Azienda Ospedaliera
SAN PAOLO
POLO UNIVERSITARIO

VII CONGRESSO DI **ECOCARDIOCHIRURGIA**

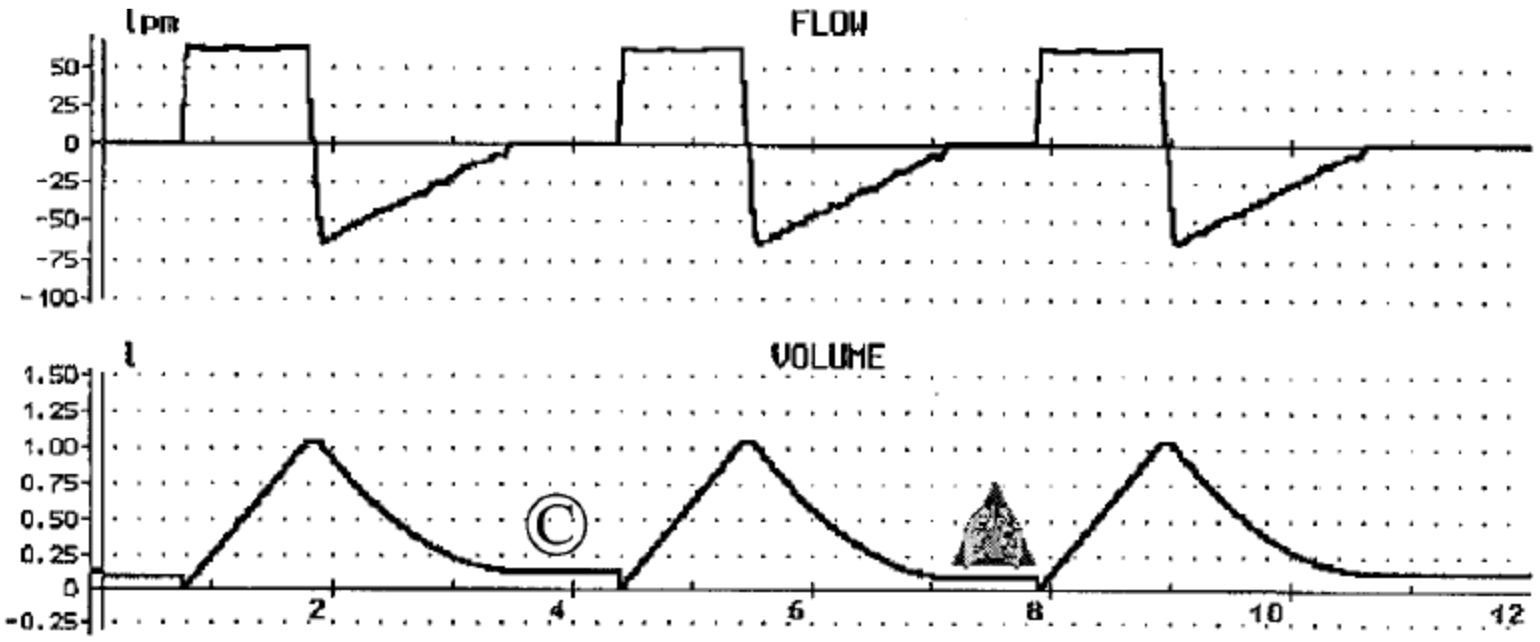
# *Le curve: come interpretarle*

**Fabiano Di Marco**

**Università degli Studi di Milano**
**Clinica di Malattie dell'Apparato Respiratorio**
**Ospedale San Paolo – Milano**
**E-mail: fabiano.dimarco@unimi.it**

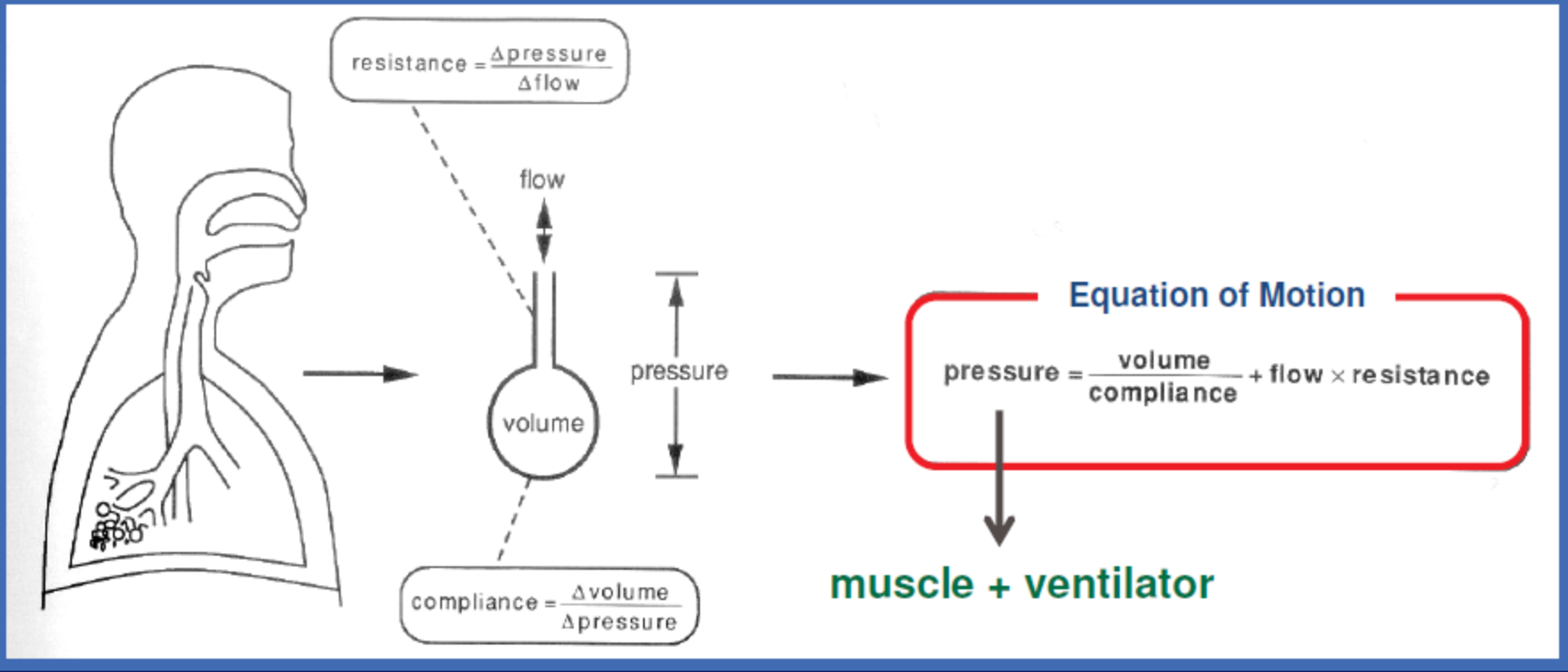
# E’ importate l’interpretazione delle curve?

