Driving Pressure: Value and Limitations

John J. Marini
University of Minnesota
Minneapolis / St. Paul (USA)
Driving Pressure Correlates Well With *Mortality* Risk

Amato et al. *NEJM* 2015
Re-Focusing on Airway Driving Pressure

*Enthusiasm With a Note of Caution*

- Definition of Driving Pressure
- Why should we pay attention?
- Why should we be cautious?
Driving Pressure Definitions

- $P_{PLAT} - PEEP$
- Ratio of tidal volume to compliance ($V_T/C$)
  
  $V_T$ *normalized* to capacity of ‘baby lung’
Driving Pressure Definitions

- $P_{PLAT} - PEEP$
  
  $$P_{PLAT} = (PEEP + Auto-PEEP)$$

- Ratio of tidal volume to compliance ($V_T/C$)

  *Respiratory system* compliance

  *Lung compliance*

  *Regional* DP’s vary

Tidal Volume
Plateau Pressure
Compliance
PEEP
Driving Pressure is a *Static* Parameter in a *Dynamic* Environment

DP Assumes *Passive* Conditions
How Should We Regard Driving Pressure?

Indicator of Severity

Driver of Injury

Cause

Effect
Why Should We Pay Attention?

• Parameter for Disease Progression or Resolution *in the individual patient*

• *Indicator for ‘Best PEEP’*

• Key Component of VILI Causation?

• Target for Adjusting Ventilator Settings?
Driving Pressure May Help Select **Best PEEP**

Tidal mechanics have disappeared from the ARDS criteria...

Constant VT

Suter NEJM 1975
Why Should We Pay Attention?

• Parameter for Disease Progression or Resolution in the individual patient
• Indicator for ‘Best PEEP’
• Key Component of VILI Causation?

• Target for Adjusting Ventilator Settings?
How Could Driving Pressure Mediate Airspace Injury?
Mechanical Stressors

Alveolar Pressure
Assumes Passive Inflation & Normal Chest Wall
Is a Given Driving Pressure Safe or Dangerous?

It could depend on the plateau & recruitability

There are ‘high risk’ junctions at every volume

From Pelosi et al
AJRCCM 2001
Junctional Lung Units and Risk of VILI
Is a Given Driving Pressure Safe (or Not) at Every PEEP?
Why Should We Pay Attention?

- Parameter for Disease Progression or Resolution *in the Individual Patient*
- Indicator for ‘Best PEEP’
- Insights to VILI Causation

- *Target for Adjusting Ventilator Settings?*
Why Should We Be Cautious?

- Better predictor than $V_T$ or $P_{Plateau}$ alone
- May overestimate risk to the lung
- May underestimate risk
  - during effort
  - Zero flow versus plateau
- Is not the only contributor to VILI
  - Cycling frequency
  - Flow amplitude and profile
  - Mechanical heterogeneity
Trans-Pulmonary Driving Pressure

Transpulmonary driving pressure (DPaw) can be calculated as:

$$DP_{aw} = \frac{V_T}{C_{RS}} = P_{plat} - PEEP = P_{plat} - PEEP_{TOT}$$

Components of transpulmonary driving pressure (P_{TP}) are:

- **Inspiration (in)**:
  $$P_{TP}^{\text{Insp}} = P_{plat} - PES_{INSPIRE}$$

- **Expiration (exp)**:
  $$P_{TP}^{\text{Exp}} = PEEP_{TOT} - PES_{EXPIRATION}$$

$$DP_{TP} = \frac{V_T}{C_L} = \text{Insp} P_{TP}^{\text{Insp}} - \text{Exp} P_{TP}^{\text{Exp}}$$

Diagram:
- **PEEP**
  - PEEP_{TOT}:
    - Resting Lung Volume
    - FRC
  - PES_{EXP}:
    - End Inspiratory Lung Volume
    - FRC + V_T

**PEEP** and **PES** are critical components in understanding lung mechanics and their effects on breathing.
The Chest Wall May Distort Airway Pressure Readings
The assessment of transpulmonary pressure in mechanically ventilated ARDS patients

ARDS Chest Wall is Often NOT Normal

Fig. 5 Distribution (histogram) of directly measured esophageal pressure at 5 cmH₂O of PEEP
Global Airway Driving Pressure Increases During Proning But VILI Declines
Abdominal Hypertension Increases Calculated Driving Pressure

Cortes GA, Marini JJ; 2013
Ratios of Transpulmonary and Airway Driving Pressures At Two Levels of Abdominal Pressure

Correspondence Between $\text{DP}_{\text{TP}}$ and $\text{DP}_{\text{AW}}$

Cortes-Puentes et al, *Crit Care Med* 2015
Vertical Gradient of Driving Pressures

- $r = 0.95$
- $p < 0.0001$
- slope = -0.13
- $y$-intercept = 11.1

Am J Respir Crit Care Med Vol 164. pp 122–130, 2001
Why Should We Be Cautious?

