Fisiologia Respiratória
&
Ventilação Mecânica

Plínio Vasconcelos Maia
Hospital Municipal Esaú Matos

www.paulomargotto.com.br

Brasília, 12 de agosto de 2014

Disponível em:

Paulo Roberto Margotto

www.paulomargotto.com.br

VM e Proteção Pulmonar

Parâmetros da VM

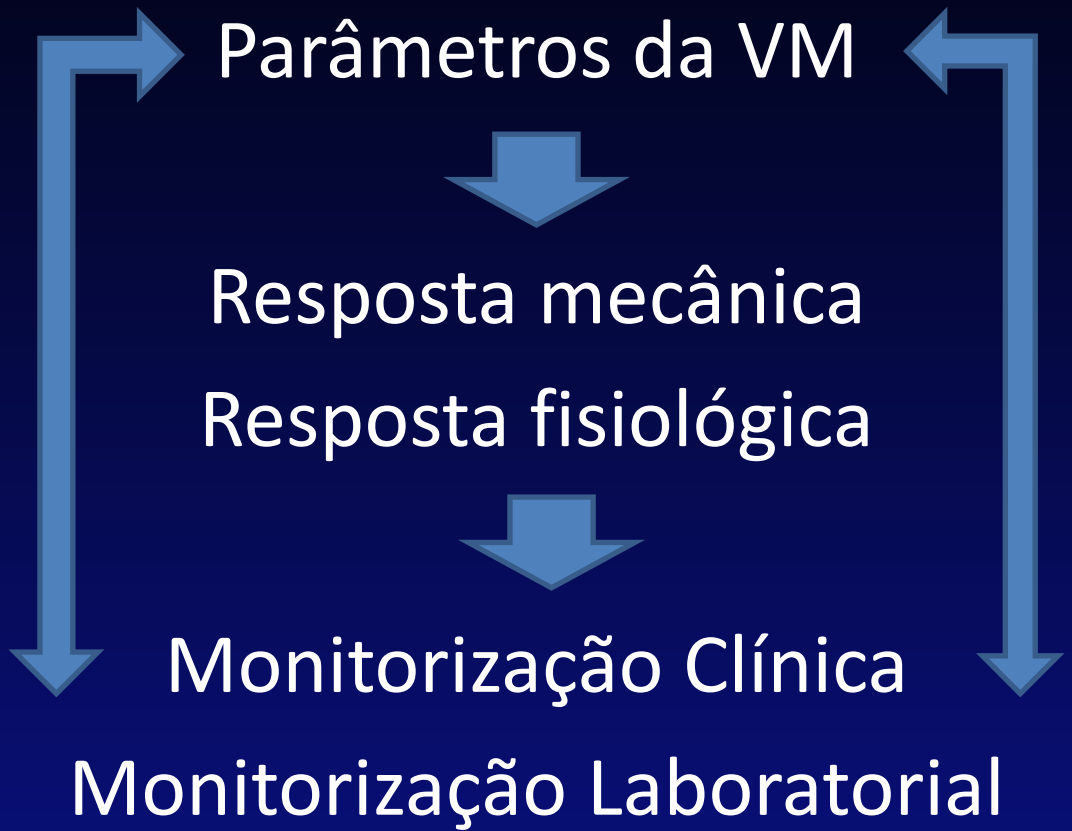
Resposta mecânica

Resposta fisiológica