# Basta una sola curva?



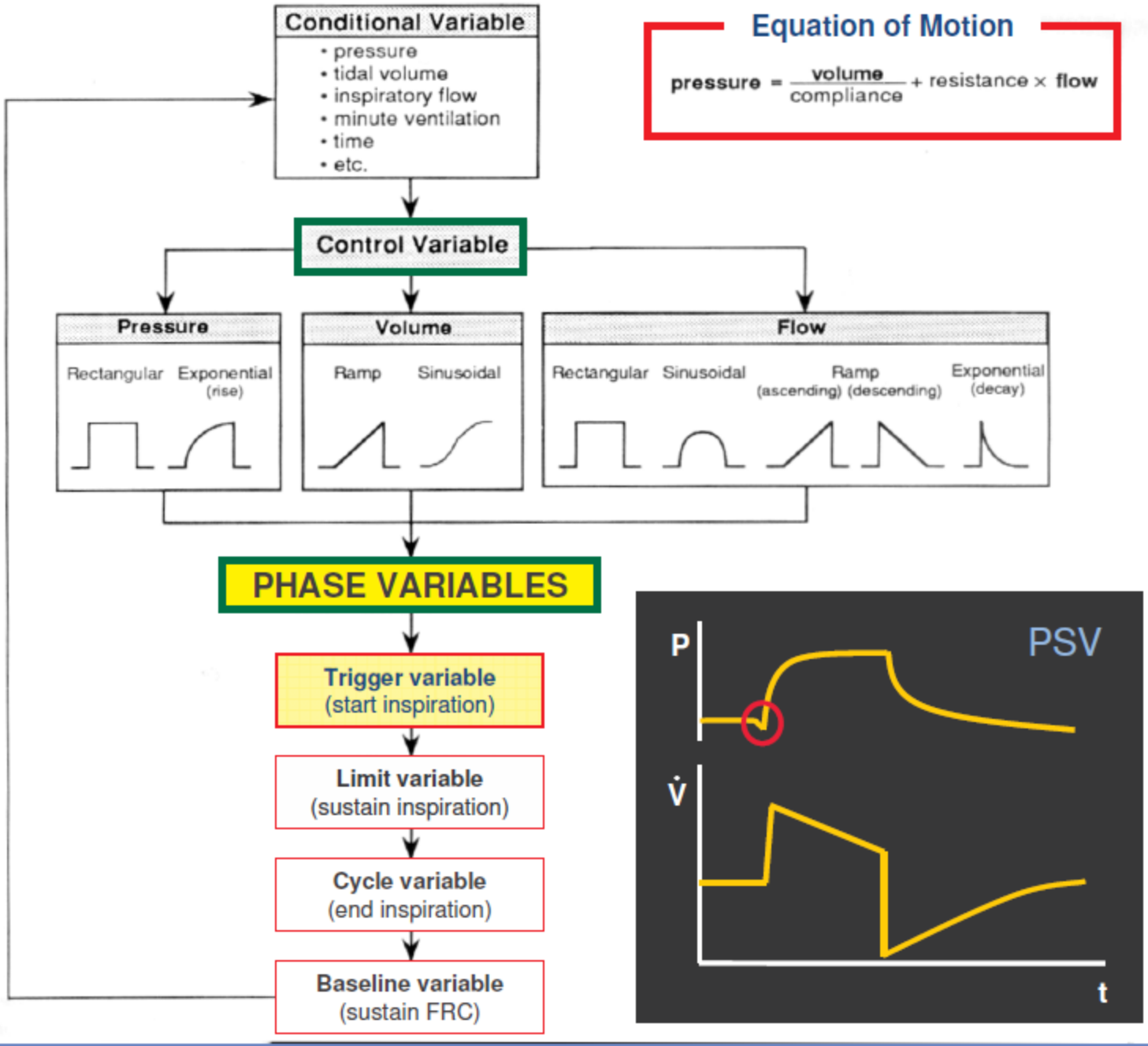

Nilsestuen et al. Resipr Care 2005; 50:202-232

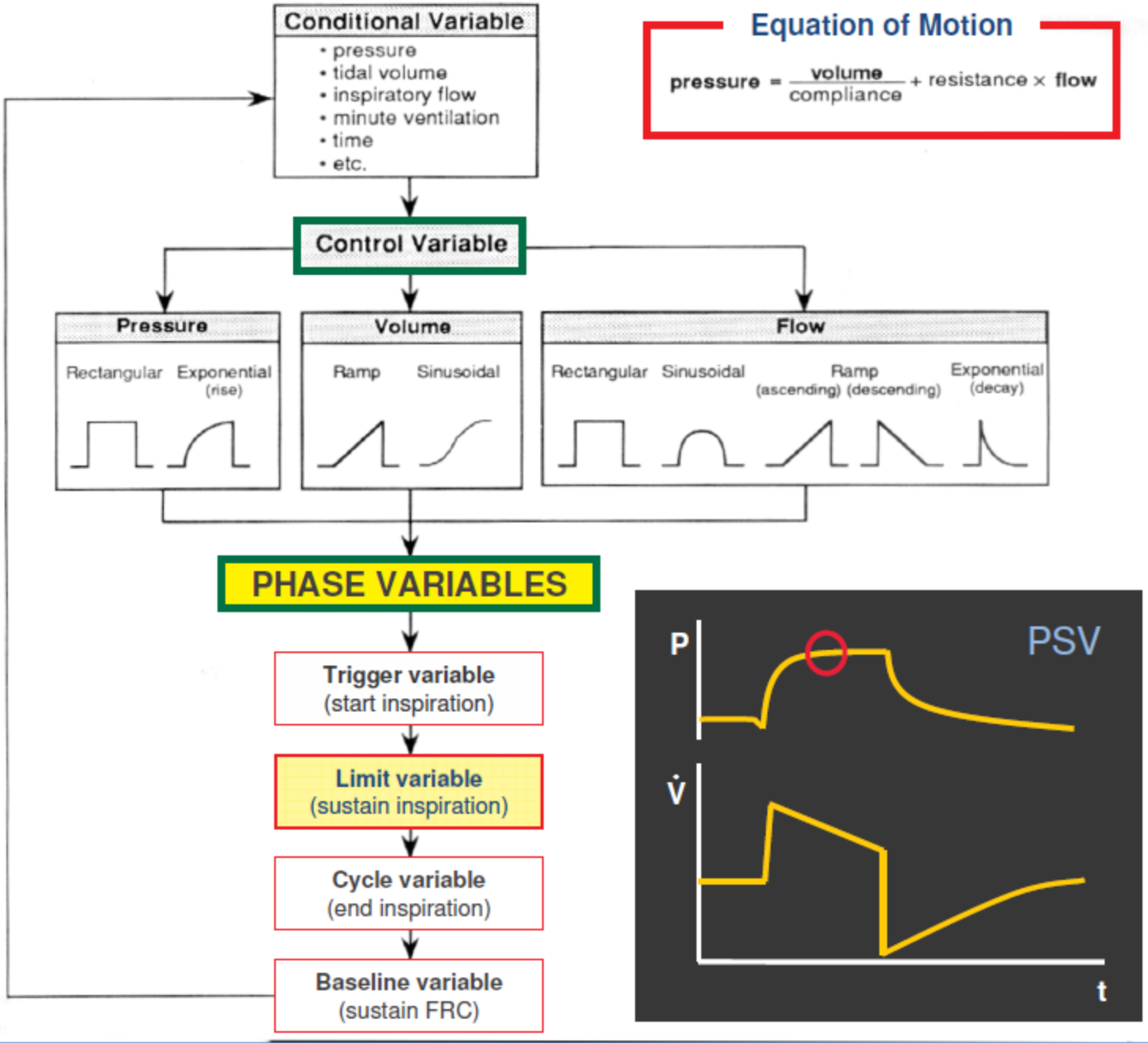
# RESPIRATORY SYSTEM MODEL

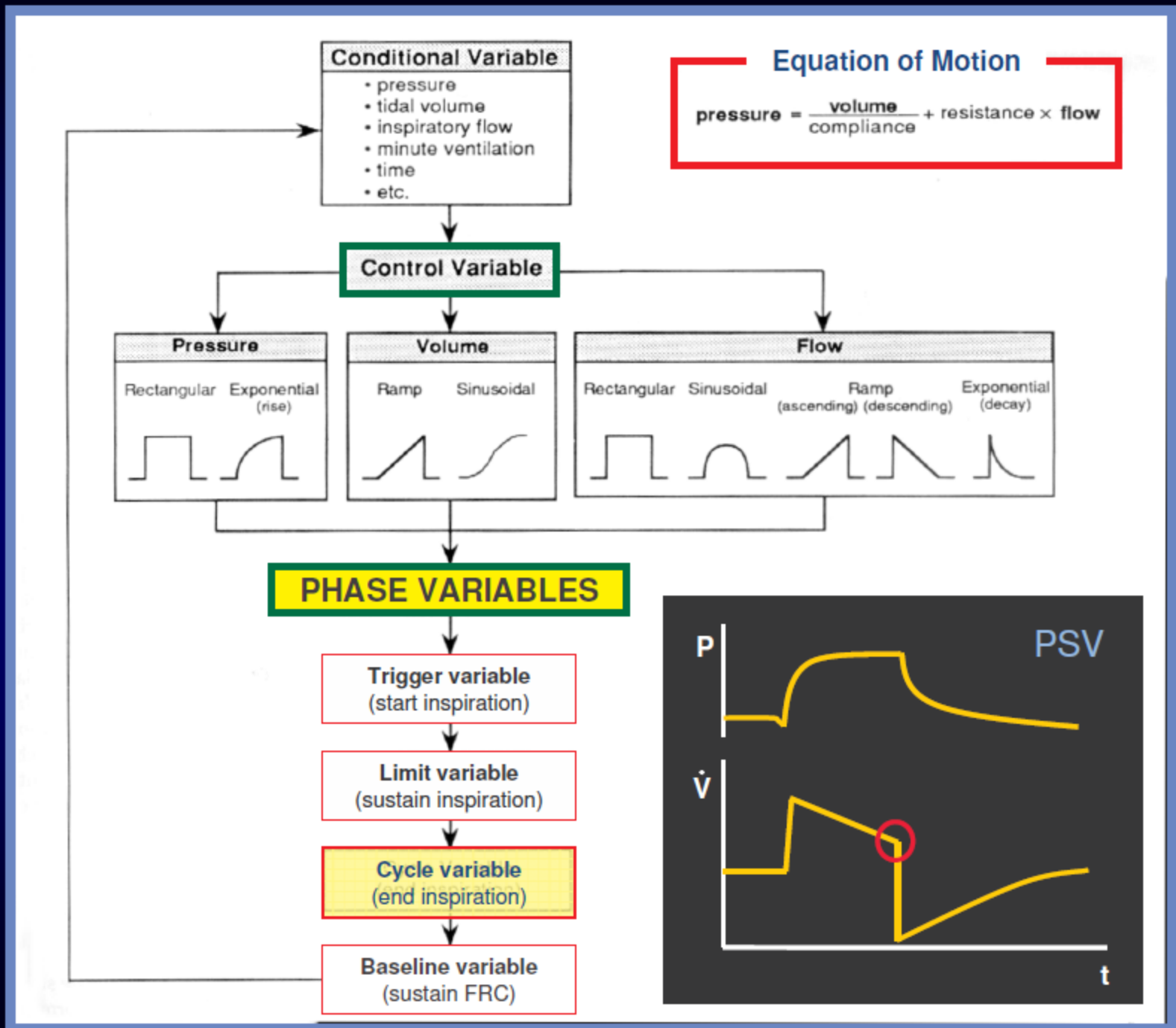


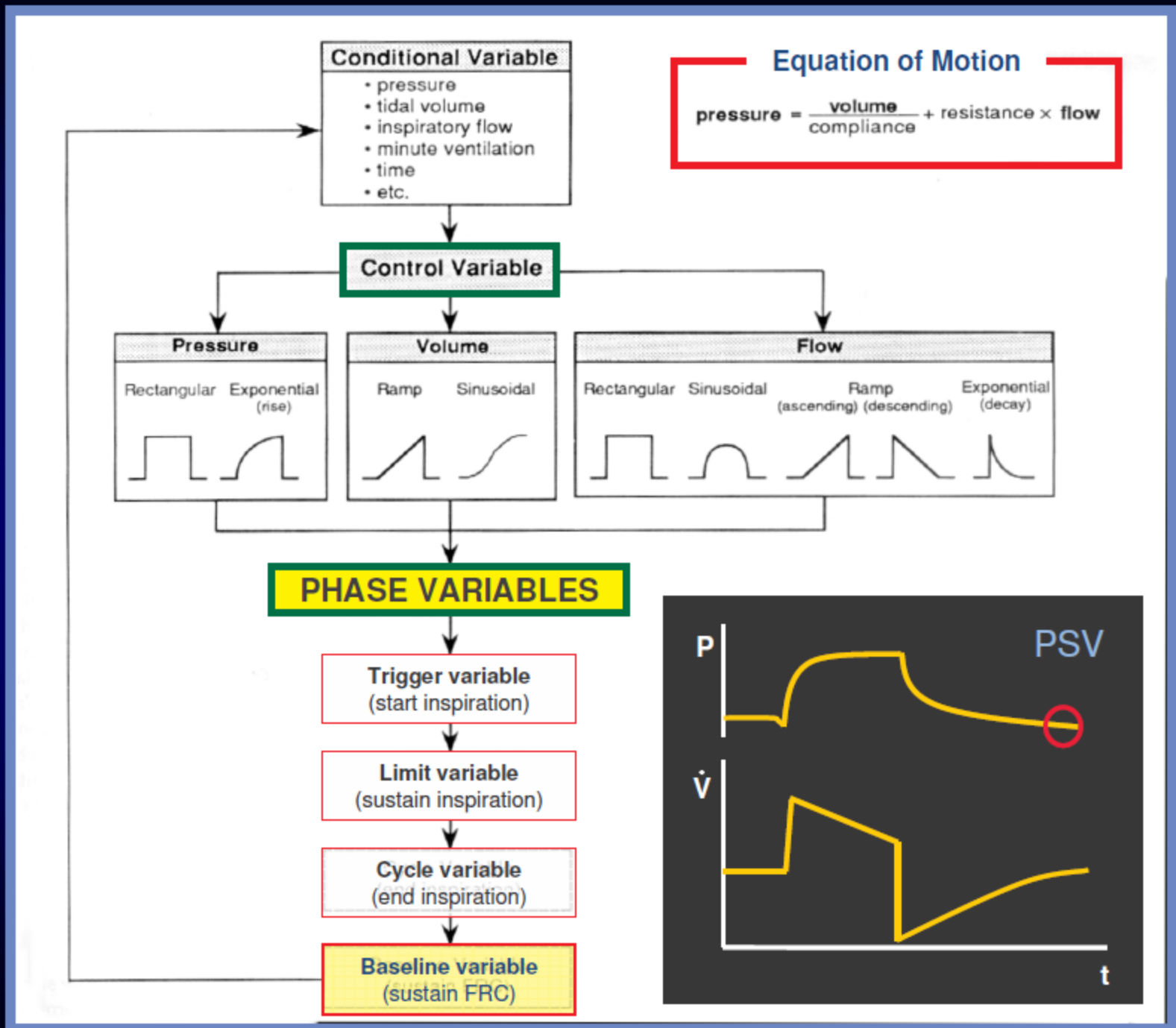

Pressure, Volume, Flow (and Time) = VARIABLES

Compliance and Resistance = CONSTANTS


Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
P
PSV
V̇
t


Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
P
PSV
V̇
t


Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
PSV
P
V̇
t


Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
P
PSV
V̇
t

# BREATH CLASSIFICATION

| Breath Type | | Trigger | Limit | Cycle |
|---|---|---|---|---|
| Mandatory | | Machine | Machine | Machine |
| Assisted | | Patient | Machine | Machine |
| Supported | **PSV** | Patient | Machine | Patient |
| Spontaneous | **CPAP** | Patient | Patient | Patient |

# PEEP-CPAP: Cardiogenic pulmonary oedema

Noninvasive Ventilation in Acute Cardiogenic Pulmonary Edema

Alasdair Gray, M.D., Steve Goodacre, Ph.D., David E. Newby, M.D., Moyra Masson, M.Sc., Fiona Sampson, M.Sc., and Jon Nicholl, M.Sc., for the 3CPO Trialists*

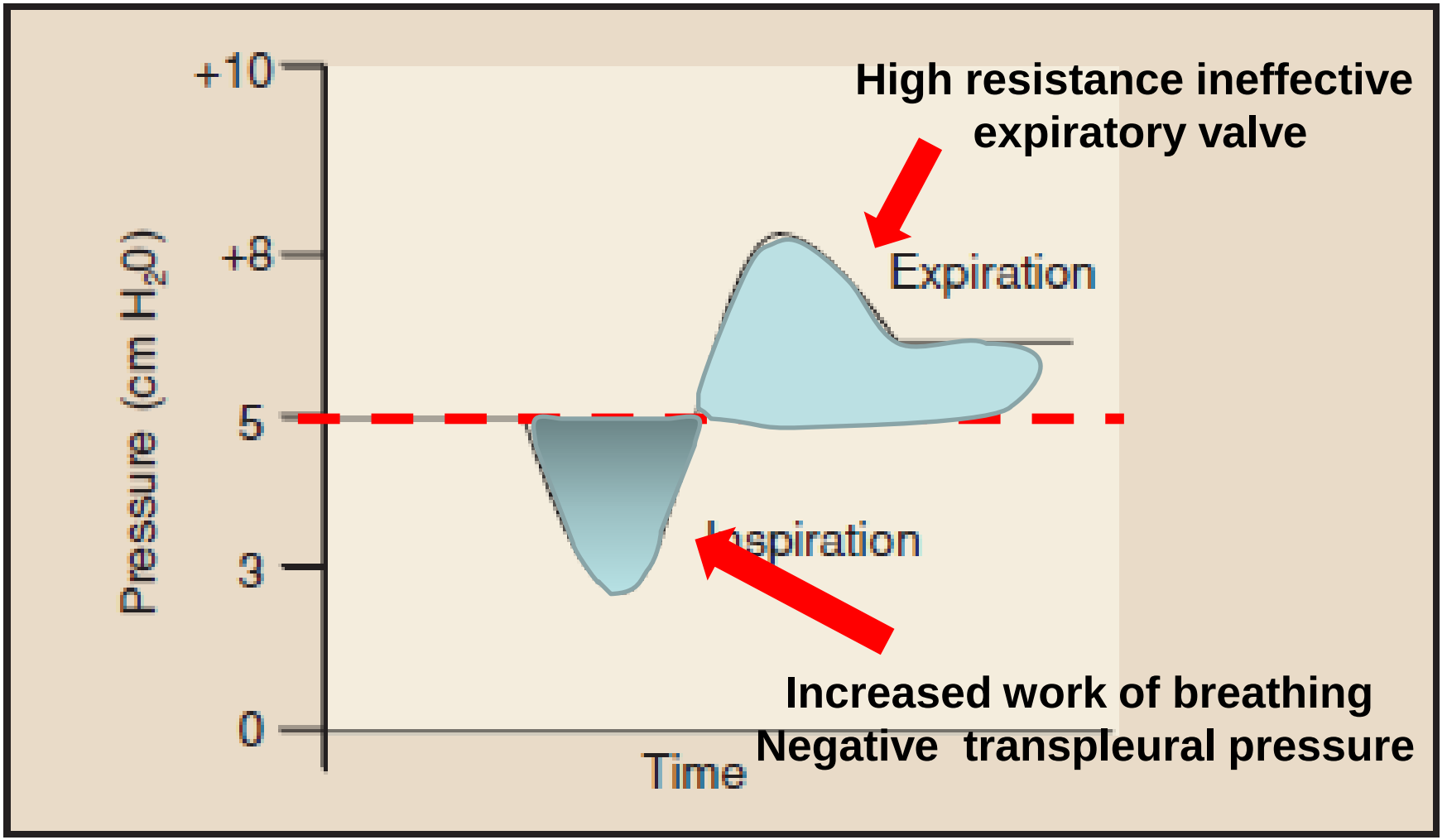
N Engl J Med 2008;359:142-51.

In a multicenter, open, prospective, randomized, controlled trial, patients were assigned to standard oxygen therapy, CPAP (5 to 15 cm of water), or NIPPV (inspiratory pressure, 8 to 20 cm of water; expiratory pressure, 4 to 10 cm of water). The primary end point

- Why is PEEP useful in CPO?
  - To reduce venous return
  - To reduce left ventricular transmural pressure

# PEEP-CPAP: diversi sistemi

# How to judge a CPAP system?



# How to judge a CPAP system?

Intensive Care Med. 1988;14(6):632-9.

