, Maggiore SM, Jonson B, Duvaldestin P, Brochard L
Intensive Care Med. 2006 Sep;32(9):1322-8
PMID 16826390, **http://www.ncbi.nlm.nih.gov/pubmed/16826390**

Design	Prospective randomized crossover study
Patients	19 ARDS patients
Objectives	Evaluate safety and reliability of PV curve measurements under deep sedation without neuromuscular blockade and compare with PV curve under neuromuscular blockade
Main Results	Mean linear compliance did not differ significantly with paralysis and apneic sedation. The bias of agreement for linear compliance was –0.2 ml/cmH2O with a 95% CI (confidence interval) of bias of –3.5 to 3.0. In the five patients with Peso recordings, Ccw (compliance of chest wall) did not differ between apneic sedation and paralysis. The bias of agreement for Ccw was –0.7 ml/cmH2O with a 95% CI of bias of –5.3 to 3.9. Mean LIP (lower inflection point) did not differ between paralysis and apneic sedation (bias –0.3 cmH2O and 95% CI –1.0 to 0.4), nor did the mean UIP (upper inflection point) differ (bias –0.4 cmH2O and 95% CI –1.9 to 1.2). In eight patients, no UIP was recorded under paralysis or apneic sedation; one patient had a UIP (17.2 cmH2O) under paralysis but not under apneic sedation, and two had a UIP under apneic sedation but not under paralysis (mean UIP 17.5 ± 1 cmH2O). Mean PEEPtot just before PV curve recording did not differ significantly under paralysis and apneic sedation.
Conclusion	The level of variability indicated that the PV curve without paralysis should be used with caution. A single administration of neuromuscular blockade was associated with better hemodynamic status than increasing sedation

Temporal change, reproducibility, and interobserver variability in pressure-volume curves in adults with acute lung injury and acute respiratory distress syndrome

Mehta S, Stewart TE, MacDonald R, Hallett D, Banayan D, Lapinsky S, Slutsky A
Crit Care Med. 2003 Aug;31(8):2118-25
PMID 12973168, **http://www.ncbi.nlm.nih.gov/pubmed/12973168**

Design	Prospective interventional study
Patients	11 ALI/ARDS patients
Objectives	Assess the temporal change in UIP (upper inflection point) and LIP (lower inflection point) measured from PV curves and assess the inter- and intraobserver variability in detection of the UIP and LIP
Main Results	134 PV curves from ZEEP were generated. LIP and UIP could be detected in 90%-94% and 61%-68% of curves, respectively. When the 3 successive PV curves were compared, both the LIP and UIP were within 3 cmH2O in >65% of curves. The intraclass correlation coefficient in LIP and UIP was 0.92 and 0.89 for interobserver variability and 0.90 and 0.88 for intraobserver variability. Daily variability was as high as 7 cmH2O for LIP and 5 cmH2O for UIP.
Conclusion	The PV curve was reproducible, thus avoiding the need for multiple measurements at a single time, with good interobserver and intraobserver correlation in manual identification of the LIP and UIP

An objective analysis of the pressure-volume curve in the acute respiratory distress syndrome

Harris RS, Hess DR, Venegas JG
Am J Respir Crit Care Med. 2000 Feb;161(2 Pt 1):432-9
PMID 10673182, **http://www.ncbi.nlm.nih.gov/pubmed/10673182**

Design	Prospective interventional study
Patients	18 ARDS patients
Objectives	Assess the interobserver and intraobserver-variability in the clinical evaluation of the quasi-static PV curve
Main Results	The LIP (lower inflection point) defined by the clinician rarely coincided with the point of maximum compliance increase defined by a sigmoid curve-fit with large differences in LIP seen both among and within observers.
Conclusion	Calculating objective parameters from the PV curve was important to minimize the large interobserver and intra-observer variability

Pressure-volume curves and compliance in acute lung injury: evidence of recruitment above the lower inflection point

Jonson B, Richard JC, Straus C, Mancebo J, Lemaire F, Brochard L

Am J Respir Crit Care Med. 1999 Apr;159(4 Pt 1):1172-8
PMID 10194162, **http://www.ncbi.nlm.nih.gov/pubmed/10194162**