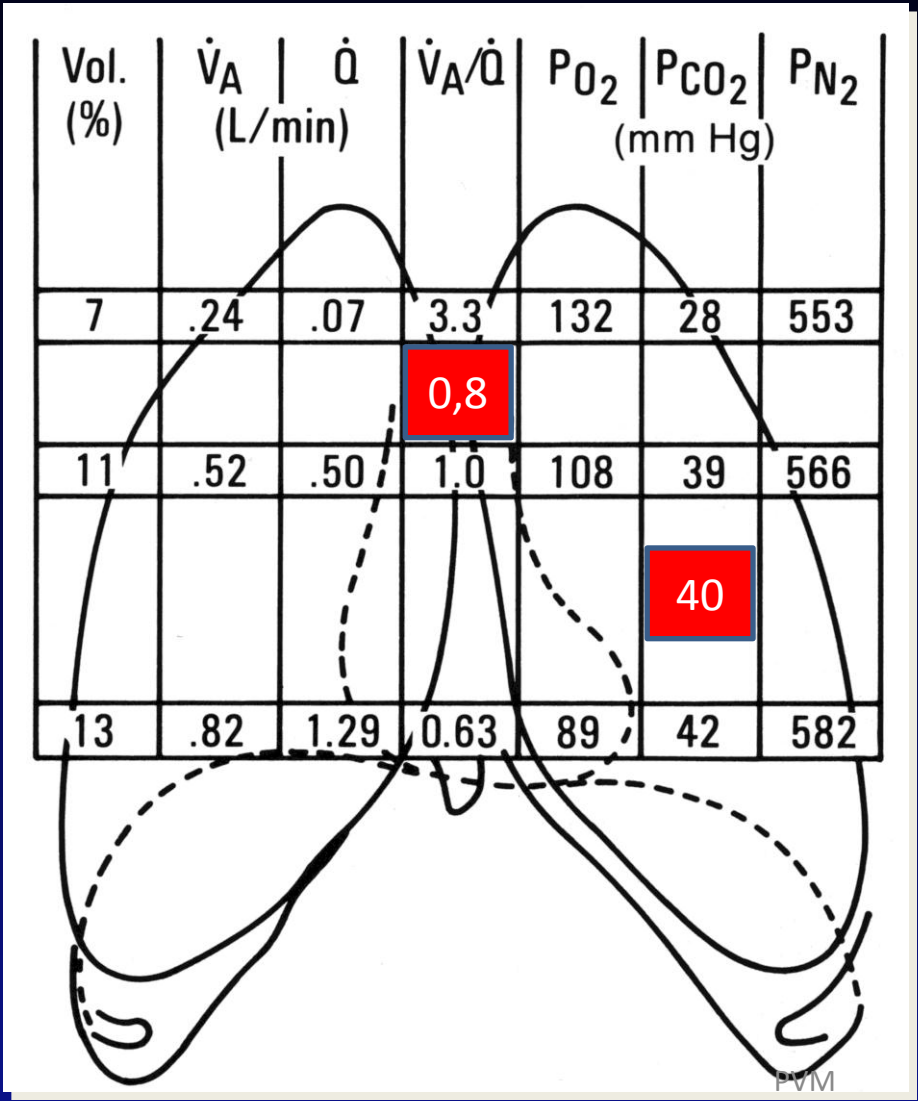
Monitorização Clínica

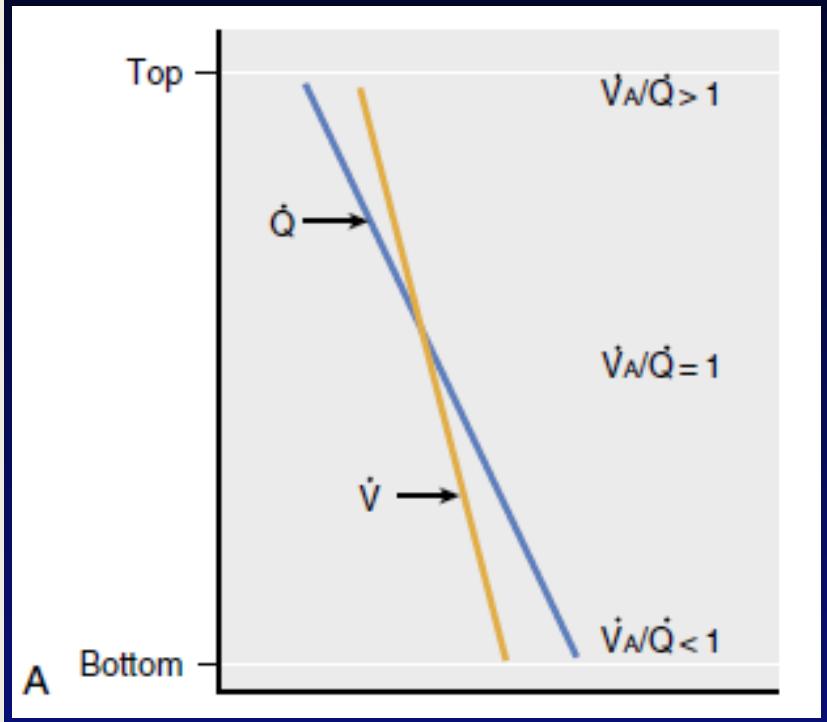
Monitorização Laboratorial

VM e Proteção Pulmonar

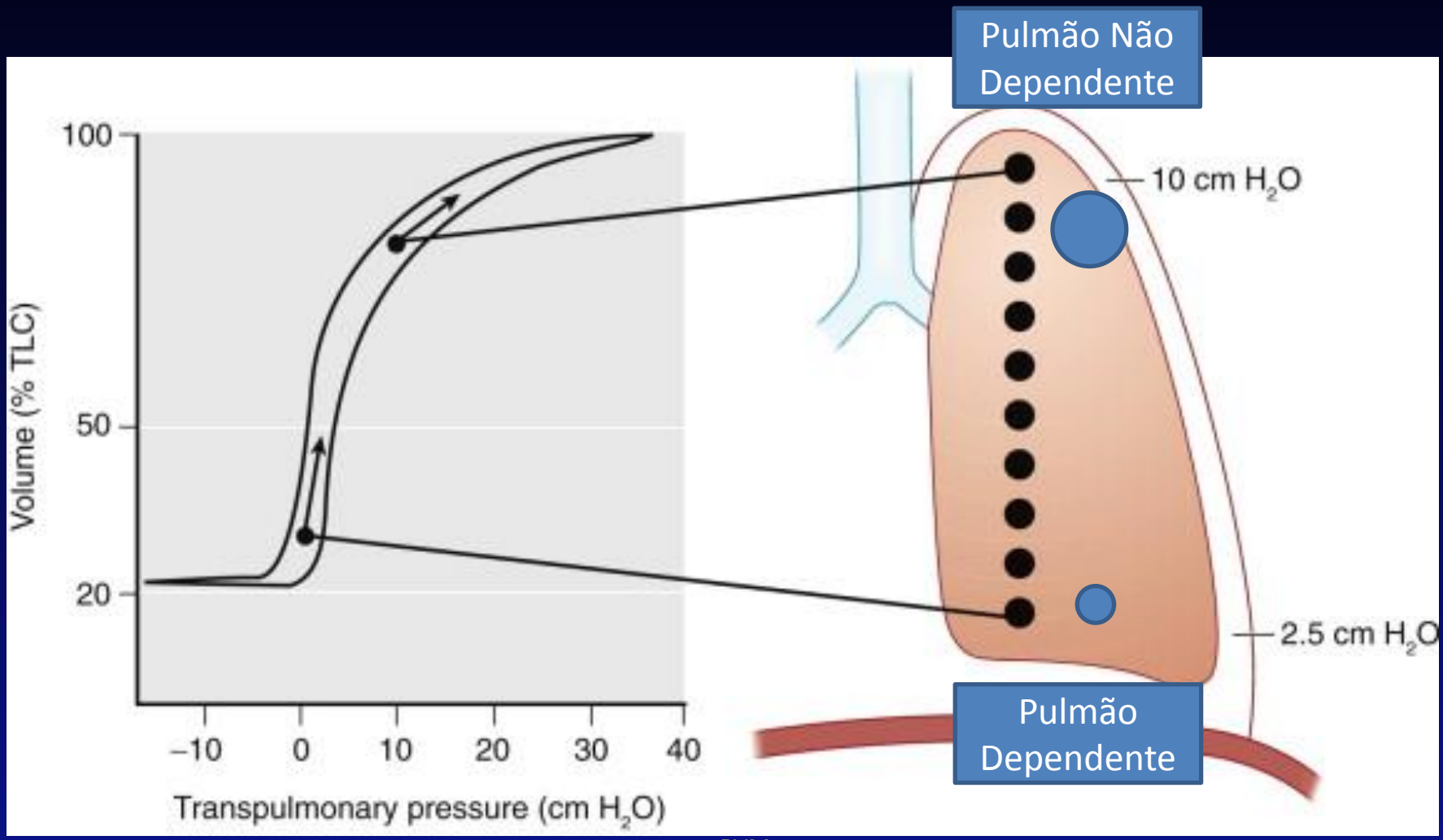


Fisiologia do Tórax

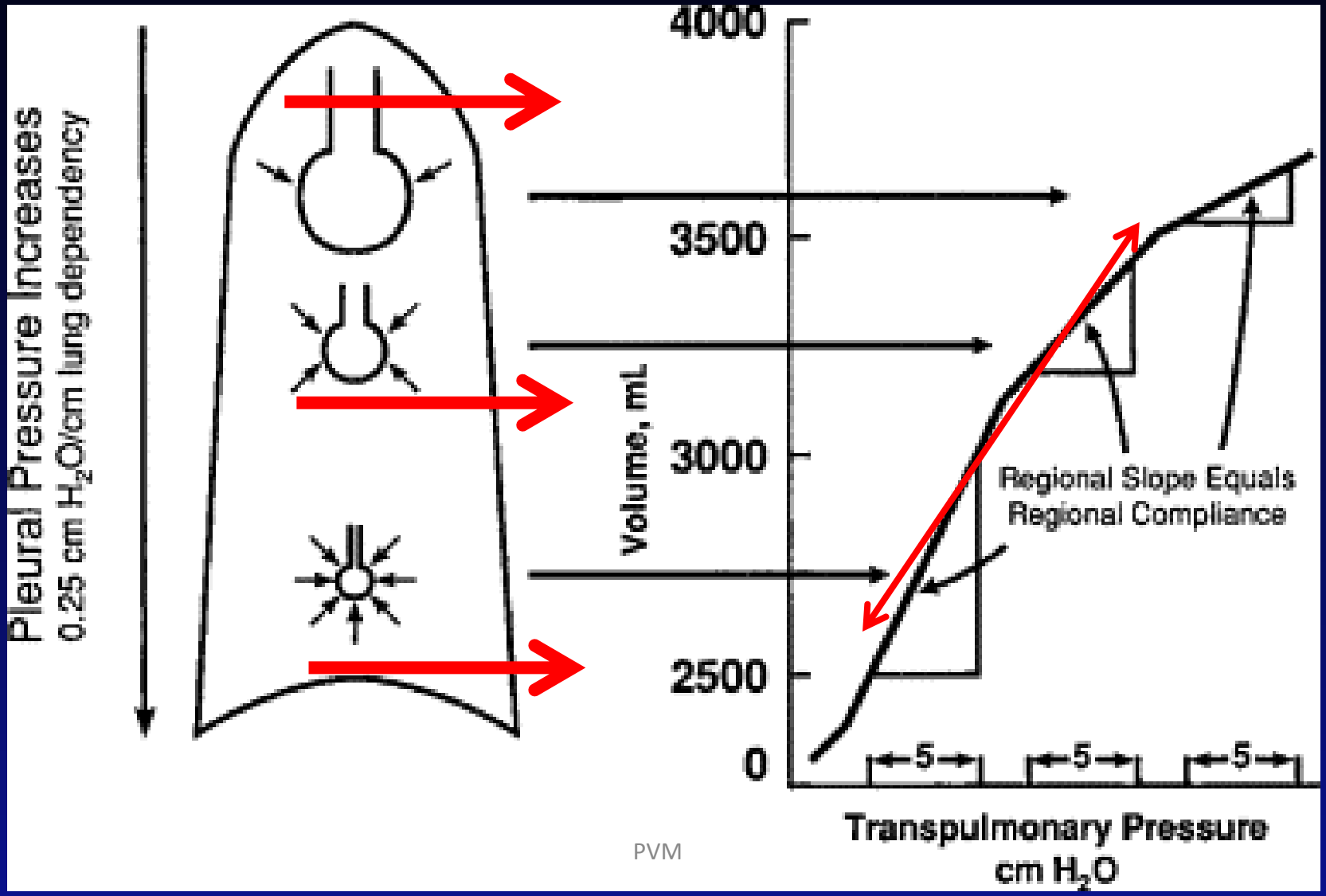




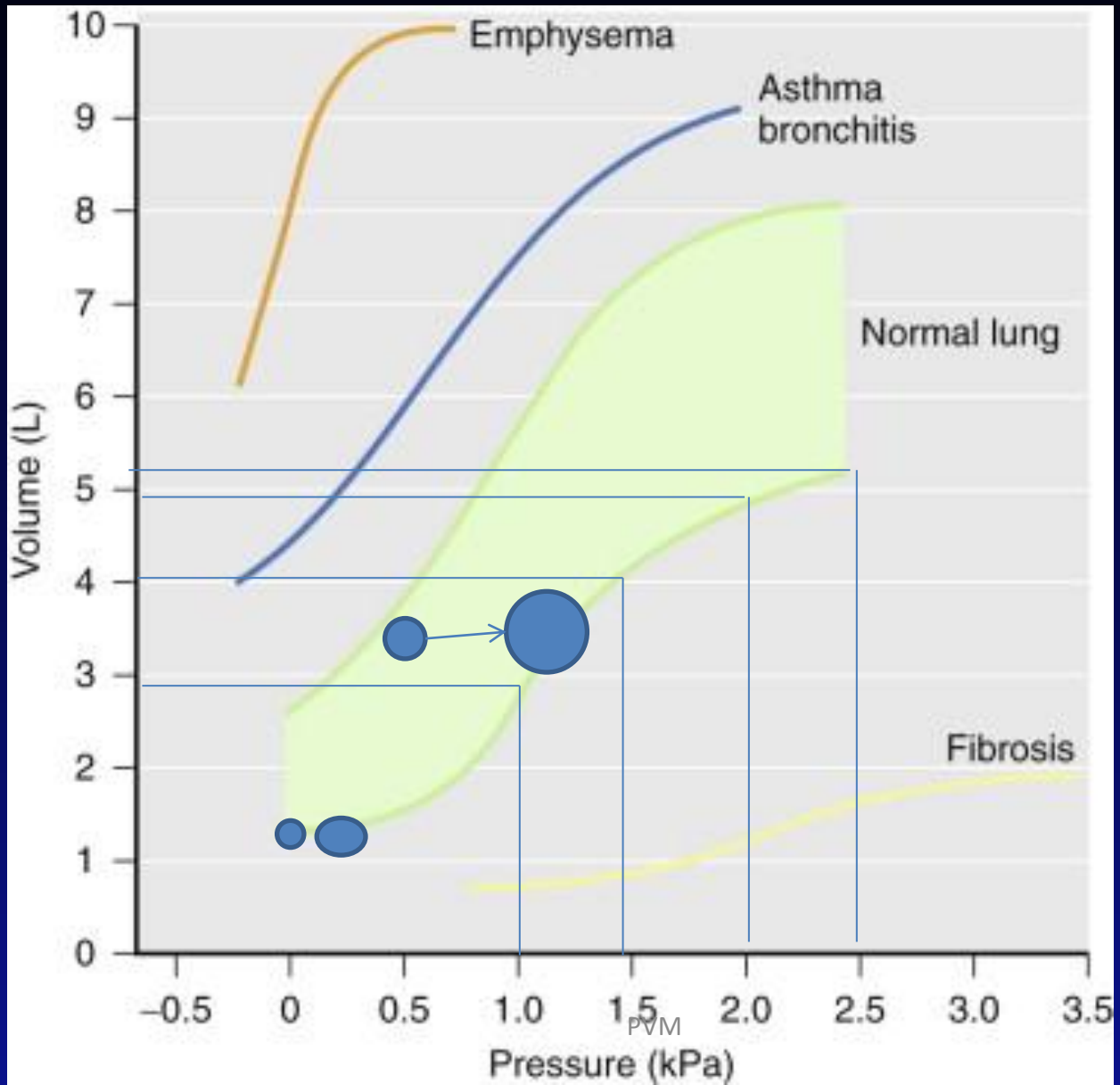
Fisiologia do Tórax



Complacência Torácica



Fisiologia do Tórax