**Total inspiratory work with modern demand valve devices compared to continuous flow CPAP.**

Samodelov LF, Falke KJ.

Department of Anesthesia, University of Düsseldorf, FRG.

## Comparison of Work of Breathing on High Gas Flow and Demand Valve Continuous Positive Airway Pressure Systems*

*R. T. Noel Gibney, M.D.; Roger S. Wilson, M.D.; and Henning Pontoppidan, M.D., F C.C.P.*

*Chest* 1982;82;692-695

Am Rev Respir Dis. 1988 Aug;138(2):300-4.

**Inspiratory work of breathing during spontaneous ventilation using demand valves and continuous flow systems.**

Beydon L, Chasse M, Harf A, Lemaire F.

Service de Réanimation Médicale, INSERM U296, Hôpital Henri Mondor, Université Paris-Val de Marne, Creteil, France.

# Effects of different continuous positive airway pressure devices and periodic hyperinflations on respiratory function

Paolo Pelosi, MD; Davide Chiumello, MD; Enrico Calvi, MD; Paolo Taccone, MD; Nicola Bottino, MD; Mauro Panigada, MD; Paolo Cadringher; Luciano Gattinoni, MD

**High flow CPAP** **Ventilator**

| | HM | HBM | LBM | LBW | S | PC-SIMV |
|---|---|---|---|---|---|---|
| WOB/min, J/min | | | | | | |
| Total | 13.9 ± 9.0 | 14.5 ± 8.5 | 12.7 ± 7.5 | 12.1 ± 6.0 | 10.7 ± 9.5 | 6.3 ± 5.7[b] |
| Spont | — | — | — | — | — | 5.6 ± 4.8 |
| Assist | — | — | — | — | — | 0.7 ± 1.0 |
| WOB/L, J/L | | | | | | |
| Total | 1.2 ± 0.5 | 1.2 ± 0.5 | 1.2 ± 0.5 | 1.1 ± 0.5 | 1.0 ± 0.5 | 0.6 ± 0.5[b] |
| Spont | — | — | — | — | — | 0.7 ± 0.5 |
| Assist | — | — | — | — | — | 0.3 ± 0.4 |
| P0.1, cm $H_2O$ | | | | | | |
| Spont | 3.5 ± 2.4 | 4.6 ± 2.8 | 3.5 ± 1.5 | 3.5 ± 1.7 | 3.2 ± 2.5 | 2.4 ± 1.9 |
| Dyspnea scale (cm) | | | | | | |
| Total | 2.7 ± 1.2 | 2.6 ± 1.1 | 2.1 ± 1.2 | 1.9 ± 1.2 | 1.6 ± 1.2 | 1.1 ± 0.8[b] |

HM, high flow + mechanical valve; HBM, high flow + balloon + mechanical valve; LBM, low flow + balloon + mechanical valve; LBW, low flow + balloon + water valve; S, CPAP Servo; PC-SIMV, CPAP Servo + pressure-controlled synchronous intermittent mandatory ventilation; WOB/min, inspiratory work of breathing per minute of ventilation; Total, spontaneous breaths + assisted breaths; Spont, spontaneous breaths; Assist, assisted breaths; WOB/L, inspiratory work of breathing per liter of ventilation; P0.1, occlusion pressure.

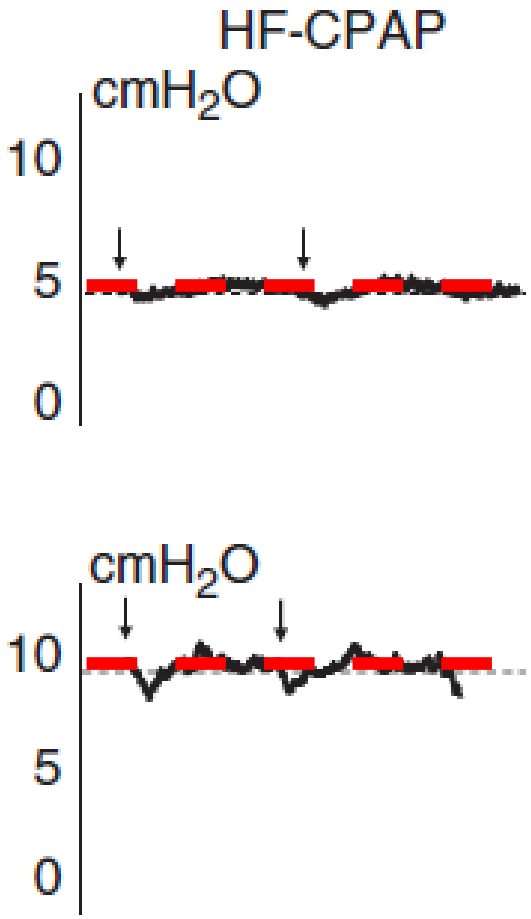
[a]Values are mean ± SD. [b]$p < .05$ vs. S.

**No difference in terms of WOB between HFCPAP and ventilator**

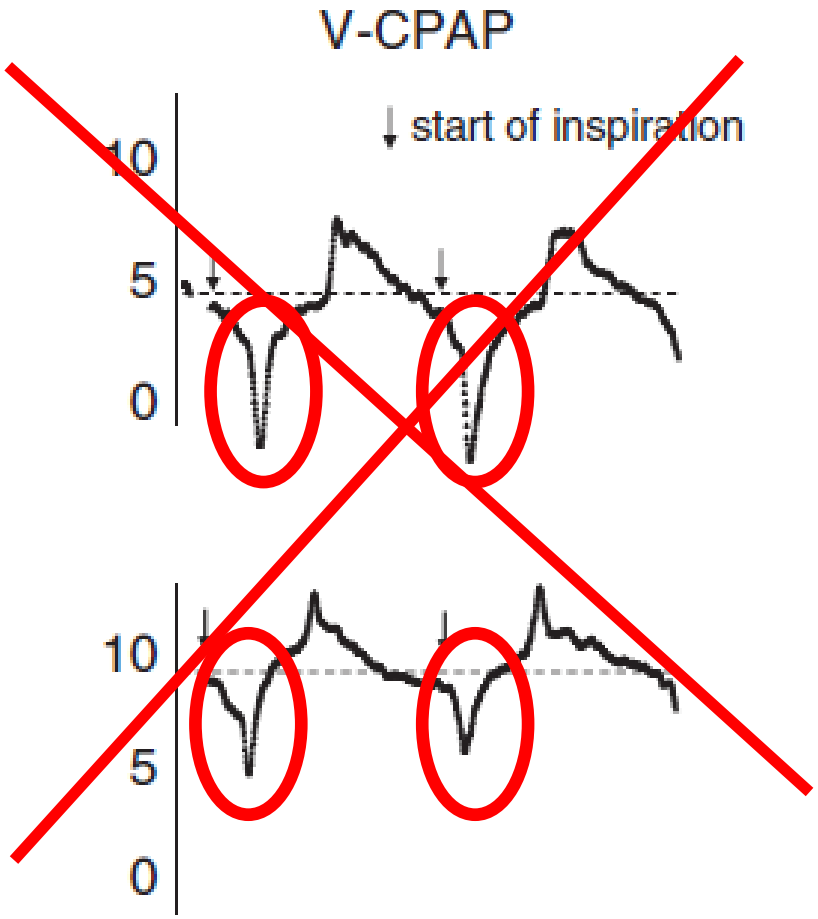
Crit Care Med 2001 Vol. 29, No. 9

# End-expiratory lung volume and ventilation distribution with different continuous positive airway pressure systems in volunteers

## High flow CPAP

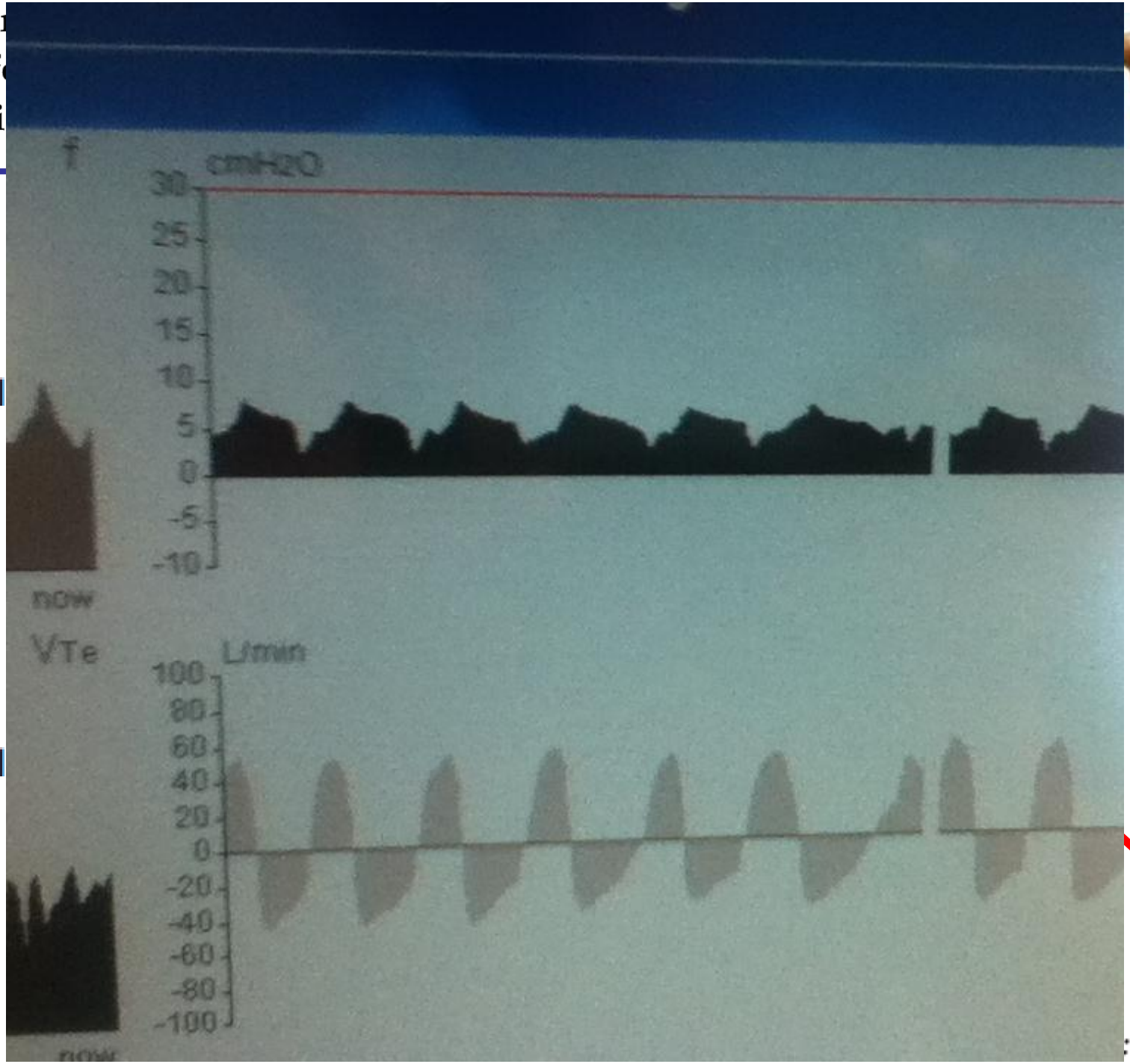



## Ventilator




*Acta Anaesthesiol Scand* 2010; **55**: *157–164*

**End-expi**
**with diff**
**systems i**




: 157–164

# *Take home message: CPAP*

- Continuous high-flow CPAP systems are generally efficient;

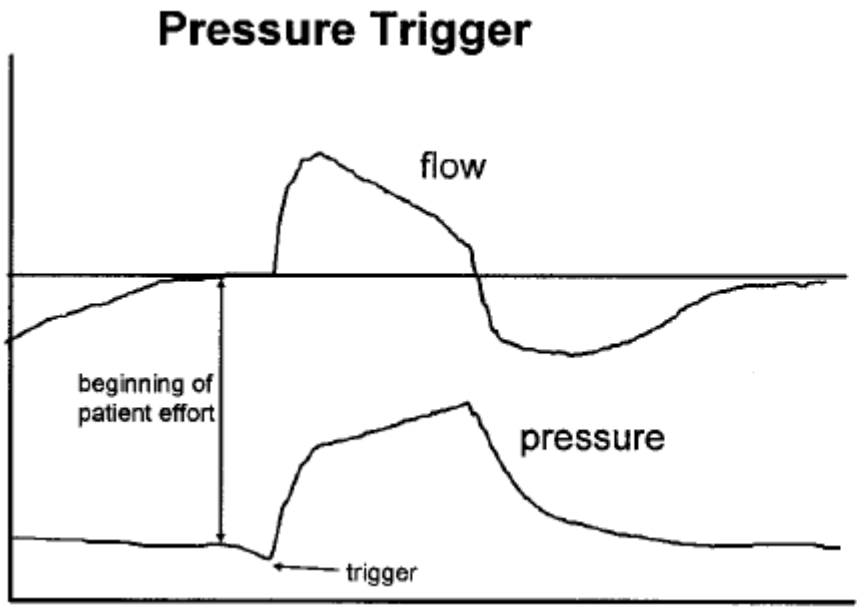
- It's worth evaluating the pressure waveform when using CPAP mode with a ventilator (set-up of a pressure support in case of inspiratory pressure drop to balance the increase work of breathing?).

