

# P/V curves

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# 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>

<b>Design</b>	Prospective comparative interventional study
<b>Patients</b>	10 ALI/ARDS patients
<b>Objectives</b>	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
<b>Main Results</b>	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 curvature) 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 ( $0.51 \pm 0.95$ cmH2O; -1.36 to 2.38 cmH2O), for UIP ( $0.53 \pm 1.52$ cmH2O; -2.44 to 3.50 cmH2O), and for PMC ( $-0.62 \pm 0.89$ cmH2O; -2.35 to 1.12 cmH2O) were clinically acceptable. No adverse effects were observed.
<b>Conclusion</b>	The P/V Tool was equivalent to the CPAP method for tracing static PV curves of the respiratory system

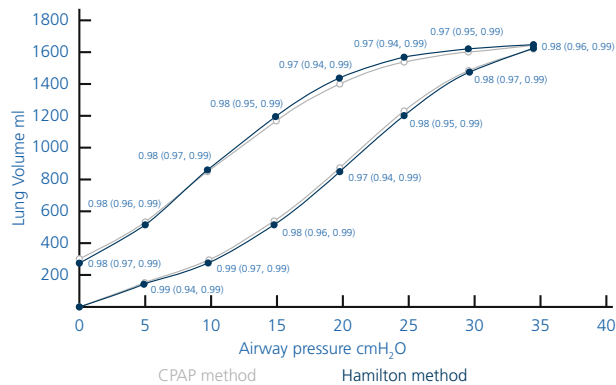


Figure 1: Comparison between P/V Tool and CPAP method; the two PV curves were superimposed

# 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-Gasselín J  
Intensive Care Med. 2008 Nov;34(11):2019-25  
PMID 18575846, <http://www.ncbi.nlm.nih.gov/pubmed/18575846>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	26 ARDS patients
<b>Objectives</b>	Estimate potential lung recruitability by hysteresis of quasi-static PV curve
<b>Main Results</b>	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 cmH <sub>2</sub> O, divided by the predicted body weight), and recruited volume (measured by integration of the flow required to maintain the pressure at 40 cmH <sub>2</sub> O 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.
<b>Conclusion</b>	Hysteresis of the PV curve could assess the recruitability of the lung at the bedside

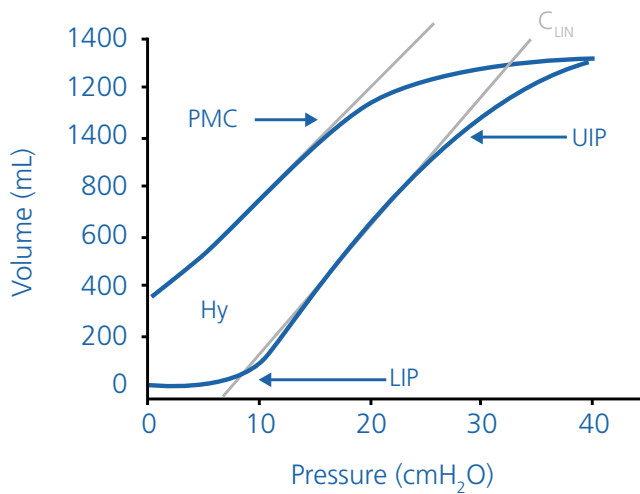


Figure 2: Example of LIP, UIP, PMC, C<sub>dyn</sub> and hysteresis

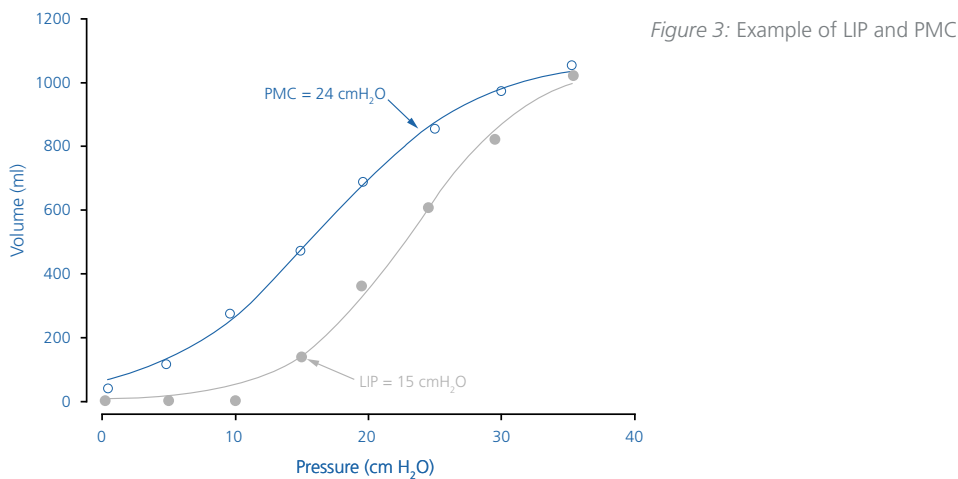
# Inspiratory vs. expiratory pressure-volume curves to set end-expiratory pressure in acute lung injury