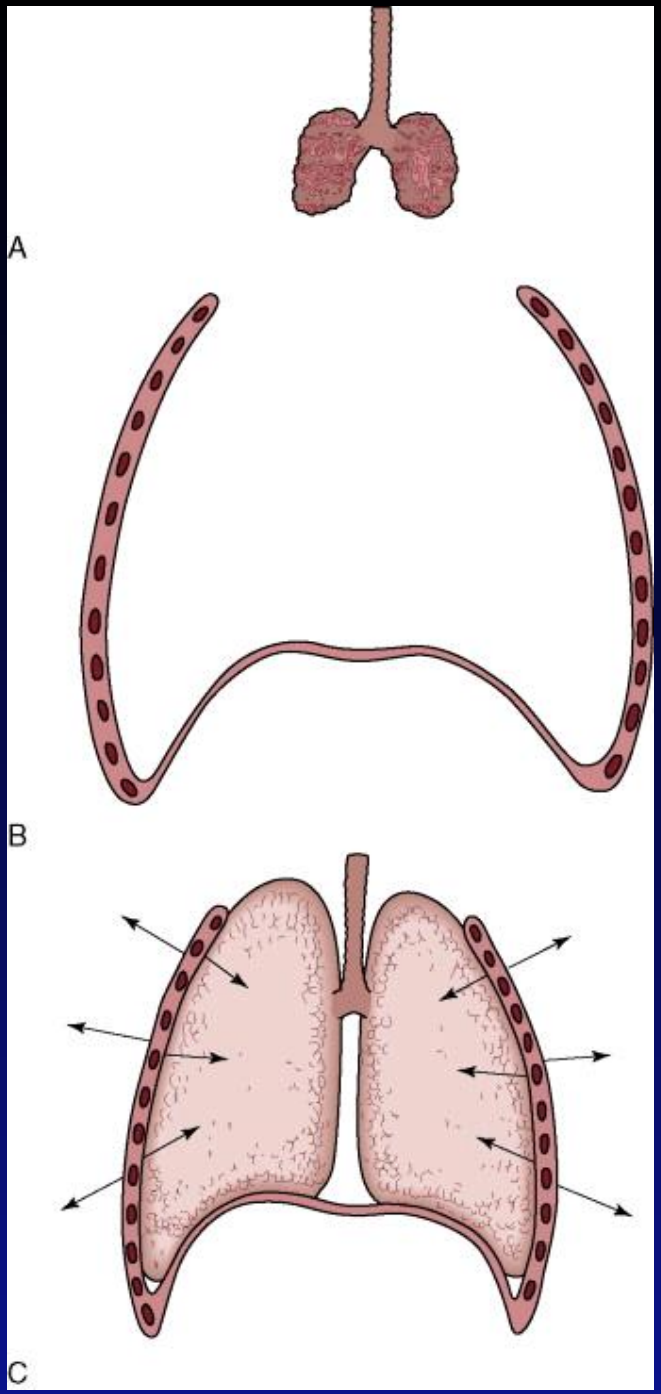


Complacência Torácica

- O que mantém a CRF
  - Tórax: arcabouço ósseo e tônus da musculatura intercostal.
  - Surfactante (fosfatidil colina)
    - Mais eficiente nos alvéolos de menor raio.
  - PEEP natural: fechamento das cordas vocais antes do fim da expiração, alta resistência nasal.
  - Conteúdo alveolar: oxigênio e nitrogênio