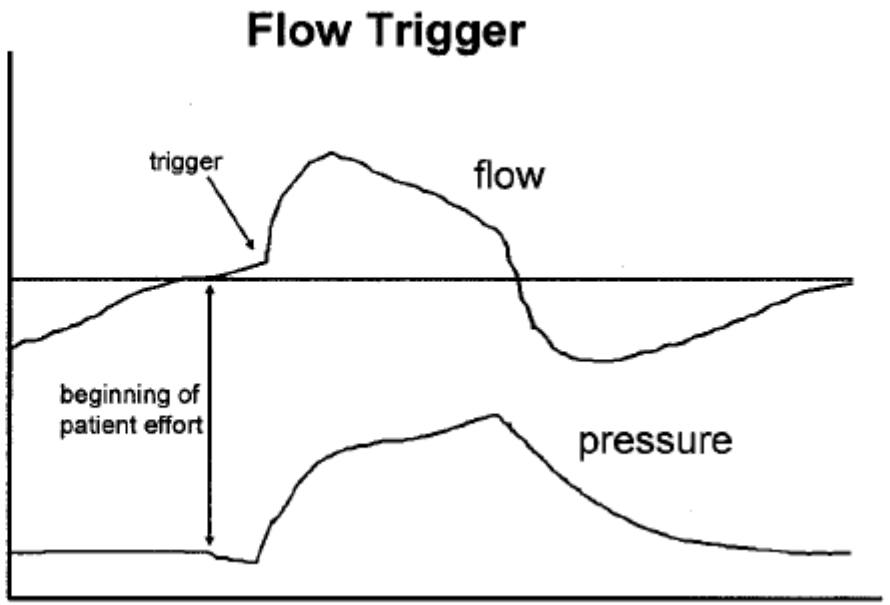
# Pressure Support (PSV)

Control Variable: Pressure

| Breath | TRIGGER | LIMIT | CYCLE |
|---|---|---|---|
| Supported | Pressure, Flow/Volume | Pressure | Flow |

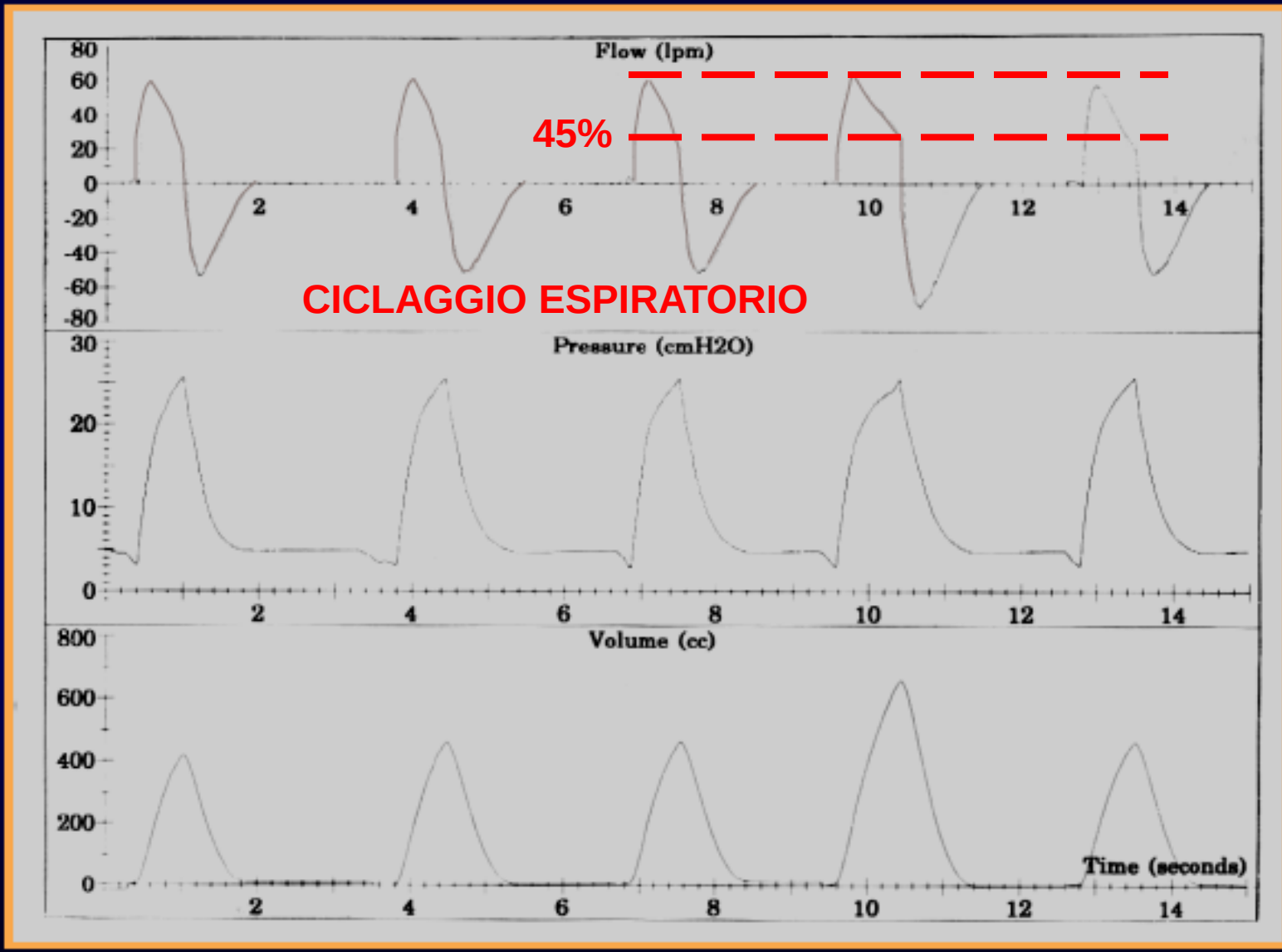
# Trigger inspiratori a flusso e pressione

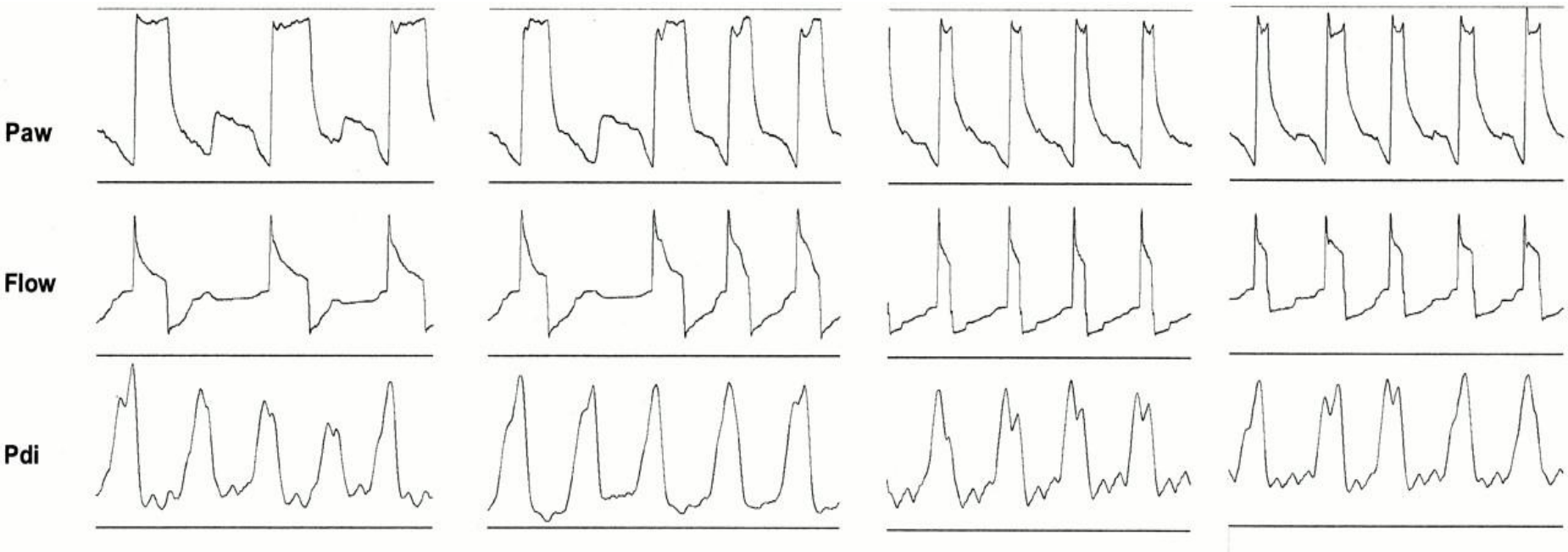



Hess DR. Respiratory Care 2005

# Pressure Support (PSV)






Cosa cambia rispettivamente nei 4 tracciati?

*Tassaux et al. Am J Respir Crit Care Med 2005;172:1283*

# Asynchrony between patient and ventilator

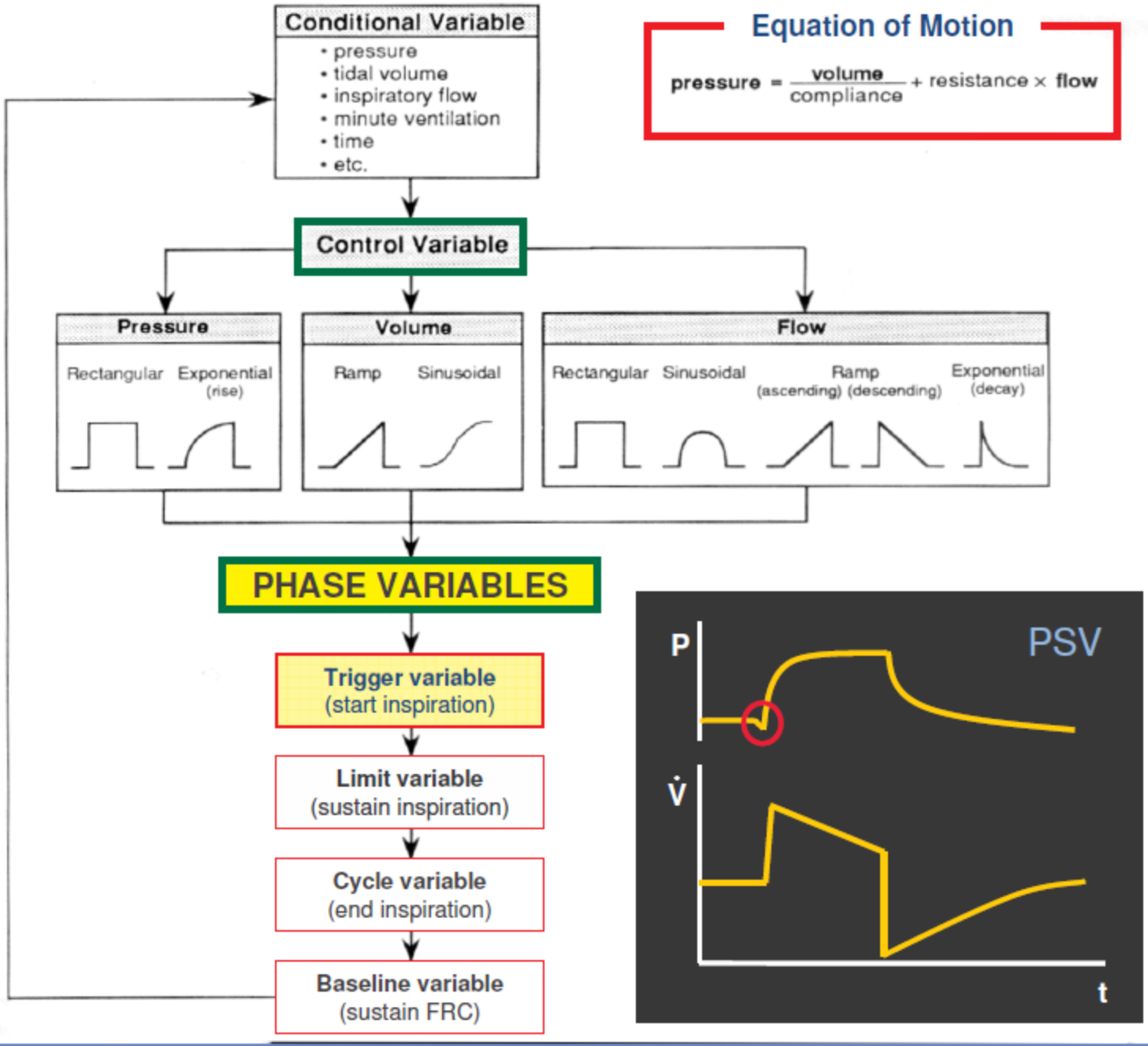
*Problems:*

- Increased work of breathing
- Need for sedation
- "Fighting the ventilator"
- Ventilation-Perfusion-Mismatch
- Dynamic hyperinflation
- Underestimation of RR