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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	8 ALI patients VC Vt 6 ml/kg
<b>Objectives</b>	Study the effects of two levels of PEEP, 2 cmH <sub>2</sub> O above LIP (lower inflection point) and equal to the PMC (point of maximum curvature) of the PV curve, in gas exchange, respiratory mechanics, and lung aeration
<b>Main Results</b>	PEEP 2 cmH <sub>2</sub> O above LIP was 15.5 ±3.1 cmH <sub>2</sub> O and a PEEP equal to PMC was 23.5 ±4.1 cmH <sub>2</sub> O. 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 PaCO <sub>2</sub> , Paw (airway pressure), and hyperaerated lung volume.
<b>Conclusion</b>	PEEP according to PMC recruited some parts and overdistended others parts of lungs



# 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>

<b>Design</b>	Prospective comparative interventional study
<b>Patients</b>	ALI patients: 8 with LIP (lower inflection point), 6 without LIP
<b>Objectives</b>	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 cmH <sub>2</sub> O and PEEP2 = LIP + 7 cmH <sub>2</sub> O, or PEEP1 = 10 cmH <sub>2</sub> O and PEEP2 = 15 cmH <sub>2</sub> O in the absence of an LIP
<b>Main Results</b>	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 ( $24 \pm 22\%$ vs $55 \pm 12\%$ , $p < 0.05$ ) and the percentage of poorly aerated lung was greater ( $40 \pm 12\%$ vs $23 \pm 8\%$ , $p < 0.05$ ) 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.
<b>Conclusion</b>	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 overdistension

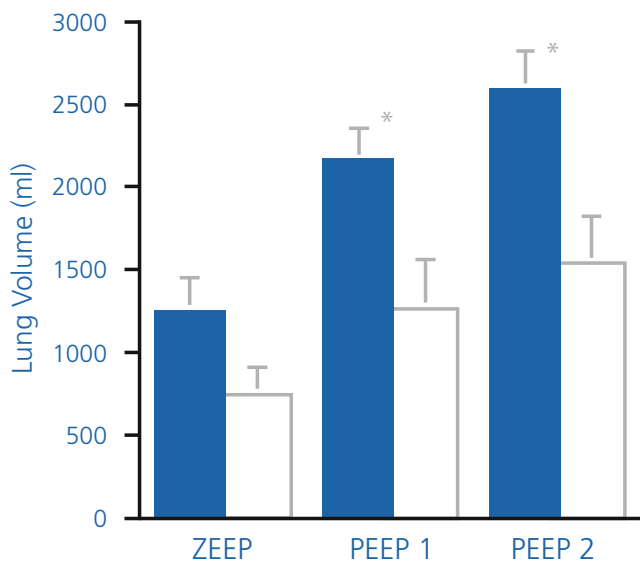


Figure 4: Patients with LIP had more aerated tissue than patients without LIP: lung density histograms Tomographic lung scan cuts at ZEEP, PEEP1, PEEP2

# 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>

<b>Design</b>	Multi-Center RCT Protective versus Conventional ventilation
<b>Patients</b>	53 ARDS patients
<b>Objectives</b>	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 $V_t < 6$ 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, $V_t = 12$ ml/Kg PBW and normal PCO2
<b>Main Results</b>	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.
<b>Conclusion</b>	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