X

  - Recolhimento elástico do pulmão

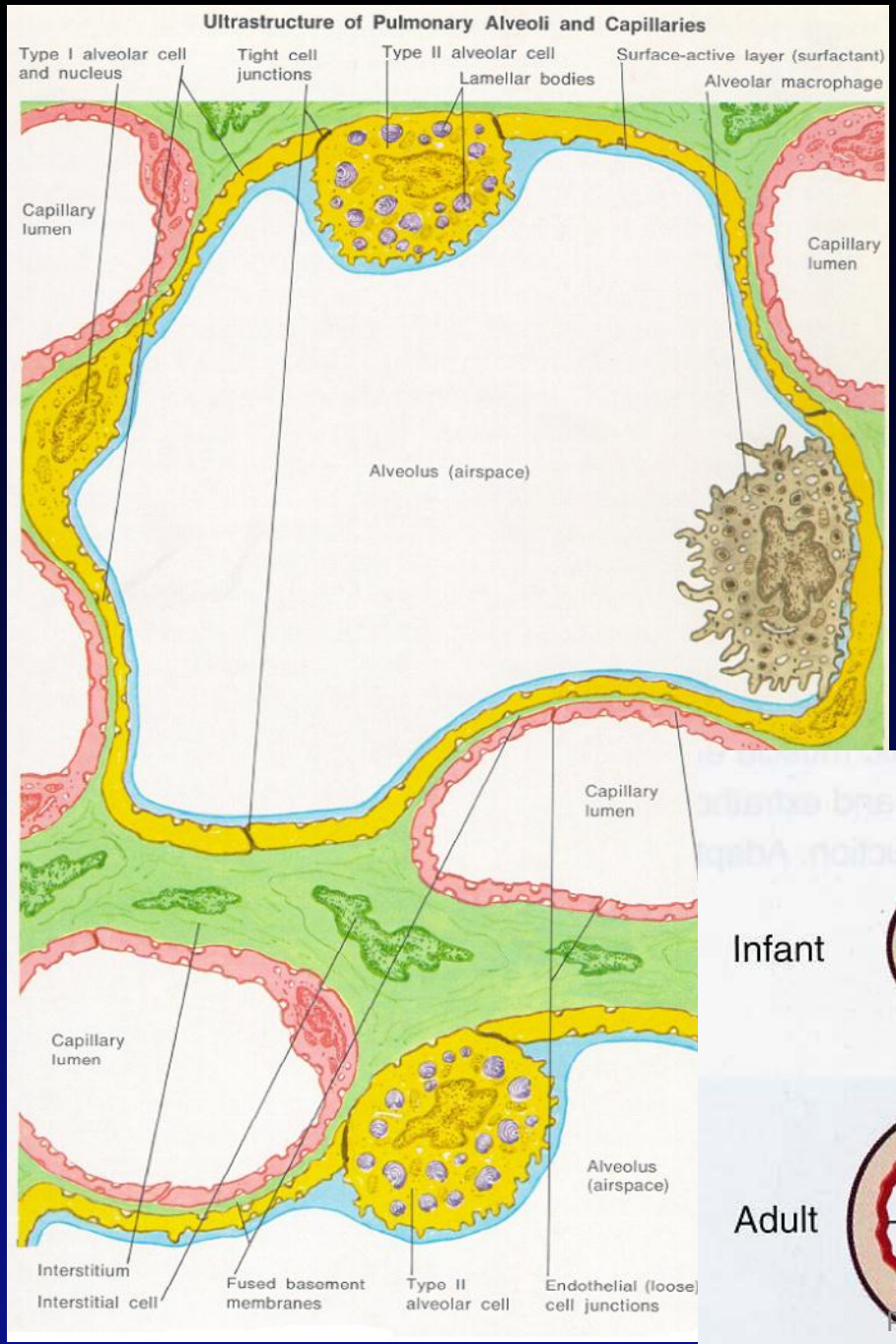


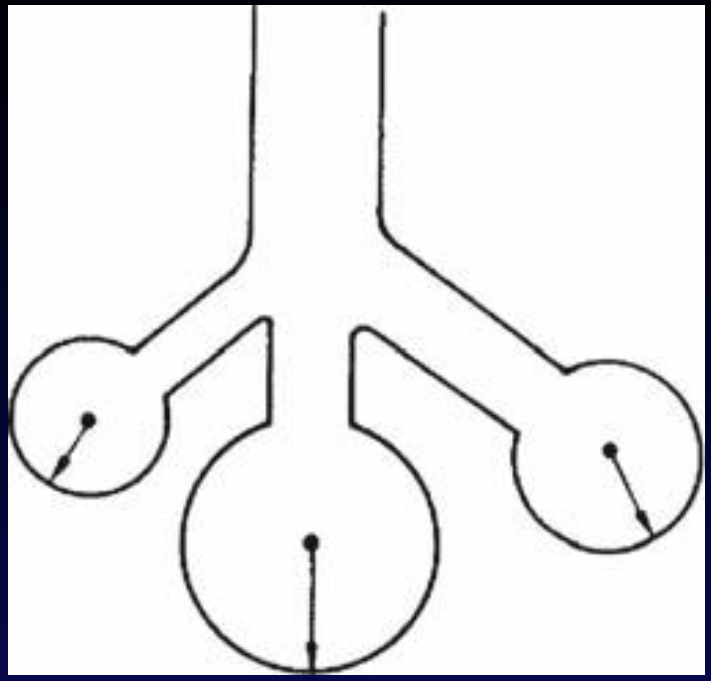
CRF

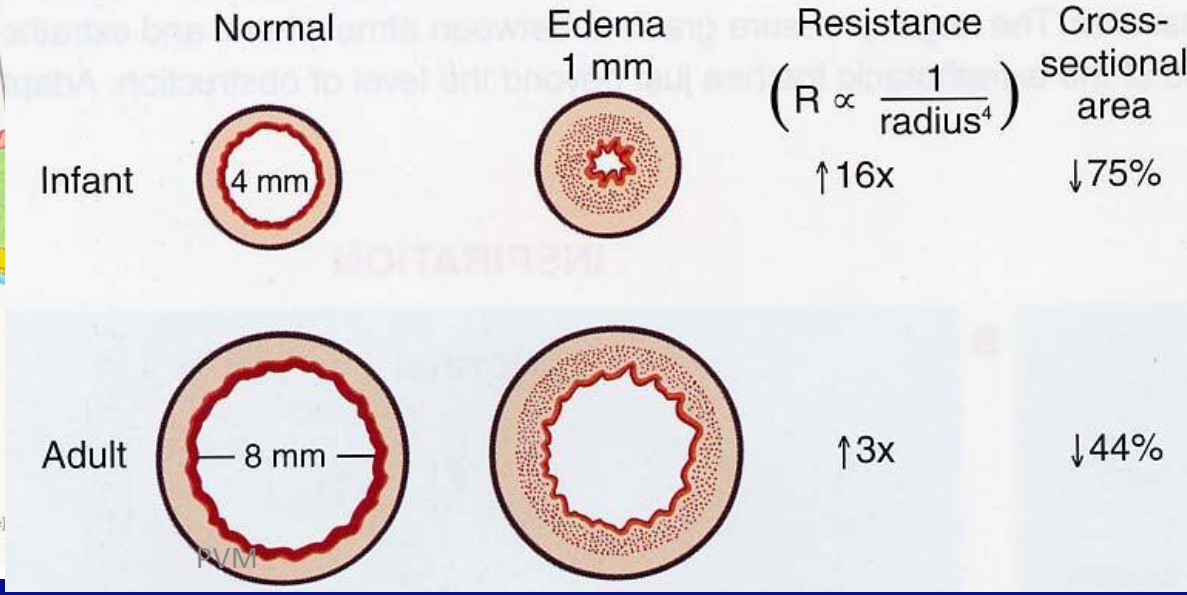
The balance of inward recoil of the lung tissue tending to collapse the lung countered by outward recoil of the chest wall tending to expand the lung. The exact balance of these forces at the end of expiration represents the functional residual capacity (FRC) of the lung. C, The lung volume that exists at the end of expiration, the FRC.

Kendig and Chernick's Disorders of the Respiratory Tract in Children , Eighth Edition

PVM


Ultrastructure of Pulmonary Alveoli and Capillaries
Type I alveolar cell and nucleus
Tight cell junctions
Type II alveolar cell
Lamellar bodies
Surface-active layer (surfactant)
Alveolar macrophage
Capillary lumen
Capillary lumen
Alveolus (airspace)
Capillary lumen
Capillary lumen
Alveolus (airspace)
Interstitium
Interstitial cell
Fused basement membranes
Type II alveolar cell
Endothelial (loose) cell junctions




Normal
Edema 1 mm
Resistance $\left(R \propto \frac{1}{\text{radius}^4}\right)$
Cross-sectional area
Infant
4 mm
↑16x
↓75%
Adult
8 mm
↑3x
↓44%

PVM

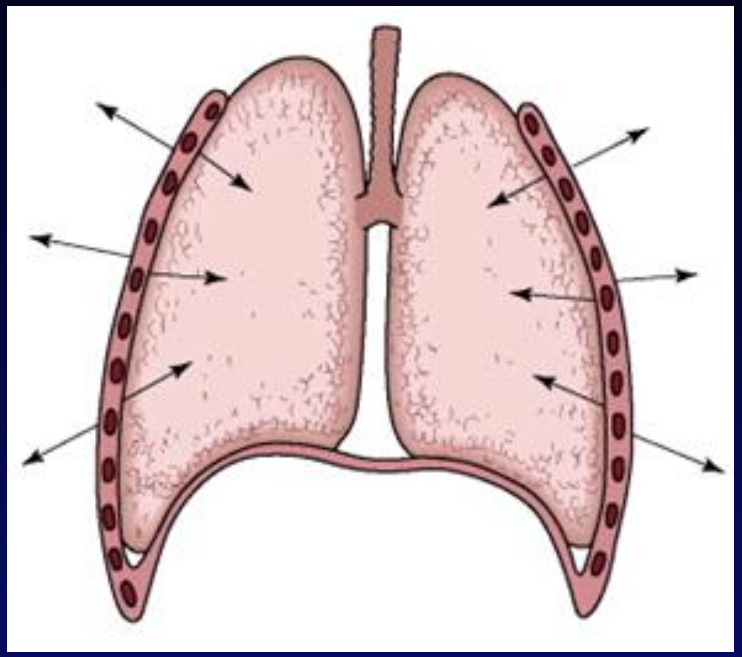
Volume de Fechamento (VF)