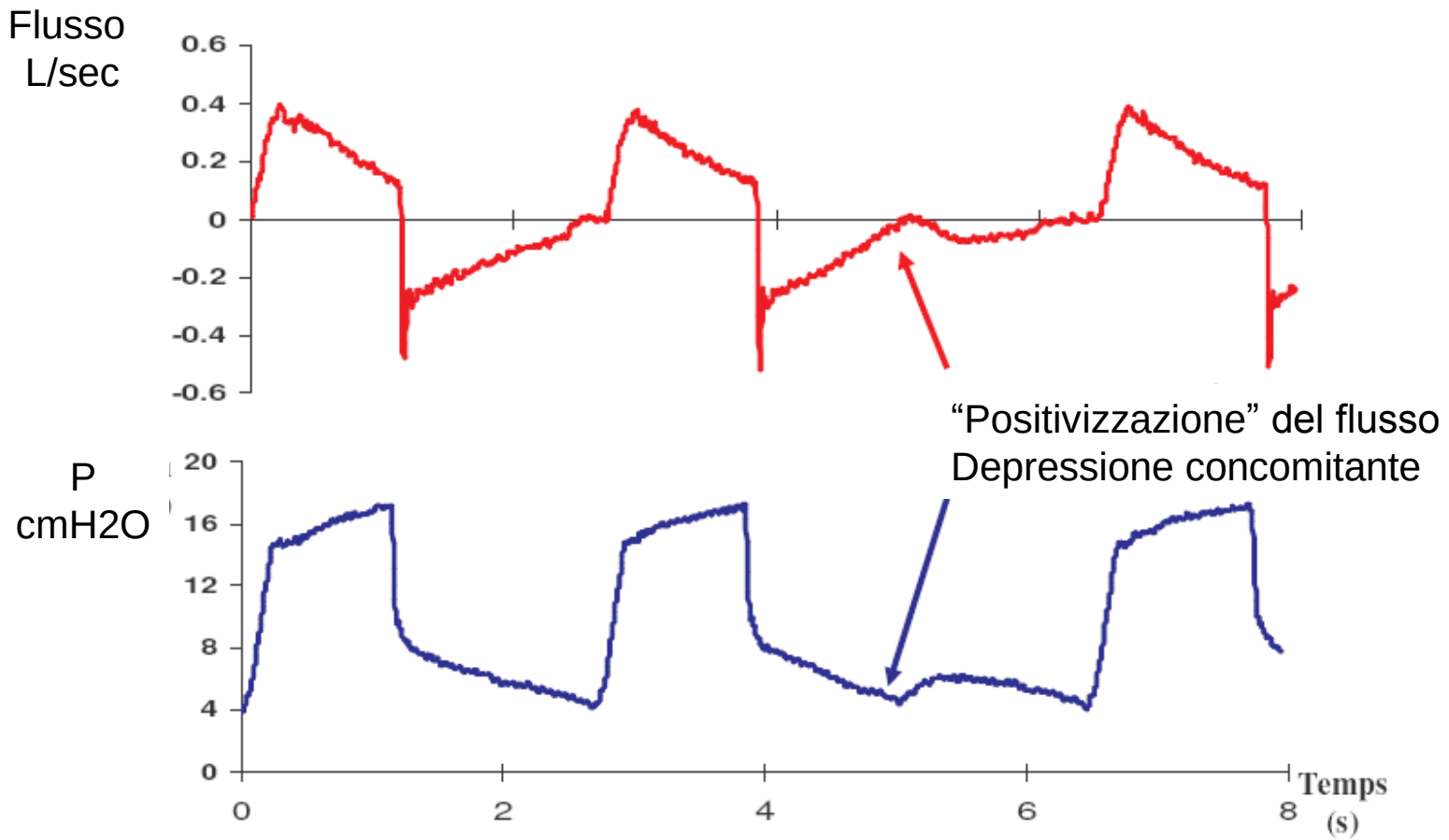
*Consequences:*

- Insufficient ventilation
- Withdrawal from NIV
- Weaning failure
- Prolonged ICU stay
- Costs

} Prognosis !

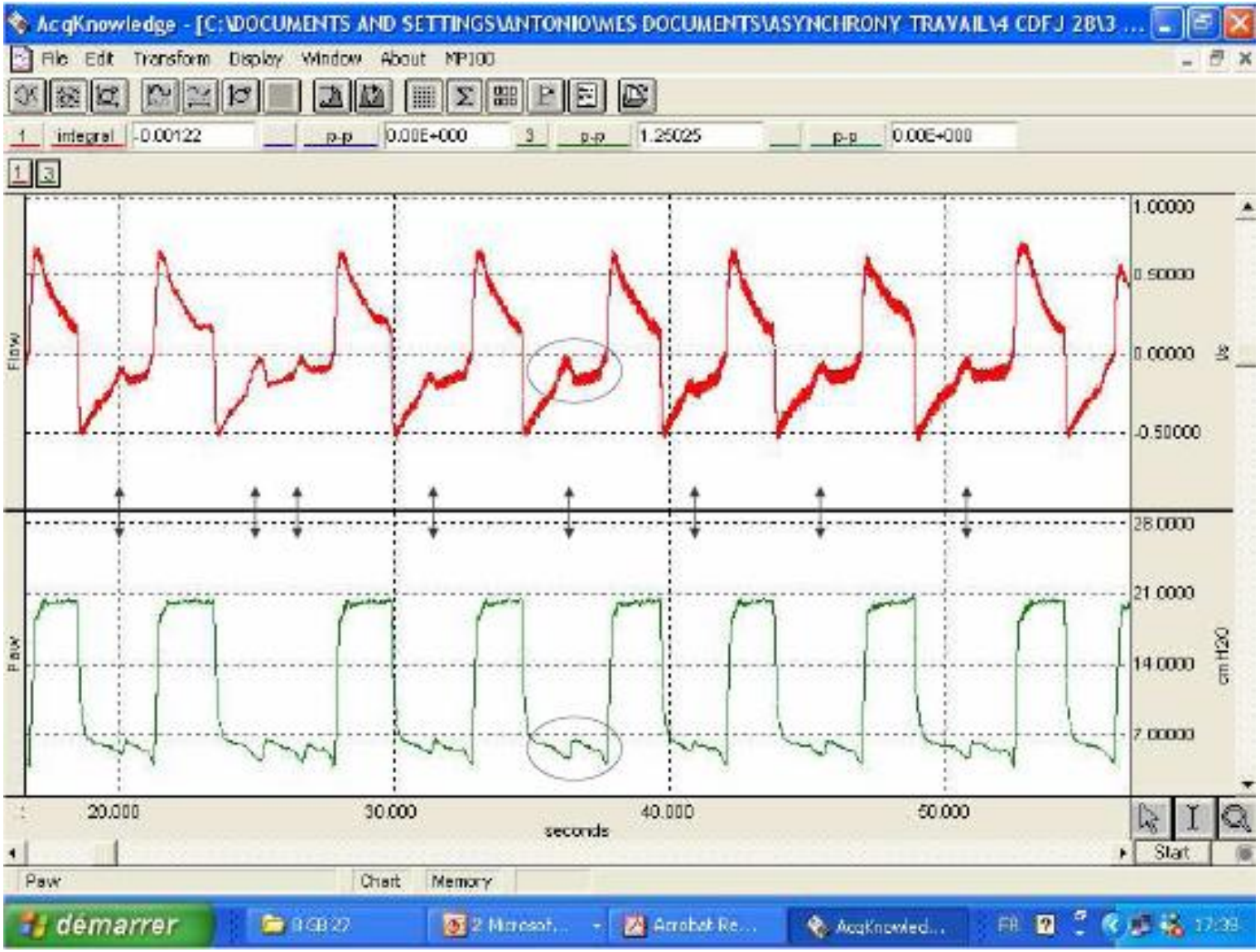

Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
P
PSV
V̇
t

# Sforzi inspiratori inefficaci



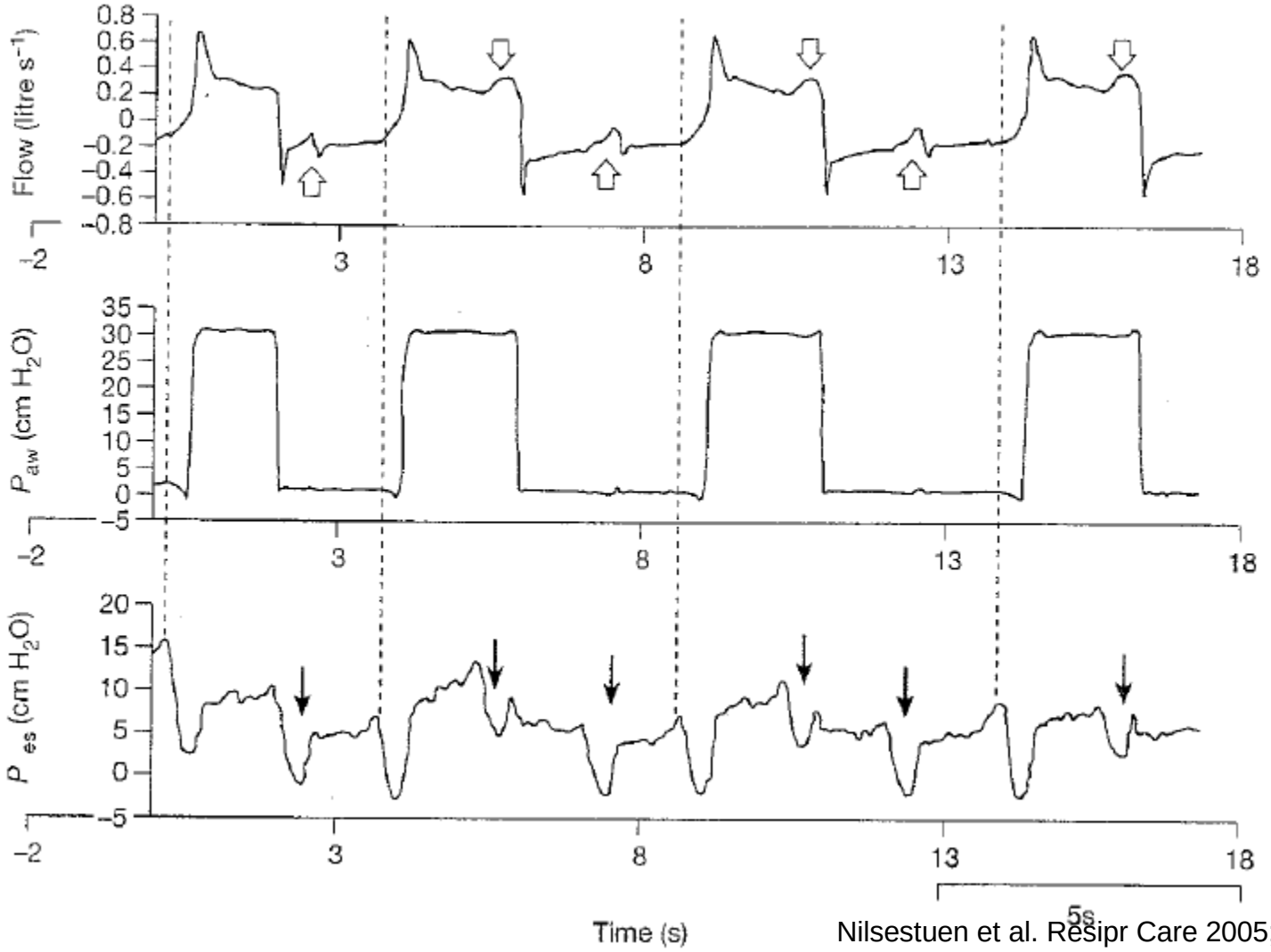

"Positivizzazione" del flusso
Depressione concomitante

# Sforzi inspiratori inefficaci



# Ineffective efforts

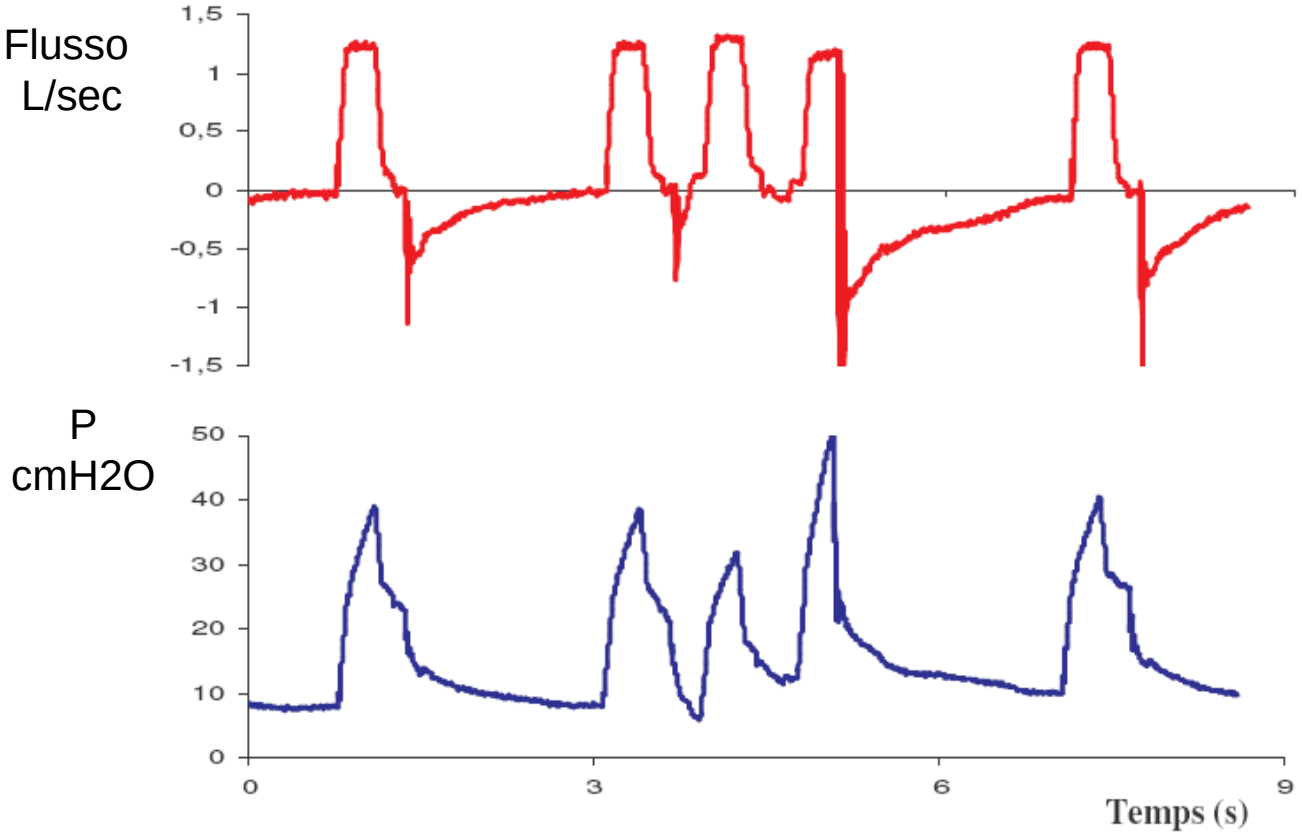
Respiratory rate underestimation (13 vs 33)