Design	Prospective interventional study
Patients	11 ALI patients
Objectives	Evaluate the effect of recruitment/derecruitment on the shape of the PV curve and on Crs (compliance of respiratory system) by prolonged expiration from PEEP to elastic equilibrum volume
Main Results	Curve I was recorded during inflation from the volume attained after a prolonged expiration at PEEP = 9.0 ±2.2 cmH2O, and Curve II after expiration to the elastic equilibrium volume at ZEEP. In each patient, Curve II was shifted toward lower volumes than Curve I. The volume shift, probably due to derecruitment, was 205 ±100 ml at 15 cmH2O and 78 ±93 ml at 30 cmH2O; At any pressure, compliance was higher on the curve from ZEEP than from PEEP, by 10.0 ±8.7 ml/cmH2O at 15 cmH2O ($p < 0.01$), and by 5.4 ±5.5 at 30 cmH2O.
Conclusion	In ALI patients, a single expiration to ZEEP led to lung collapse. High Crs during inflation from ZEEP indicated that lung recruitment happened above the LIP.

Generation of a single pulmonary pressure-volume curve does not durably affect oxygenation in patients with acute respiratory distress syndrome

Roch A, Forel JM, Demory D, Arnal JM, Donati S, Gainnier M, Papazian L

Crit Care. 2006 Jun;10(3):R85
PMID 16740174, **http://www.ncbi.nlm.nih.gov/pubmed/16740174**

Design	Randomized crossover study
Patients	17 ARDS patients
Objectives	Investigate the effects over time of static and dynamic PV curves on gas exchange and hemodynamic
Main Results	PV curves did not significantly affect PaO2, PaCO2, mean arterial pressure, and lung mechanics. 2 patients had a sustained increase in PaO2 of more than 20%, 1 h after obtaining a dynamic PV curve. 2 patients had a decrease in PaO2, by more than 20%, after a static PV curve. These 2 patients had a UIP (upper inflection point) identified on the PV curve. After the static PV curve, PaCO2 increased by more than 10 mmHg in 2 patients and returned to baseline after 15 minutes. 1 patient had a decrease in mean arterial pressure of more than 10 mmHg for less than 5 minutes after the static PV curve and 1 patient after the dynamic PV curve.
Conclusion	Static and dynamic PV curves were safe in ARDS patients

Adjusting positive end-expiratory pressure and tidal volume in acute respiratory distress syndrome according to the pressure-volume curve

Pestaña D, Hernández-Gancedo C, Royo C, Uña R, Villagrán MJ, Peña N, Criado A
Acta Anaesthesiol Scand. 2003 Mar;47(3):326-34
PMID 12648200 , **http://www.ncbi.nlm.nih.gov/pubmed/12648200**

Design	Prospective interventional study
Patients	27 ALI/ARDS patients
Objectives	Study the relationship between the different inflection points of the PV curve in ARDS patients. Assess the changes following its use in the empiric PEEP and Vt.
Main Results	LIP (lower inflection point) was found in all patients and the PEEP was modified by the clinician in 80% of the cases according to the LIP value. A UIP (upper inflection point) was observed in 16 out of 69 measurements and the Vt was modified by the clinician in 20% of the cases according to the UIP value.
Conclusion	Quasi-static measurement of the PV curve was a simple method, that is easy to interpret for adjustment of the ventilatory parameters

The upper inflection point of the pressure-volume curve. Influence of methodology and of different modes of ventilation

Servillo G, De Robertis E, Maggiore S, Lemaire F, Brochard L, Tufano R
Intensive Care Med. 2002 Jul;28(7):842-9
PMID 12122520, **http://www.ncbi.nlm.nih.gov/pubmed/12122520**

Design	Prospective interventional study
Patients	13 ARDS patients
Objectives	Test the influence of PV curve tracing methodology on the presence and value of the UIP (upper inflection point): constant flow allowed for a dynamic PV curve and interruption of flow allowed for a static PV curve
Main Results	Differences in UIP were found in the static and dynamic conditions between the two levels of Vt: the UIP was lower with the higher Vt.
Conclusion	Dynamic and static methods gave similar results. Previous Vt influenced the pressure value of the UIP suggesting that it was dependent on tidal alveolar recruitment

Safety of pressure-volume curve measurement in acute lung injury and ARDS using a syringe technique