• Better predictor than $V_T$ or $P_{Plateau}$ alone
• May overestimate risk to the lung
• May underestimate risk
  – Zero flow pressure versus plateau pressure
  – During effort
• Is not the only contributor to VILI
  – Cycling frequency
  – Flow amplitude and profile
  – Mechanical heterogeneity
Zero Flow Point > Pplat

Driving Pressure

Airway Pressure

cm H₂O

Time (s)
The Application of Esophageal Pressure Measurement in Patients with Respiratory Failure

Evangelia Akourianaki, Salvatore M. Maggiore, Franco Valenza, Giacomo Bellani, Amal Jubran, Stephen H. Loring, Paolo Pelosi, Daniel Talmor, Salvatore Grasso, Davide Chiumello, Claude Guérin, Nicolo Patroniti, V. Marco Ranieri, Luciano Gattinoni, Stefano Nava, Pietro-Paolo Terragni, Antonio Pesenti, Martin Tobin, Jordi Mancebo, and Laurent Brochard

American Journal of Respiratory and Critical Care Medicine Volume 189 Number 5 | March 1 2014
Vigorous Breathing Violates Objectives of Lung Protection

Consider BOTH phases of the cycle!
High Driving Pressures Occur Normally Occur During Vigorous Exercise

PTP correlates with minute ventilation

Normal Subjects on Treadmill

42 +/- 16 cmH2O

(CHEST 1997; 112:829-32)
Expiratory Muscle Activity May Contribute to VILI

Abdominal Muscle Activity Increases Lung Injury

Control    Abd Effort    Paralysis
Why Should We Be Cautious?

• Better predictor than $V_T$ or $P_{Plateau}$ alone
• May overestimate risk to the lung
• May underestimate risk
  — During effort
  — Zero flow versus plateau
• *Is not the only contributor* to VILI
  — Cycling frequency
  — Flow amplitude and profile
  — Mechanical heterogeneity
Injurious *Driving Power*  
`Ergo-trauma`  

---

**Dynamic predictors of VILI risk: beyond the driving pressure**

John J. Marini, ¹,*  
Email: marin002@umn.edu  

Samir Jaber, ¹²  

¹ University of Minnesota, Minneapolis/Saint Paul, MN, USA  

This editorial refers to the article available at: doi:10.1007/s00134-016-4505-2  

---

*Int Care Med* September 2016
Machine Work During Inflation

PEEP Increases Machine Work, But Stores Until Potential Energy is Released In Exhalation.

Int Care Med September 2016
Non-Resistive Power At Two Driving Pressures
Injurious *Driving Power* ‘*Ergotrauma*’

- Power = Energy per cycle x Frequency
- *Relevant* component of power is the product of driving pressure and minute ventilation
  - \( P_{tot} = \text{Pres} + \text{DP} + \text{PEEP} \)
  - Product of \( \text{DP} \) and \( \text{VE} \) is dynamic parenchymal component of power--- The Driving *Power*
- Normalize for capacity of smaller ‘Baby Lung’
  - Stress Intensity = \( \frac{[\text{DP} \times \text{VE}]}{10 \ C} \)

*Int Care Med* September 2016
Unrecovered (Absorbed) Energy

Volume

Pressure

Int Care Med September 2016
Unrecovered Energy Load

- Surface forces
- Disruption and displacement of liquid bridges
- Rearrangement of connective tissues
- *Etc.*
Is VILI Caused By *Unrecovered Work* During The Inflation Cycle?

“Stress”
Don’t Forget the $V_E$ & the Vascular Side!

**Identical Driving Pressures but Different Damage**
Three Flow Options for Tidal Volume Delivery

Pressure-controlled Time-cycled
Flow-controlled Volume-cycled

Same Tidal Volume and I:E Ratio
Differing Inspiratory Flows & Injuries

**Identical Airway Driving Pressures**

Maeda *Anesthesiology* 2004
**How Fast** Strain and Driving Pressure Are Applied are Important Especially at High Stretch

![Graph showing strain rate vs strain with different markers for different conditions.](image)

Protti et al *Crit Care Med* 2016
Trajectory of DP May Be Important

Piglets ventilated with low or high lung strain rates were quite well matched for driving airway (21±4 vs. 24±6 cmH₂O; p=0.169) and transpulmonary (9±3 vs. 11±5 cmH₂O; p=0.214) pressures. Even so, incidence of pulmonary edema was as low as 20% among animals ventilated with low strain rates and as high as 73% among those ventilated with high strain rates. Therefore, driving airway or transpulmonary pressures did not predict lung outcome.

Protti et al *Crit Care Med* 2016 (in press)
Stress Focusing Amplifies Effect Of Global *Airway* Driving Pressure
Stress is amplified in high stiffness zones

Can Driving Pressure Predict VILI Risk?

• Better predictor than $V_T$ or $P_{Plateau}$ alone
• Not the only contributor to VILI
  – Amplified junctional forces
  – Tidal opening & closure
  – Frequency & minute ventilation
  – Inspiratory flow and flow profile
  – Vascular pressures & flows
• May overestimate risk
  – Stiff chest wall
  – Unmeasured auto-PEEP
• May underestimate risk
  – P1 vs. Plateau
  – Spontaneous breathing efforts

Dynamics of energy delivery
DP is a Conceptual Step Forward…

…But Maybe Not Quite *Everything* We Need!
Static and *Dynamic* Driving Pressures

**Passive Inflation**

**Auto-PEEP**

**Total**
Is VILI Caused By *Unrecovered Work* During The Inflation Cycle?

"Stress"
My Respectfully Cautious View Of Airway Driving Pressure

John J. Marini
University of Minnesota
Minneapolis / St. Paul (USA)
Extreme Strain is Dangerous but....

Driving Pressure Parallels Stress & Strain

Recruitability as well as Alveolar Strain Are Important Contributors to Mortality Risk

Caironi, Cressoni, Chiumello, et al.: Lung Opening and Closing in ARDS
Am J Respir Crit Care Med Vol 181. pp 578-586, 2010

ARDS N=68

- Alveolar strain
- Opening and closing lung tissue
- Mortality