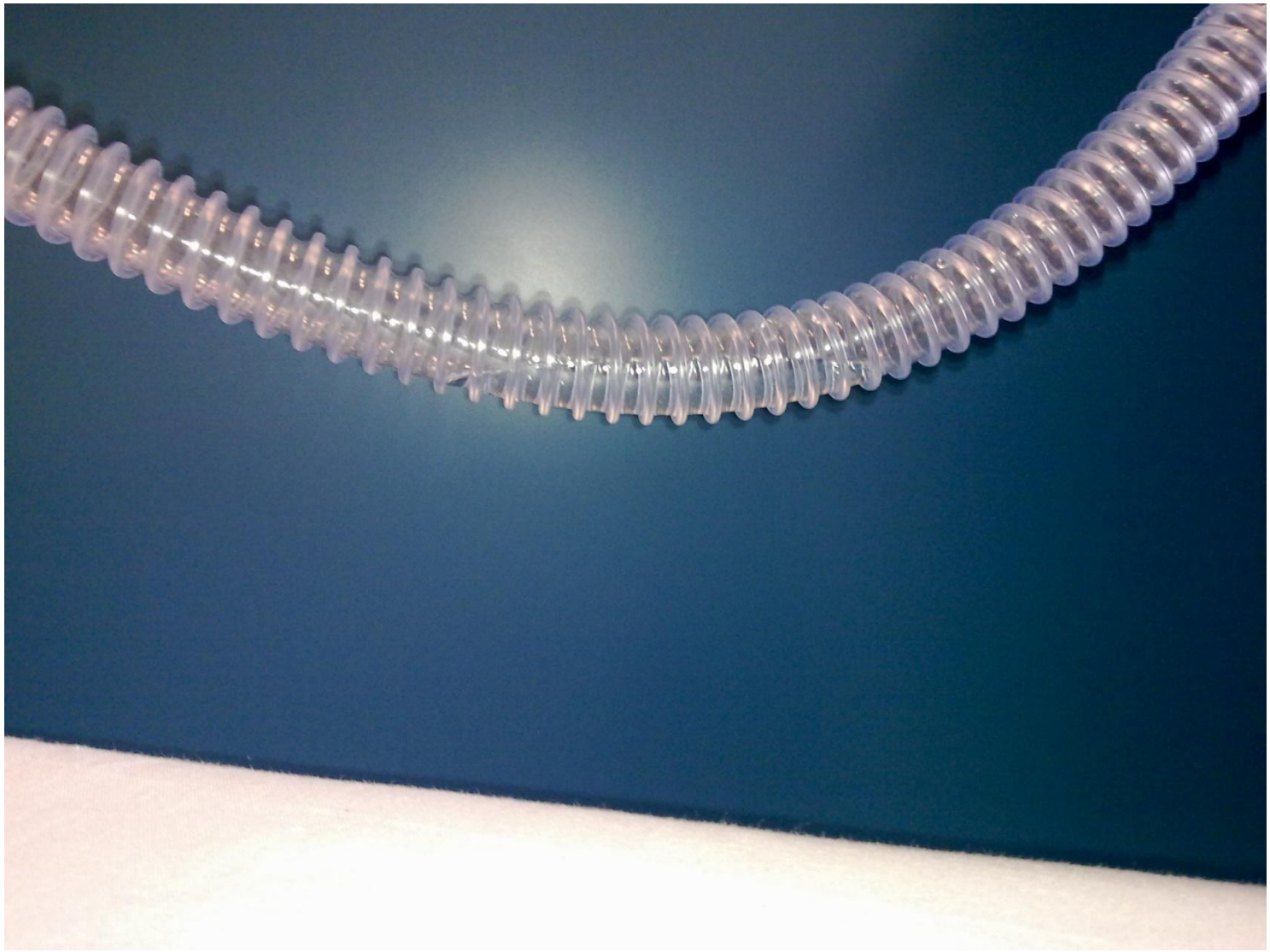

Nilsestuen et al. Resipr Care 2005; 50:202-232

# Autotrigger

Attivazione tripla del trigger inspiratorio

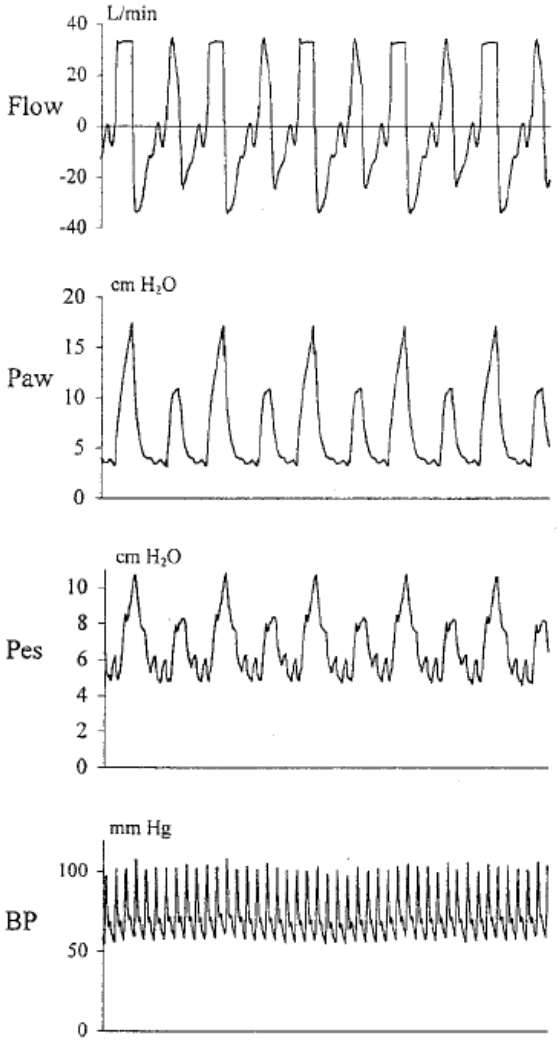


# Autotrigger: attenzione ai circuiti



# Autotrigger

1 L/min



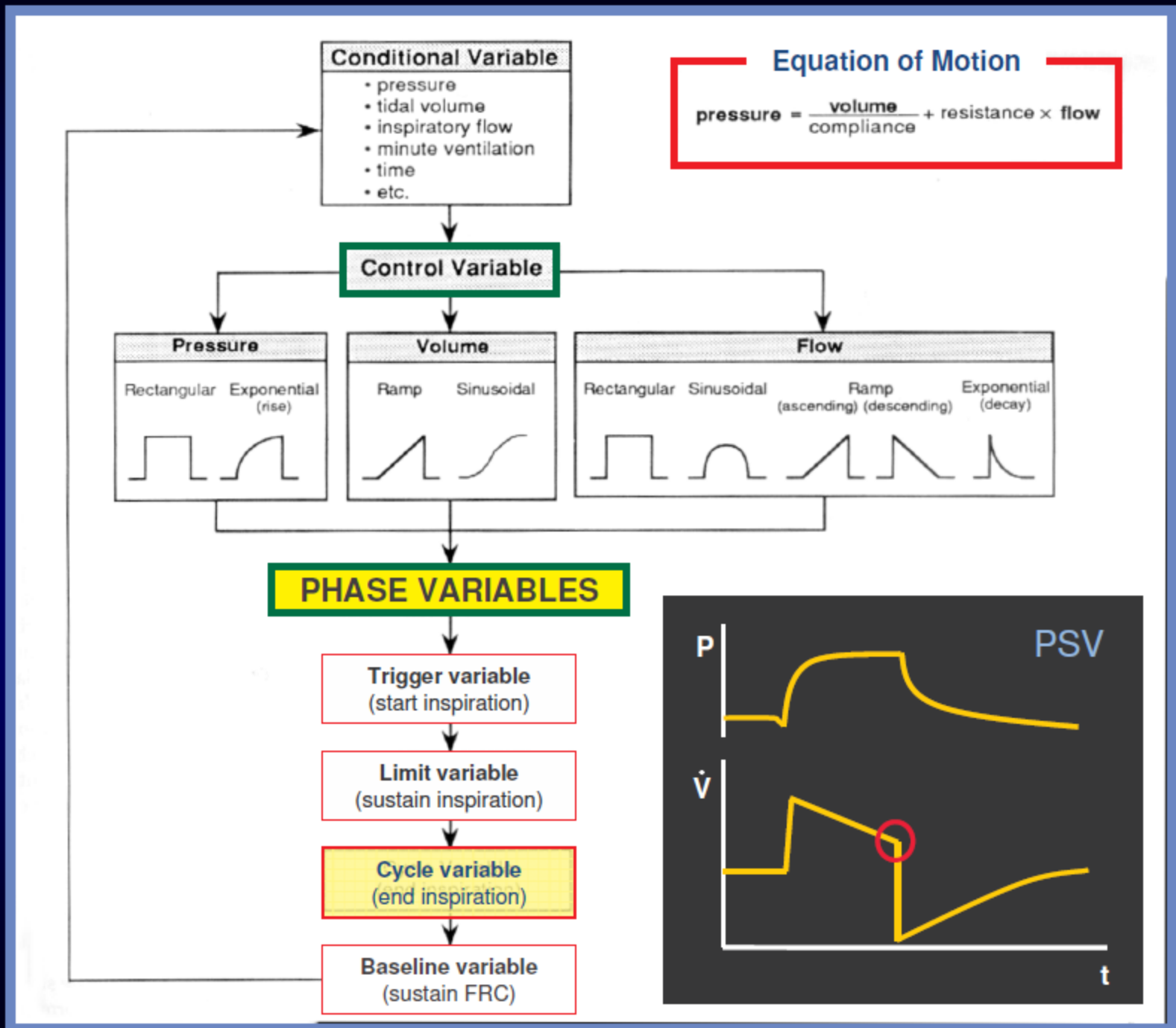

Nilsestuen et al. Resipr Care 2005; 50:202-232

# Regolazione del trigger inspiratorio

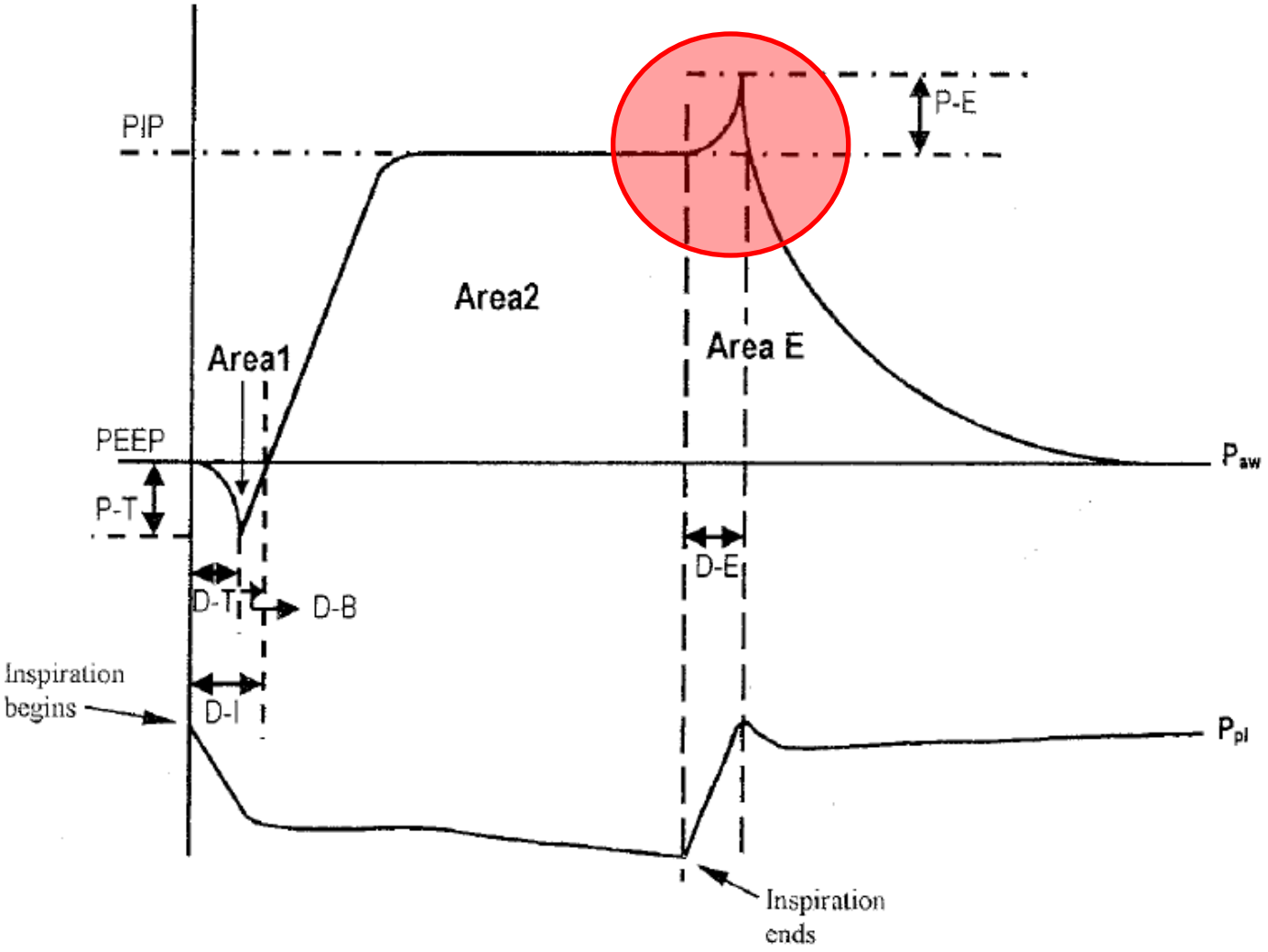
trigger asynchrony | insensitive trigger | **Sensitive trigger** | auto-triggering