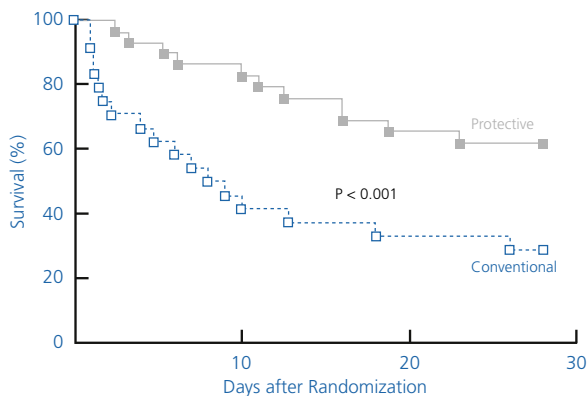


Figure 5: Survival was higher with protective ventilation, including PEEP set with LIP rather than with conventional ventilation

# 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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	19 ARDS patients
<b>Objectives</b>	Assess the value of measuring compliance
<b>Main Results</b>	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: Decreased 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.
<b>Conclusion</b>	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

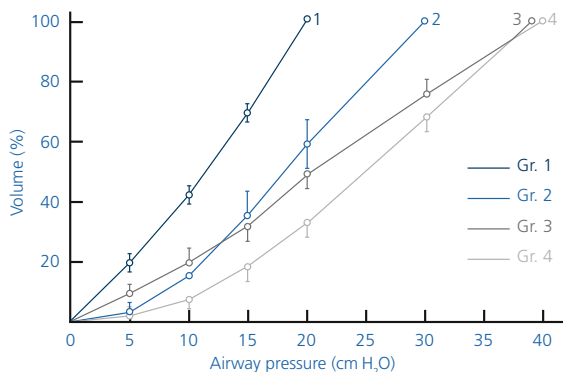


Figure 6: Example of ascending limb for each group Group 1: no LIP Group 2: presence of a LIP Group 3: presence of a LIP Group 4: no LIP, decreased Crs



## 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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	19 ALI/ARDS patients
<b>Objectives</b>	Compare PEEP-induced lung derecruitment assessed by a PV curve and CT scan methods for assessing alveolar derecruitment after the removal of PEEP
<b>Main Results</b>	Alveolar derecruitments between PEEP of 15 cmH <sub>2</sub> O 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.
<b>Conclusion</b>	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>

<b>Design</b>	Multi-Center RCT standard ventilation versus lowVt/PEEP set with LIP (lower inflection point)
<b>Patients</b>	103 ARDS patients
<b>Objectives</b>	Compared outcome of standard ventilation: Vt = 9-11 ml/kg PBW (predicted body weight), PEEP ≥ 5 cmH <sub>2</sub> O, FiO <sub>2</sub> to SpO <sub>2</sub> > 90%, PO <sub>2</sub> = 70-100 mmHg LowVt/PEEP set with LIP : Vt = 5-8 ml/kg, PEEP = LIP + 2 cmH <sub>2</sub> O, FiO <sub>2</sub> to SpO <sub>2</sub> > 90%, PO <sub>2</sub> = 70-100 mmHg
<b>Main Results</b>	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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	35 postoperative patients with ALI/ARDS
<b>Objectives</b>	Study the variations of the PV curve after recruitment maneuver (RM): 2 PV curves separated by an RM (40 cmH <sub>2</sub> O)
<b>Main Results</b>	73 procedures. LIP (lower inflection point) and PMC (point of maximum curvature) 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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	7 pulmonary ARDS patients and 5 extrapulmonary ADRS patients
<b>Objectives</b>	Assess changes in lung parenchyma by CT scan at different inflection points
<b>Main Results</b>	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 curvature) 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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	54 ARDS patients
<b>Objectives</b>	Evaluate recruitment obtained at a constant elastic pressure of 20 cmH <sub>2</sub> O by superimposing the PV curve at ZEEP and at PEEP
<b>Main Results</b>	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 cmH <sub>2</sub> O). Use of a low PEEP (6 ±2 cmH <sub>2</sub> O) produced recruitment in type 1 patients (74 ±53 ml), which was marginally improved by a higher (12 ±2 cmH <sub>2</sub> O) PEEP (89 ±54 ml). In type 2, recruitment produced by PEEP was lower (48 ±26 ml).
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	16 ALI patients
<b>Objectives</b>	Determine alveolar closing pressures by calculating alveolar derecruitment induced by decreasing PEEP
<b>Main Results</b>	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 cmH <sub>2</sub> O.
<b>Conclusion</b>	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>