Lee WL, Stewart TE, MacDonald R, Lapinsky S, Banayan D, Hallett D, Mehta S
Chest. 2002 May;121(5):1595-601
PMID 12006449, **http://www.ncbi.nlm.nih.gov/pubmed/12006449**

Design	Prospective interventional study
Patients	11 ALI/ARDS patients
Objectives	Assess the safety of frequent PV curves in patients with ALI/ARDS
Main Results	SpO_2 was 93 ±4% before the maneuvres and fell to 89 ±5% during PV curve and increased to 97 ±4% immediately afterwards. HR (heart rate) was 106 ±22 before and 108 ±22 beats/min immediately after the maneuver. Mean arterial pressure was 93 ±15 mmHg before and 100 ±17 mmHg immediately afterward.
Conclusion	PV curve maneuvres were well tolerated in most patients

A comprehensive equation for the pulmonary pressure-volume curve

Venegas JG, Harris RS, Simon BA
J Appl Physio. 1998 Jan;84(1):389-95
PMID 9451661, **http://www.ncbi.nlm.nih.gov/pubmed/9451661**

Design	Retrospective comparative experimental study
Patients	10 ARDS patients 2 normal doglungs, 9 hypocapnic pneumoconstricted doglungs, 2 open right chest, 2 oleic acid-induced ARDS
Objectives	Compare sigmoidal equation with PV curves in a variety of experimental and pathological conditions
Main Results	The equation V = a + b[1- e-(P-c)/d]-1 was an equally good fit for the inflation and deflation limbs of PV curves from normal, ARDS and pneumoconstricted lungs with a mean goodness-of-fit coefficient of 0.997 ±0.02.
Conclusion	This equation provided a method to systematically characterize PV curves and objectively derive physiologically (vital capacity, maximal inspiratory volume) and clinically (compliance of respiratory system), lower inflection point, upper inflection point), point of maximum curvarture) useful parameters

A sigmoid model of the static volume-pressure curve of human lung

Paiva M, Yernault JC, Eerdeweghe PV, Englert M
Respir Physiol. 1975 Apr;23(3):317-23
PMID 1144946, **http://www.ncbi.nlm.nih.gov/pubmed/1144946**

Design	Prospective interventional physiological study
Patients	20 healthy subjects
Objectives	Correlate sigmoid mathematical model of PV curve with experimental data
Main Results	The sigmoid model was a better fit for the physiological data than the exponential model used before
Conclusion	The human PV curve has a sigmoidal shape

Additional files

Static pressure-volume curves of the respiratory system: were they just a passing fad?

Albaiceta GM, Blanch L, Lucangelo U
Curr Opin Crit Care. 2008 Feb;14(1):80-6
PMID 18195631 , **http://www.ncbi.nlm.nih.gov/pubmed/18195631**

Design	Review
Conclusion	Explain evolution of the concept and use of PV curve

Monitoring of pulmonary mechanics in acute respiratory distress syndrome to titrate therapy

Gattinoni L, Eleonora C, Caironi P
Curr Opin Crit Care. 2005 Jun;11(3):252-8
PMID 15928475, **http://www.ncbi.nlm.nih.gov/pubmed/15928475**

Design	Review
Conclusion	Relation between PV curves and ARDS patients

Pressure/volume curves and lung computed tomography in acute respiratory distress syndrome

Rouby JJ, Lu Q, Vieira S
Eur Respir J Suppl. 2003 Aug;42:27s-36s
PMID 12945998, **http://www.ncbi.nlm.nih.gov/pubmed/12945998**

Design	Review
Conclusion	Relation between PV curves and CT scans

Lung hysteresis: a morphological view

Escolar JD, Escolar A
Histol Histopathol. 2004 Jan;19(1):159-66
PMID 14702184, **http://www.ncbi.nlm.nih.gov/pubmed/14702184**

Design	Review
Conclusion	Explain hysteresis of the lungs

Reinterpreting the pressure-volume curve in patients with acute respiratory distress syndrome

Hickling KG
Curr Opin Crit Care. 2002 Feb;8(1):32-8
PMID 12205404, **http://www.ncbi.nlm.nih.gov/pubmed/12205404**

Design	Review
Conclusion	Explain the correct interpretation of PV curve

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