- trigger sensitivity to low
- high level of PSV
- hypercapnic encephalopathy
- sedation
- sleep
- intrinsic PEEP (COPD)
- leakages (NIV)
- tubing obstruction

- trigger sensitivity to high
- resistance changes
- tubing leakage
- cardiac oscillation

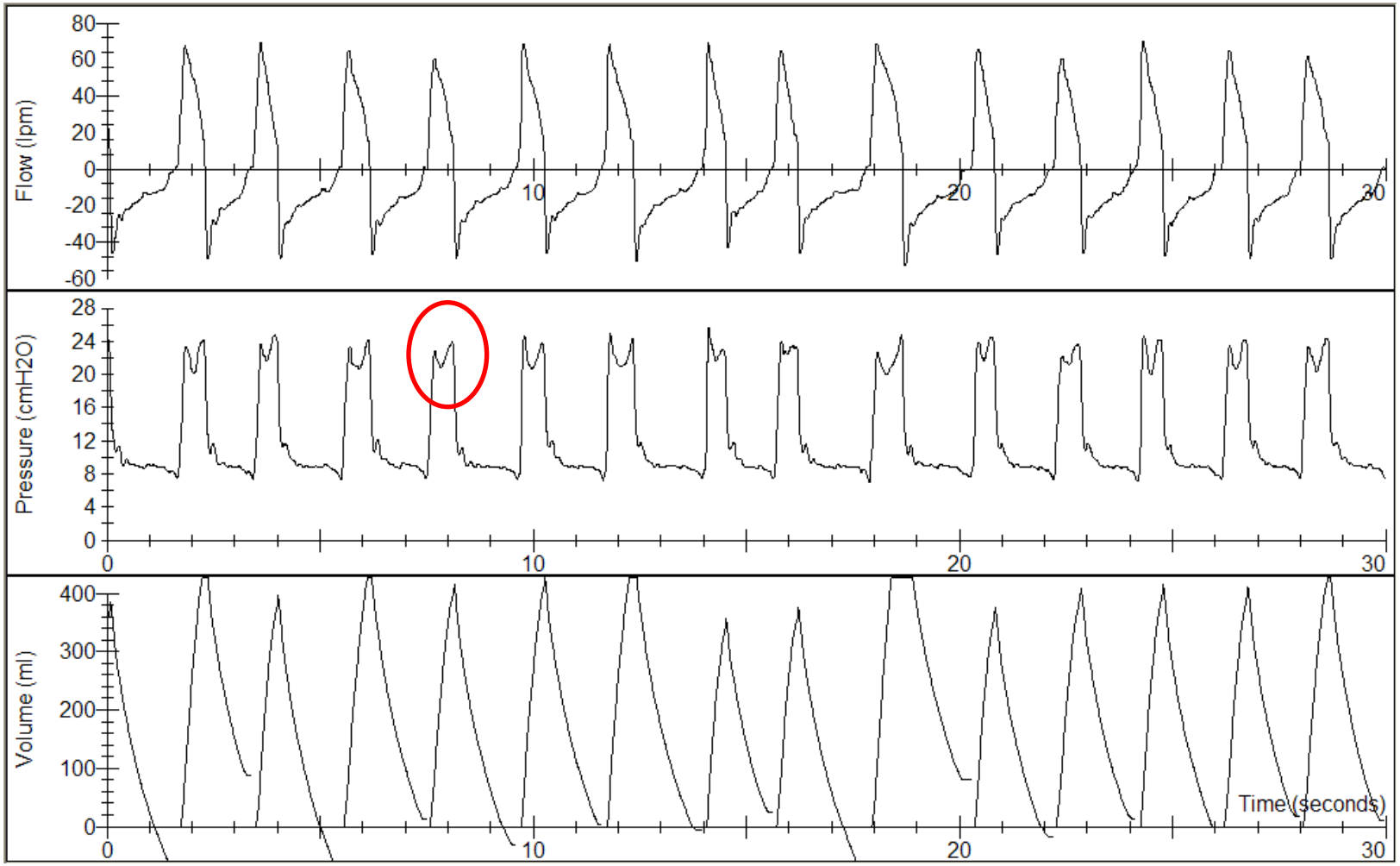

Conditional Variable
• pressure
• tidal volume
• inspiratory flow
• minute ventilation
• time
• etc.
Equation of Motion
pressure = volume / compliance + resistance × flow
Control Variable
Pressure
Rectangular
Exponential (rise)
Volume
Ramp
Sinusoidal
Flow
Rectangular
Sinusoidal
Ramp (ascending)
Ramp (descending)
Exponential (decay)
PHASE VARIABLES
Trigger variable (start inspiration)
Limit variable (sustain inspiration)
Cycle variable (end inspiration)
Baseline variable (sustain FRC)
PSV
P
V̇
t