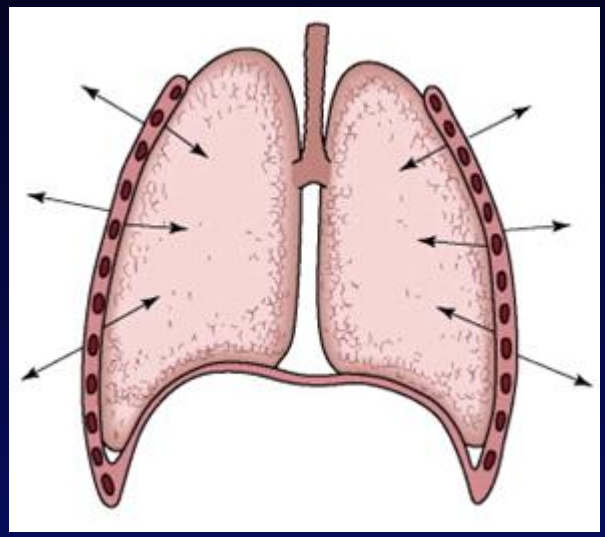
- Definição: O volume de gás que permanece no pulmão quando pequenos alvéolos e vias aéreas em regiões dependentes do pulmão são consideradas colapsadas.

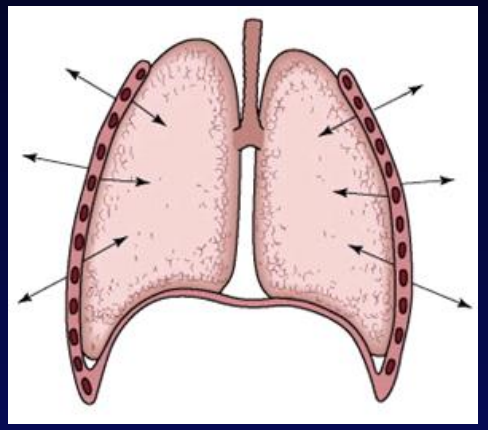
CRF

VF

CRF







Desejável

Atelectasia

Ventilação Mecânica

- Lesão pulmonar induzida pela assistência a saúde.

- Atelectrauma
- Volutrauma
- Barotrauma

Atelectasia induzida pela VM

- Atelectasia Intra-operatória
  - compressão mecânica do parênquima pulmonar
  - absorção do conteúdo gasoso alveolar
  - disfunção do sistema surfactante


Anesthesiology 2005; 102:838–54

Pulmonary Atelectasis

A Pathogenic Perioperative Entity

Michelle Duggan, M.B.,* Brian P. Kavanagh, M.B.†

Anesthesiology 2005; 102:838–54

Atelectasia induzida pela VM

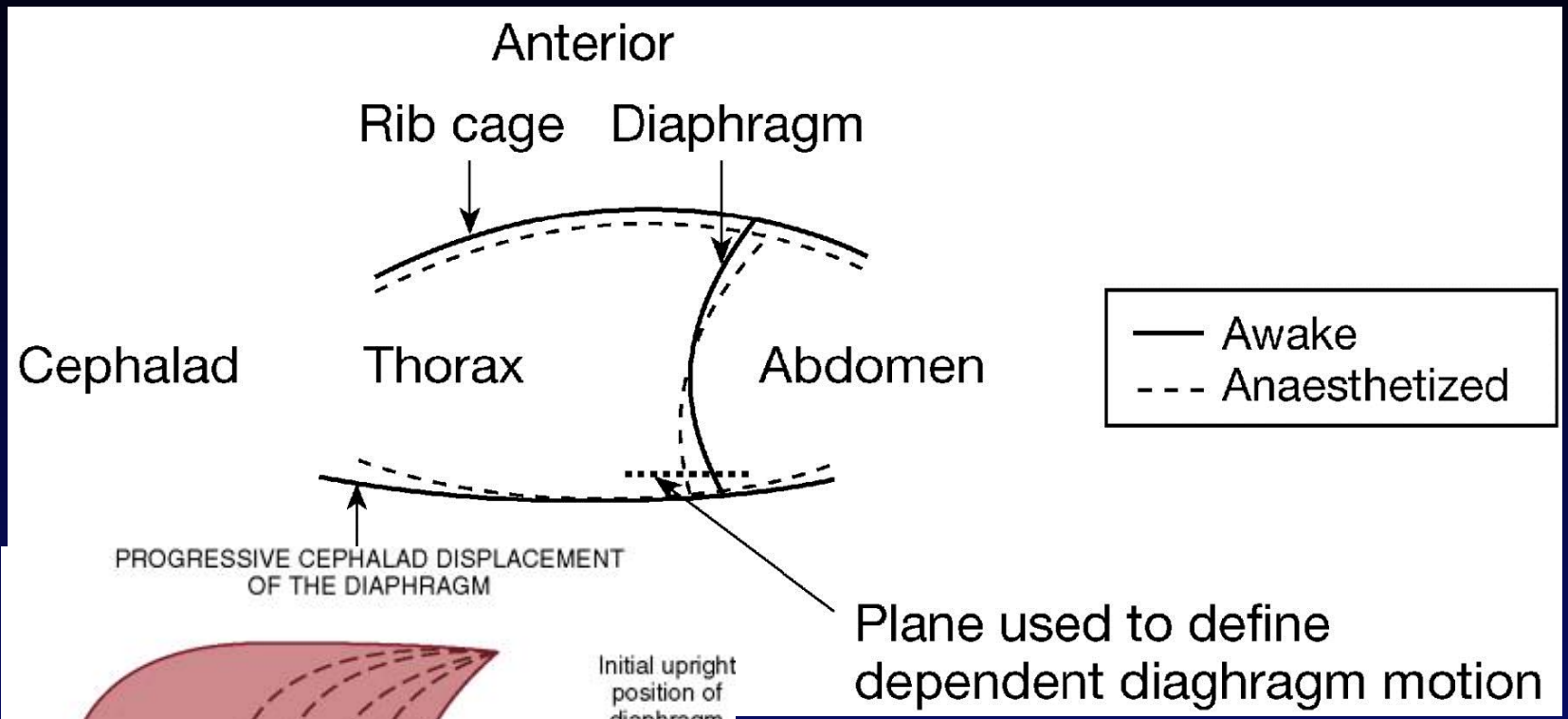
- Atelectasia
  - compressão mecânica do parênquima pulmonar
    - relaxamento da musculatura e deslocamento para dentro do tórax do diafragma relaxado
    - Peso do coração repousado sobre o parênquima pulmonar,
    - Compressão das regiões dependentes do pulmão
  - Limitação da expansão pulmonar
    - Menor expansão da caixa torácica fixa no leito

