Pressure - Volume curves in ARDS

G. Servillo

Dipartimento di Scienze Chirurgiche, Anestesiologiche-Rianimatorie e dell’Emergenza
Facoltà di Medicina e Chirurgia
Università degli Studi di Napoli “Federico II”
Basic features of Pel/V curves representing collapsed lung are known and understood since the fifties!

Expansion is irregular when lung units “pop” open. Then, a given volume must be shared by a smaller number of lung units.

Emptying is uniformly distributed.

Mead, Whittenberg & Radford
Surface tension as a factor in pulmonary Volume/pressure hysteresis
J Appl Physiol 1957, 10:191-196
ARDS and PV curves: the inseparable duet?

F. Lemaire, ICM 2000

...Tracing pressure-volume curves to assess respiratory mechanics and titrate mechanical ventilation has been a subject of research and controversy since the early descriptions of the acute respiratory distress syndrome by Asbaugh in 1967...
To measure the P-V curve from the resting volume of the respiratory system to the estimated total lung capacity it appeared attractive to use a calibrated syringe of known volume, ranging from 1.5 to 2 l, referred to as a supersyringe.

The supersyringe technique
Harf A, Lemaire F 1975

Courtesy of Prof. François Lemaire
Matamis D. Lemaire F. Chest 1984
Flow-interruption technique

...is based on analysis of the respiratory system after constant inspiratory flow occlusion...
Several authors have described techniques based on the capability of the ventilator to yield both volume and static pressures during occlusions performed at different inflation volumes with the same constant inspiratory flow.

Levy J. Crit. Care 1989
Ranieri ARRD 1991
Roupie AJRCCM 1995
Jonson J Appl Physiol 1993
A method for studying the static Pressure-Volume Curves of the respiratory system during mechanical ventilation

Levy P. and Jonson B. *Journal of Critical Care* 1989

- B1 press the inspiratory pause hold knob
- B2 wait until the plateau pressure appears
- B3 change the frequency to the first chosen value
- B4 release the inspiratory pause hold knob and immediately press the expiratory
- B5 after the ensuing expiration, let the pause last approximately 3 seconds
- B6 reset the frequency to the basic value during this pause
- B7 release the expiratory pause hold knob
Titration of Tidal Volume and Induced Hypercapnia in Acute Respiratory Distress Syndrome

ERIC ROUPIE, MICHÈLE DAMBROSIO, GIUSEPPE SERVILLO, HÉRÉVÉ MENTEC, SOUHAÎL EL ATRÔUS, LAURENT BEYDON, CHRISTIAN BRUN-BUÎSSON, FRANÇÔIS LEMAÎRE, and LAURENT BROCHARD

Medical and Surgical Intensive Care Units, INSERM U296, Hôpital Henri Mondor, Paris XII University, Créteil, France
TV 6 ml/Kg, RM 40 cmH$_2$O & PEEP 2 > Pflex (18 cmH$_2$O)

TV 12 ml/Kg, PEEP 8 cmH$_2$O

Amato et al. NEJM 1998
I seriously doubts that this measurement can be made routinely, safely, and accurately in most intensive care units...
Volume-Pressure Curve of the Respiratory System Predicts Effects of PEEP in ARDS: “Occlusion” versus “Costant Flow” Technique

Ranieri VM et al. AJRCCM 1994
A Single Computer-Controlled Mechanical Insufflation Allows Determination of the Pressure-Volume Relationship of the Respiratory System

*Servillo G and Jonson B AJRCCM 1997*
Methods:

PV curve recorded from **ZEEP**

PV curve recorded from **PEEP**
Pressure-Volume Curves in Acute Respiratory Failure
Automated Low Flow Inflation versus Occlusion

GIUSEPPE SERVILLO, CECILIA SVANTESSON, LAURENT BEYDON, ERIC ROUPIE, LAURENT BROCHARD, FRANÇOIS LEMAIRE, and BJÖRN JONSON

Department of Clinical Physiology, University Hospital of Lund, Lund, Sweden; Medical Intensive Care Unit and Surgical Intensive Care Unit, INSERM U296, Hôpital Henri Mondor, Paris XII University, Créteil, France
Application of a computerised method to measure static pressure volume curve in acute respiratory distress syndrome

G. Servillo
E. De Robertis
M. Coppola
F. Blasi
F. Rossano
R. Tufano
Low Flow PV Loop
Inspiration only or Inspiration and Expiration?