<b>Design</b>	Simulation study
<b>Patients</b>	Lung model
<b>Objectives</b>	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
<b>Main Results</b>	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.
<b>Conclusion</b>	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>

<b>Design</b>	Simulation study
<b>Patients</b>	Lung model
<b>Objectives</b>	Evaluate the effect of varying alveolar threshold opening pressures, PEEP, and P <sub>insp</sub> on the static PV curve, using a mathematical model of the ARDS lungs, with simulated gravitational superimposed pressure
<b>Main Results</b>	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. Re-inflation 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 cmH <sub>2</sub> O. UIP caused by alveolar overdistension could be modified or eliminated by recruitment with a high threshold opening pressure. With constant P <sub>insp</sub> as PEEP increased and threshold a opening pressure range of 5 to 60 cmH <sub>2</sub> O, PEEP to prevent end-expiratory collapse was indicated by a minimum PV slope above 20 cmH <sub>2</sub> O, minimum hysteresis, and maximum volume at 20 cmH <sub>2</sub> O.
<b>Conclusion</b>	No aspect of the PV curve adequately predicted optimum ventilator settings. Setting PEEP according to LIP and P <sub>plat</sub> 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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	13 patients with ARF
<b>Objectives</b>	Investigate whether chest-wall mechanics could affect the total respiratory system PV curve
<b>Main Results</b>	With ZEEP, an LIP (lower inflection point) on the respiratory system PV curve was observed in all patients ( $7.5 \pm 3.9$ cmH <sub>2</sub> O); in 2 patients a LIP was detected only on the lung PV curve (8.6 and 8.7 cmH <sub>2</sub> O), whereas in 7 patients a LIP was observed only on the chest wall PV curve ( $3.4 \pm 1.1$ cmH <sub>2</sub> O). In 4 patients, a LIP was detected on both lung and chest wall PV curves ( $8.5 \pm 3.4$ and $2.2 \pm 1.0$ cmH <sub>2</sub> O, 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 ( $11.7 \pm 4.9$ cmH <sub>2</sub> O and $8.9 \pm 4.2$ cmH <sub>2</sub> O above PEEP, respectively)
<b>Conclusion</b>	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.