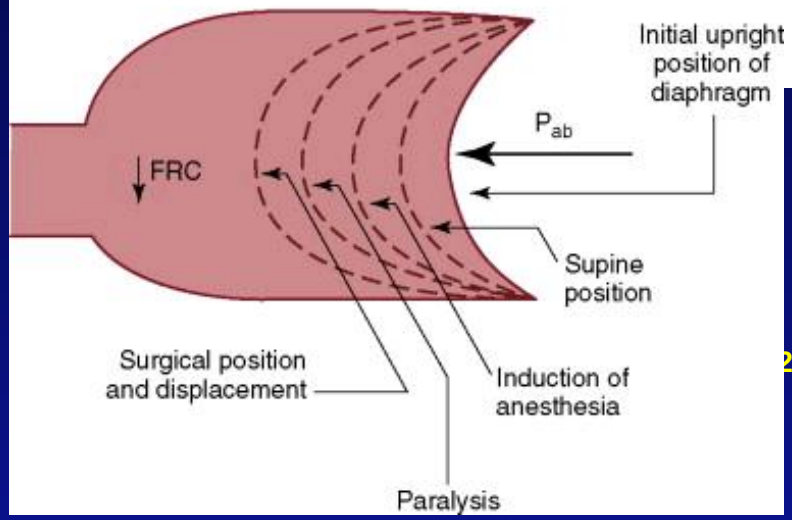
Atelectasia induzida pela VM

- Efeitos da Postura na CRF
- Deslocamento cefálico do diafragma
  - Sedação/bloqueio neuromuscular
  - Peso das estruturas
  - Pressão abdominal x torácica
  - Queda da CRF sem PEEP
- CRF x Capacidade de fechamento

Colapso pulmonar → ATELECTRAUMA

Fig 4 Diagram of a midsagittal section of the thorax while awake (solid lines) and while anaesthetized (dashed lines).