# Expiratory trigger setting (?)

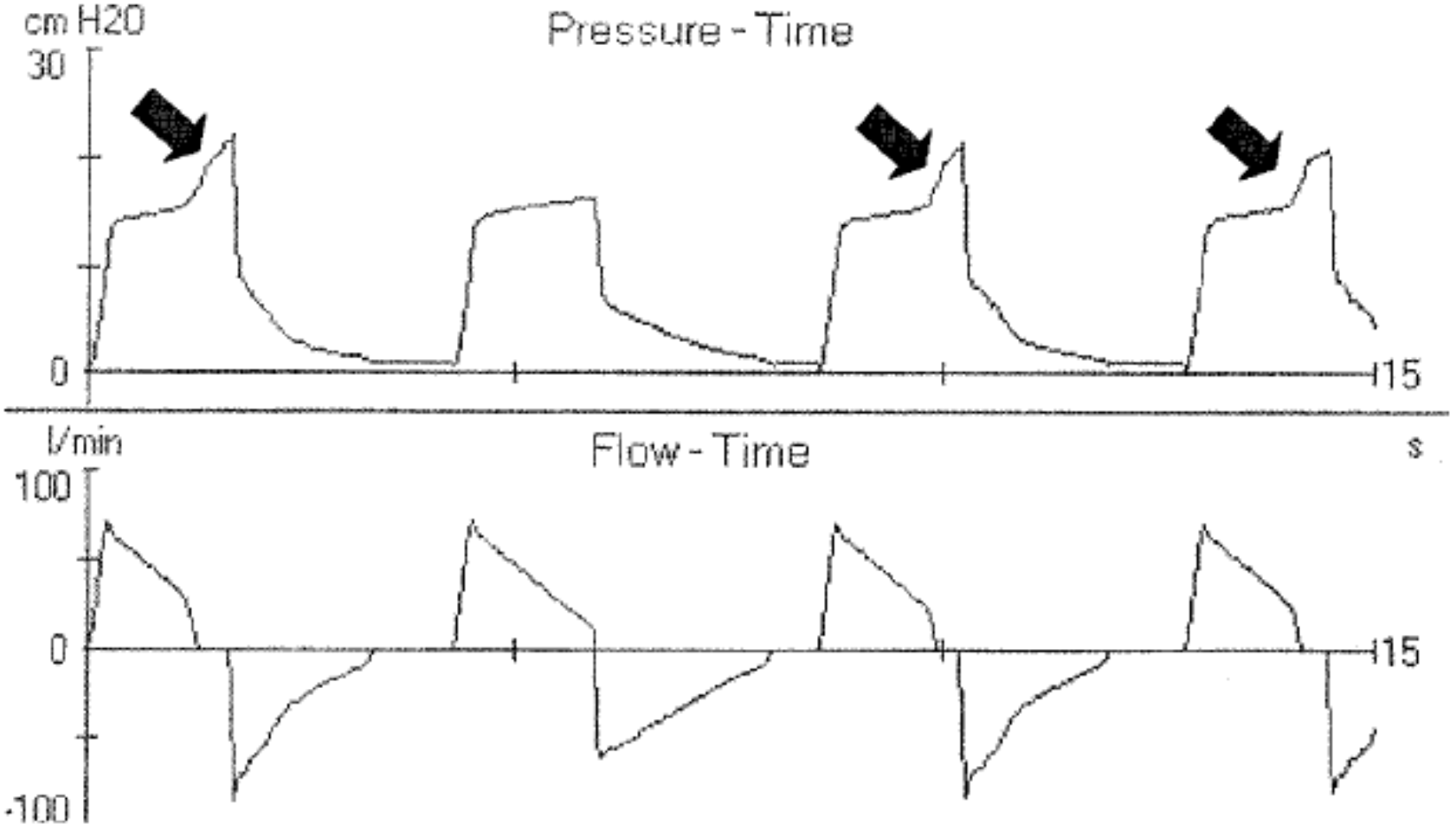



Nilsestuen et al. Resipr Care 2005; 50:202-232

# Regolazione del trigger espiratorio
# Asincronia ventilatore-paziente

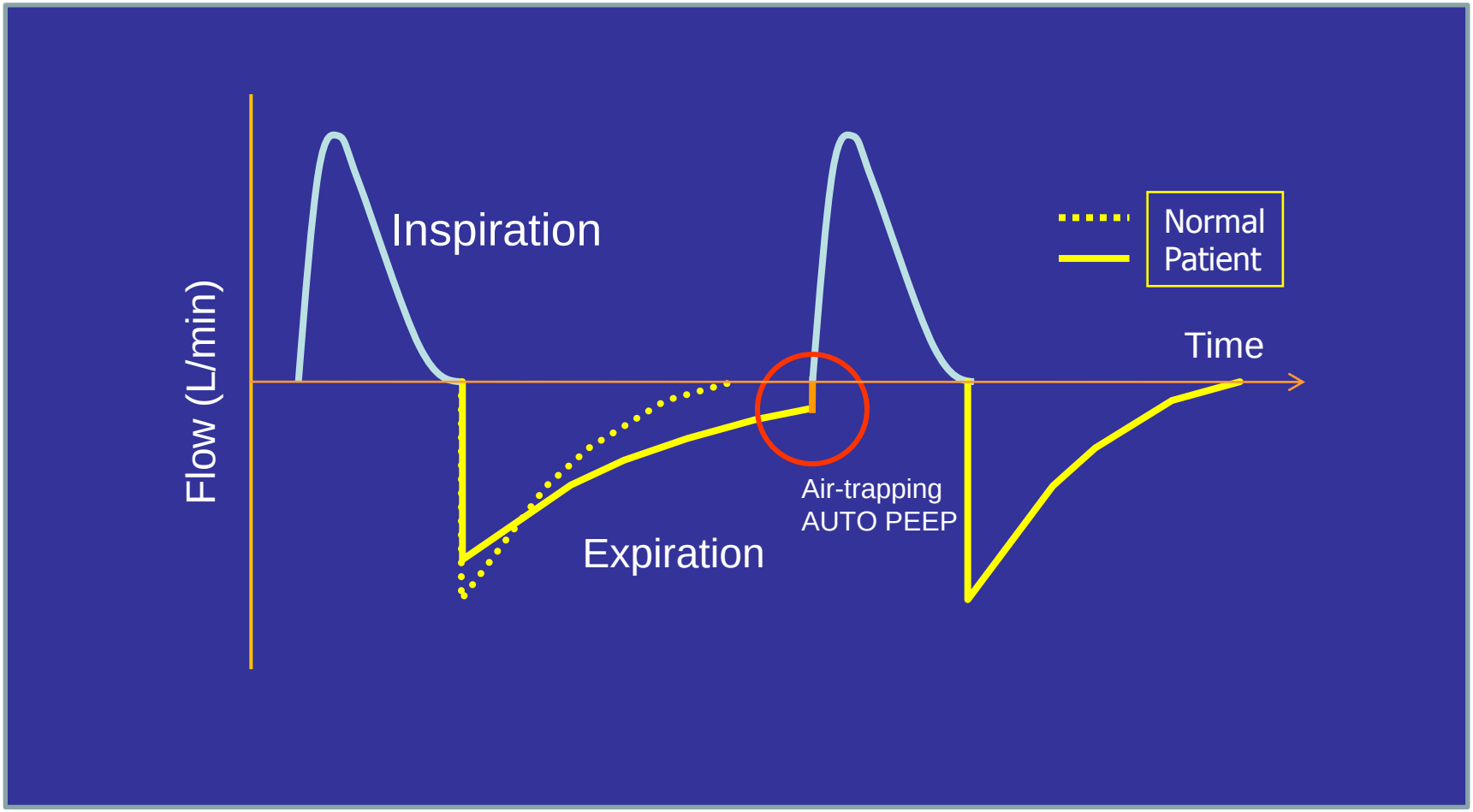


# Trigger espiratorio troppo "lungo"



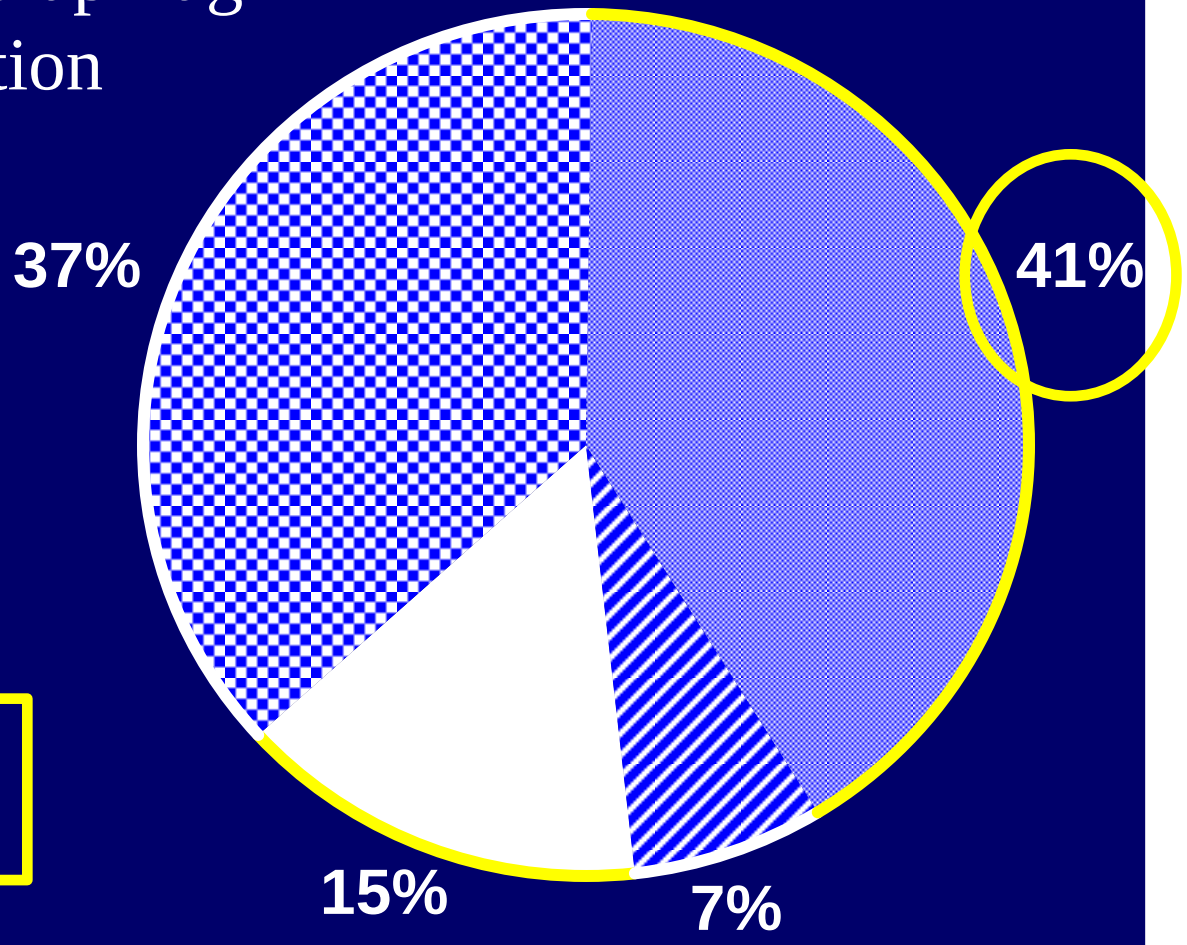

Nilsestuen et al. Resipr Care 2005; 50:202-232

# La PEEP intrinseca: buona o cattiva?



# Work of Breathing for intrinsic PEEP in COPD patients

PTPdi= extimate of diaphragm $O_2$ consumption


Appendini L. et al. AJRCCM 1996; 154:1301-1309

# *"Typical" waveforms driven setting approach*

- Individuation of autotriggering:
  - reduction of air leaks, and/or reduction of inspiratory trigger sensitivity.
- Individuation of ineffective efforts:
  - titration of pressure support, inspiratory and expiratory triggers, and PEEPext.
- Signs of potential late cycling-off (pressure increase at the end of inspiratory cycle or flow and pressure prolonged plateau):
  - reduction of air leaks and/or titration of expiratory trigger, or setting of maximal inspiratory time.

Di Marco *et al. Critical Care* 2011, **15**:R283

# *"Typical" waveforms driven setting approach*

- Potential early cycling-off (convex pattern of expiratory flow waveform and concavity of pressure waveform):
  - Action: titration of expiratory trigger.
- Signs of potentially not balanced PEEPi (expiratory flow that does not reach zero prior to inspiration or ineffective efforts):
  - Action: titration of PEEPext.

As a general rule changes in PEEP and PS were carried out by steps of 2 $cmH_2O$, and changes in inspiratory and expiratory triggers by steps of 5 to 10%.

Di Marco *et al. Critical Care* 2011, **15**:R283

# Optimization of ventilator setting by flow and pressure waveforms analysis during noninvasive ventilation for acute exacerbations of COPD: a multicentric randomized controlled trial

**Table 1 Baseline characteristics of enrolled patients**

| | Optimized Ventilation | Standard ventilation | *P* |
|---|---|---|---|
| N° | 35 | 35 | |
| Age, yrs | 76 ± 10 | 79 ± 7 | .173 |
| Men, n (%) | 24 (69) | 21 (60) | .618 |
| BMI, $Kg/m^2$ | 25.5 ± 6.2 | 27.0 ± 6.3 | .302 |
| BMI > 30, n (%) | 7 (20) | 8 (23) | .771 |
| LTOT, n (%) | 25 (71) | 20 (57) | .318 |
| Domiciliary NIV, n° (%) | 3 (9) | 7 (20) | .306 |
| Pre-NIV data | | | |
| Respiratory rate | 35 ± 6 | 33 ± 7 | .093 |
| pH | 7.27 ± .05 | 7.28 ± .05 | .450 |
| $PaO_2/FiO_2$ | 222 ± 87 | 226 ± 56 | .796 |
| $PaCO_2$, mmHg | 76 ± 17 | 71 ± 12 | .141 |
| $HCO_3^-$, mmol/l | 33 ± 6 | 32 ± 7 | .569 |

Data reported as mean ± standard deviation. No significant differences between groups. BMI, body mass index; LTOT, long-term oxygen therapy; NIV, noninvasive ventilation.

Di Marco *et al. Critical Care* 2011, **15**:R283

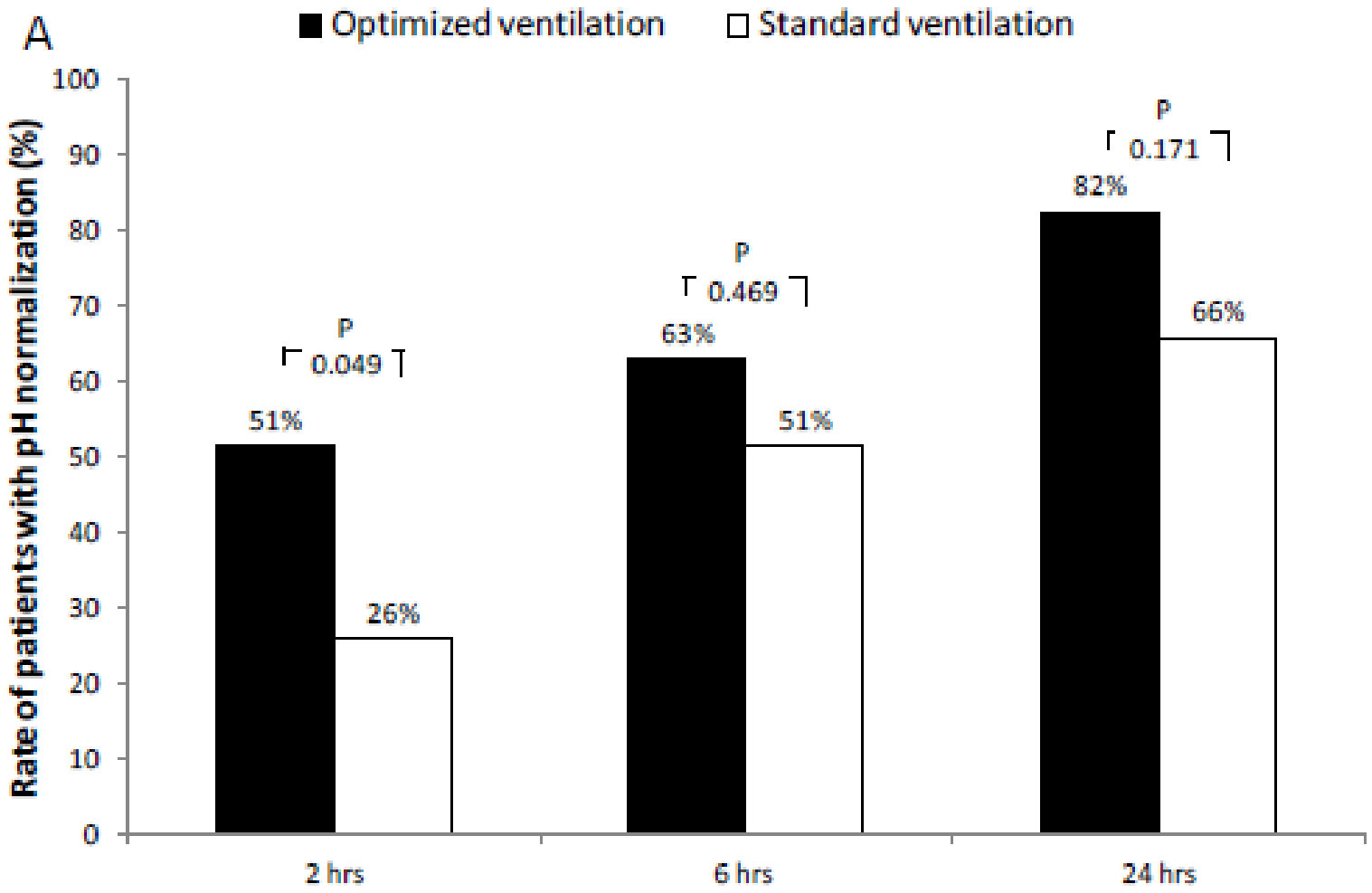
# Waveforms driven setting

# Standard setting with ventilator screen obscured


Numerical data always available

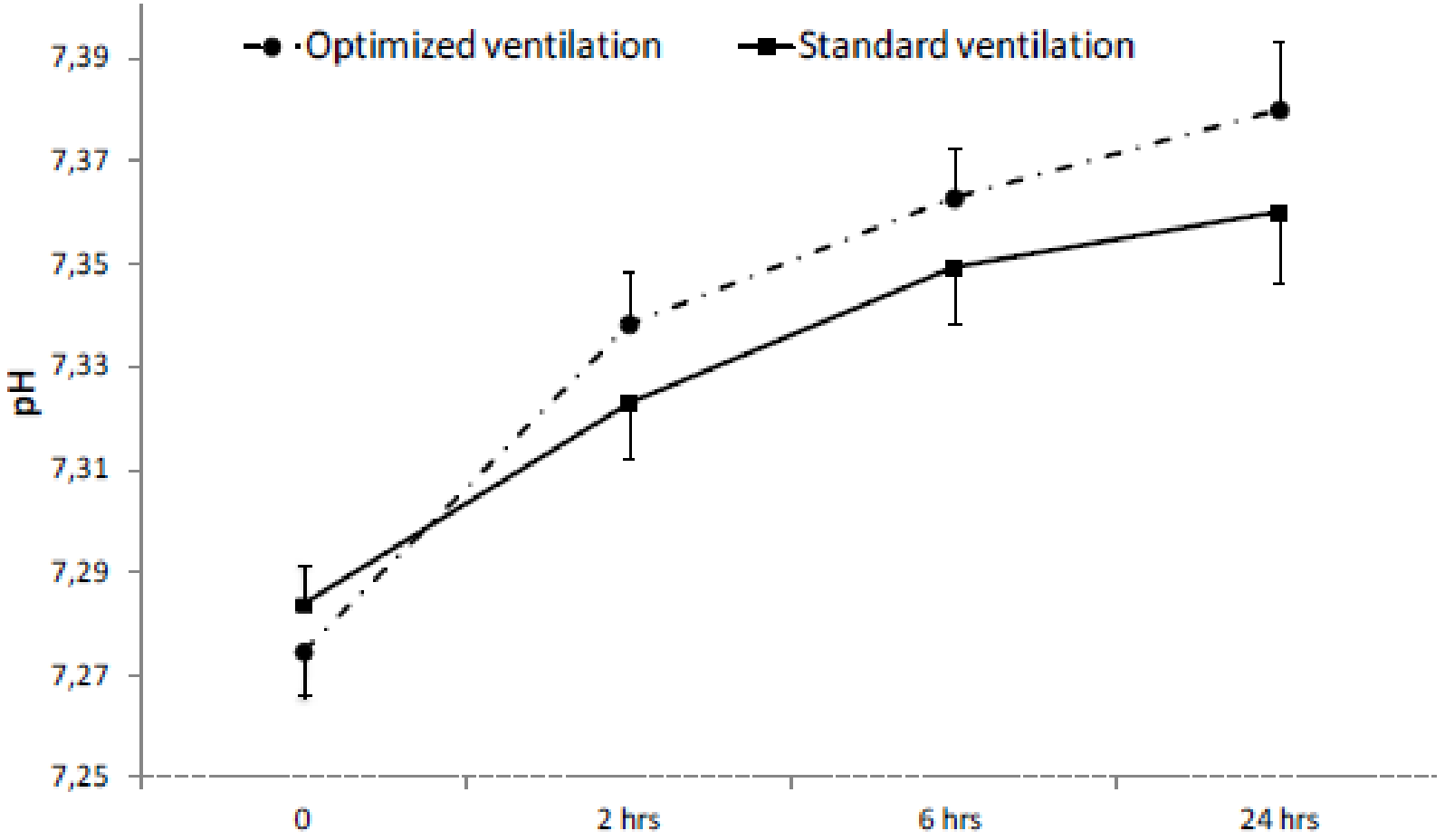
Screen obscured

# Optimization of ventilator setting by flow and pressure waveforms analysis during noninvasive ventilation for acute exacerbations of COPD: a multicentric randomized controlled trial




Di Marco *et al. Critical Care* 2011, **15**:R283

# Optimization of ventilator setting by flow and pressure waveforms analysis during noninvasive ventilation for acute exacerbations of COPD: a multicentric randomized controlled trial




Di Marco *et al. Critical Care* 2011, **15**:R283

# Waveforms driven setting

Azienda Ospedaliera
SAN PAOLO
POLO UNIVERSITARIO

VII CONGRESSO DI **ECOCARDIOCHIRURGIA**

# *Le curve: come interpretarle*

**Fabiano Di Marco**

**Università degli Studi di Milano**
**Clinica di Malattie dell'Apparato Respiratorio**
**Ospedale San Paolo – Milano**
**E-mail: fabiano.dimarco@unimi.it**