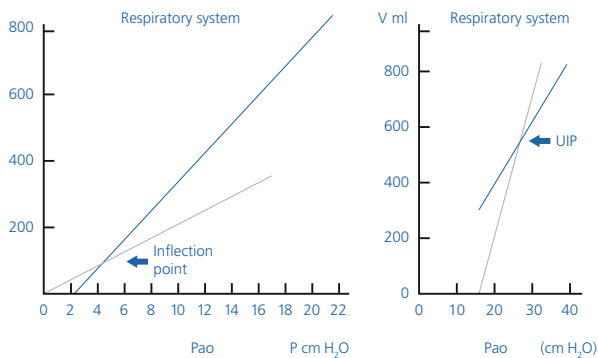


Figure 7: Example of LIP and UIP

## 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>

<b>Design</b>	Prospective randomized crossover study
<b>Patients</b>	19 ARDS patients
<b>Objectives</b>	Evaluate safety and reliability of PV curve measurements under deep sedation without neuromuscular blockade and compare with PV curve under neuromuscular blockade
<b>Main Results</b>	Mean linear compliance did not differ significantly with paralysis and apneic sedation. The bias of agreement for linear compliance was $-0.2$ ml/cmH <sub>2</sub> O with a 95% CI (confidence interval) of bias of $-3.5$ to $3.0$ . In the five patients with Pesco recordings, Ccw (compliance of chest wall) did not differ between apneic sedation and paralysis. The bias of agreement for Ccw was $-0.7$ ml/cmH <sub>2</sub> O 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 $-0.3$ cmH <sub>2</sub> O and 95% CI $-1.0$ to $0.4$ ), nor did the mean UIP (upper inflection point) differ (bias $-0.4$ cmH <sub>2</sub> O 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 ( $17.2$ cmH <sub>2</sub> O) under paralysis but not under apneic sedation, and two had a UIP under apneic sedation but not under paralysis (mean UIP $17.5 \pm 1$ cmH <sub>2</sub> O). Mean PEEP-tot just before PV curve recording did not differ significantly under paralysis and apneic sedation.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	11 ALI/ARDS patients
<b>Objectives</b>	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
<b>Main Results</b>	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 cmH <sub>2</sub> O 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 cmH <sub>2</sub> O for LIP and 5 cmH <sub>2</sub> O for UIP.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	18 ARDS patients
<b>Objectives</b>	Assess the interobserver and intraobserver-variability in the clinical evaluation of the quasi-static PV curve
<b>Main Results</b>	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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	11 ALI patients
<b>Objectives</b>	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 equilibrium volume
<b>Main Results</b>	Curve I was recorded during inflation from the volume attained after a prolonged expiration at PEEP = $9.0 \pm 2.2$ cmH <sub>2</sub> O, 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 $205 \pm 100$ ml at 15 cmH <sub>2</sub> O and $78 \pm 93$ ml at 30 cmH <sub>2</sub> O; At any pressure, compliance was higher on the curve from ZEEP than from PEEP, by $10.0 \pm 8.7$ ml/cmH <sub>2</sub> O at 15 cmH <sub>2</sub> O ( $p < 0.01$ ), and by $5.4 \pm 5.5$ at 30 cmH <sub>2</sub> O.
<b>Conclusion</b>	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, Gannier M, Papazian L

Crit Care. 2006 Jun;10(3):R85.

PMID 16740174, <http://www.ncbi.nlm.nih.gov/pubmed/16740174>

<b>Design</b>	Randomized crossover study
<b>Patients</b>	17 ARDS patients
<b>Objectives</b>	Investigate the effects over time of static and dynamic PV curves on gas exchange and hemodynamic
<b>Main Results</b>	PV curves did not significantly affect PaO <sub>2</sub> , PaCO <sub>2</sub> , mean arterial pressure, and lung mechanics. 2 patients had a sustained increase in PaO <sub>2</sub> of more than 20%, 1 h after obtaining a dynamic PV curve. 2 patients had a decrease in PaO <sub>2</sub> , 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, PaCO <sub>2</sub> 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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	27 ALI/ARDS patients
<b>Objectives</b>	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.
<b>Main Results</b>	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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	13 ARDS patients
<b>Objectives</b>	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
<b>Main Results</b>	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.
<b>Conclusion</b>	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>

<b>Design</b>	Prospective interventional study
<b>Patients</b>	11 ALI/ARDS patients
<b>Objectives</b>	Assess the safety of frequent PV curves in patients with ALI/ARDS
<b>Main Results</b>	SpO <sub>2</sub> was 93 ±4% before the manoeuvres 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.
<b>Conclusion</b>	PV curve manoeuvres were well tolerated in most patients

## A comprehensive equation for the pulmonary pressure-volume curve

Venegas JG, Harris RS, Simon BA

J Appl Physiol. 1998 Jan;84(1):389-95

PMID 9451661, <http://www.ncbi.nlm.nih.gov/pubmed/9451661>

<b>Design</b>	Retrospective comparative experimental study
<b>Patients</b>	10 ARDS patients 2 normal doglungs, 9 hypocapnic pneumoconstricted doglungs, 2 open right chest, 2 oleic acid-induced ARDS
<b>Objectives</b>	Compare sigmoidal equation with PV curves in a variety of experimental and pathological conditions
<b>Main Results</b>	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 $0.997 \pm 0.02$ .
<b>Conclusion</b>	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 curvature) 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>

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

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**Conclusion** Explain evolution of the concept and use of PV curve

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## 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

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**Conclusion** Relation between PV curves and ARDS patients

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## 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

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**Conclusion** Relation between PV curves and CT scans

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## 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

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**Conclusion**                Explain hysteresis of the lungs

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# 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

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**Conclusion**        Explain the correct interpretation of PV curve

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Hamilton Medical AG

Via Crusch 8, 7402 Bonaduz, Switzerland

 +41 58 610 10 20

[info@hamilton-medical.com](mailto:info@hamilton-medical.com)

[www.hamilton-medical.com](http://www.hamilton-medical.com)