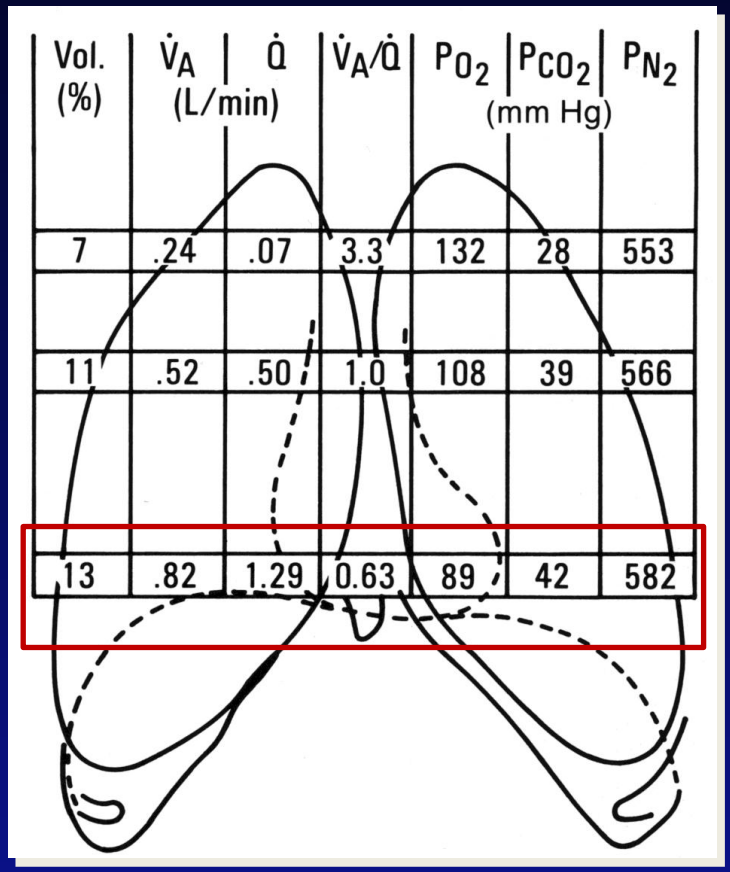




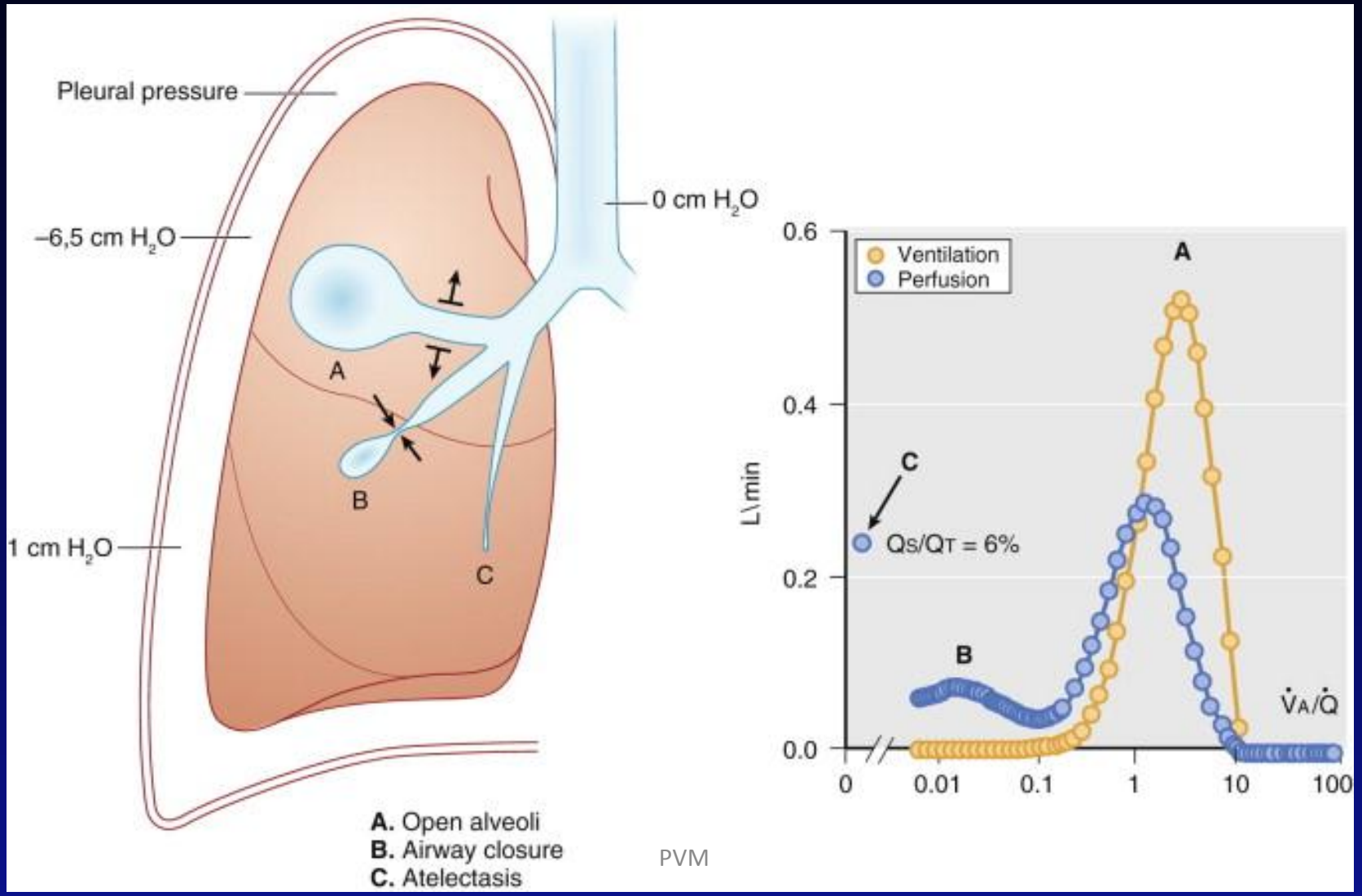
BJA British Journal of Anaesthesia

Atelectasia induzida pela VM

- Mistura de Gases
  - Atelectasia de reabsorção
  - Após oclusão completa