- What points shall be found?
- What period is acceptable?
- How low shall the flow be?

Inspiration only

- slow inflation with set flow
- when Plimit or Vlimit reached, pressure will be reduced with 5 cmH2O/sec (to avoid cardiac overloading)

Inspiration and Expiration

- slow inflation and deflation with set flow
- when Plimit or Vlimit reached, slow inflation turns into slow deflation

How is the maximum maneuver time calculated?

**Insp only**: \( \frac{V_{\text{limit}}}{\text{Flow}} + \frac{P_{\text{limit}}}{5 \text{ cmH}_2\text{O} / \text{s}} \)

**Insp + Exp**: \( \left( \frac{V_{\text{limit}}}{\text{Flow}} \right) \times 2 \)

Insp only might be longer than Insp + Exp if a very high Plimit is selected.

It is a calculated maximum time, period can be considerably shorter!
Non-homogenous lung models different SD $P_{opening}$.

Mean $P_{opening} = 15$ cm H$_2$O, SD $P_{opening} = 2$, 6, 12

LIP demonstrates the lower range of opening pressure!
UIP demonstrates the upper range of opening pressure!

Volume-Pressure Curve of the Respiratory System Predicts Effects of PEEP in ARDS: “Occlusion” versus “Costant Flow” Technique

Ranieri VM et al. AJRCCM 1994
Pressure-Volume Curves and Compliance in Acute Lung Injury.

Evidence of Recruitment Above the Lower Inflexion Point

The de-recruitment at a single deep expiration was studied!
Volume loss and de-oxygenation

$\rho = 0.6$

$p = 0.02$

$\Delta PaO_2/FiO_2(15-5)$ (mmHg)

$V_{DER(15-5)}$ (mL)
Insufflation

Normal breaths

Paw

PEEP 15

PEEP 11.25

PEEP 7.5

Flow

De Robertis E. EJA, 2003
De Robertis ICM 2001
COMPLIANCE

\[ C = \frac{\Delta V}{\Delta P_{el}} \]

What does it signify?

\[ \Delta V = \Delta V_{\text{distension}} + \Delta V_{\text{recruitment}} \]

Distension of open units \(-\Delta V_{\text{distension}}\)

Recruitment of closed units \(-\Delta V_{\text{recruitment}}\)

\[ C = \frac{\Delta V_{\text{distension}} + \Delta V_{\text{recruitment}}}{\Delta P_{el}} \]

Maximum compliance may indicate maximum shear!

Fraser, Weber & Franz, Respir Physiol 65, 277, 1985
Jonson & Svantesson, Thorax 54, 82, 1999
Oleic Acid Injury in Dogs

Pelosi ....Gattinoni, Marini  AJRCCM 164, 122-130. 2001
Opening and closing pressures

5 patients, ALI / ARDS

In ARDS:

A respiratory pattern should open up closed units and maintain aeration and stability throughout the respiratory cycle.

Jonson B, 1982

Positive Airway Pressure: Some physical and biological effects.

in Applied Physiology in Clinical Respiratory Care

Martinus Nijhoff Publishers.

Open up the lung, and keep it open!! Lachman

The Open Lung Concept
Characteristical Points on a PV curve and their suggested meaning

Traditional interpretation: not much interest as difficult to obtain

More recent interpretation: increased interest in expiratory limb as PEEP is expiratory, probably indicates required PEEP to maintain recruitment influenced by volume history

Traditional interpretation: lung fully recruited at this point, set PEEP above this point

More recent interpretation: start of recruitment of alveoli with similar opening pressures, influenced by chestwall