  - Relação v/Q baixa
  - FiO2 alta

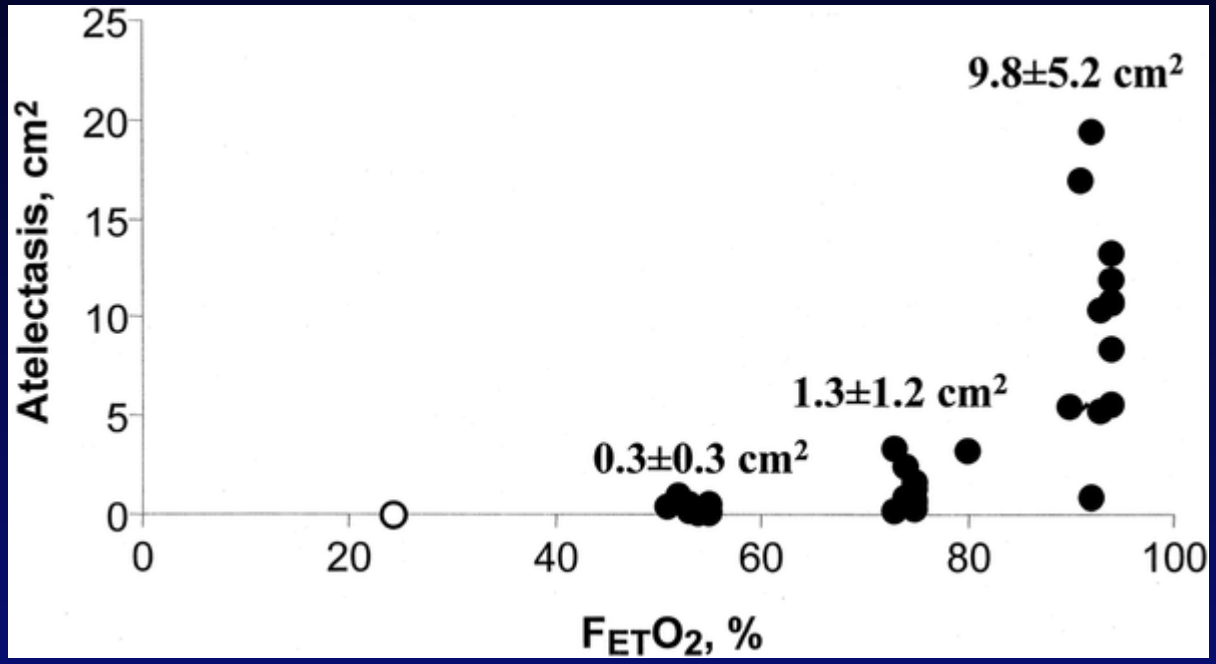


Atelectasia induzida pela VM



Atelectasia induzida pela VM

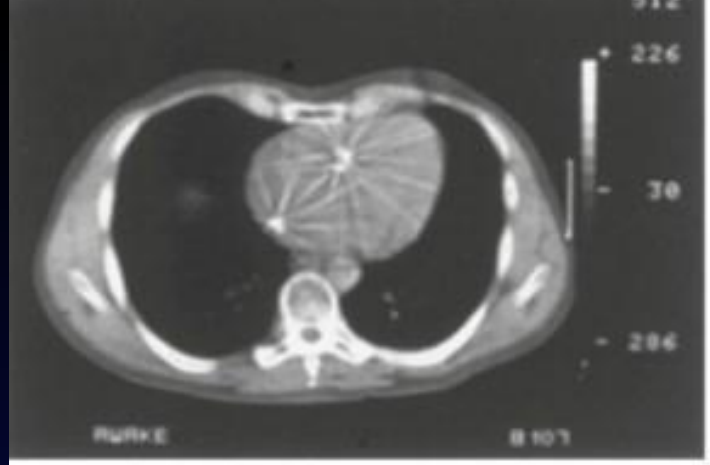
- Mistura de Gases

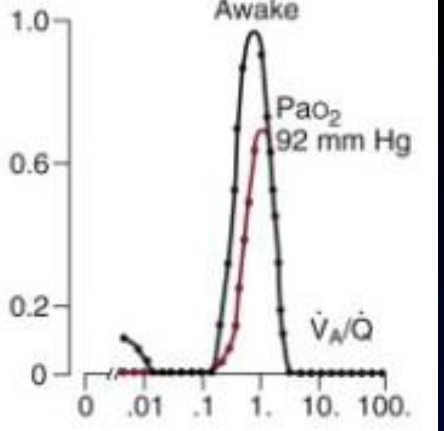


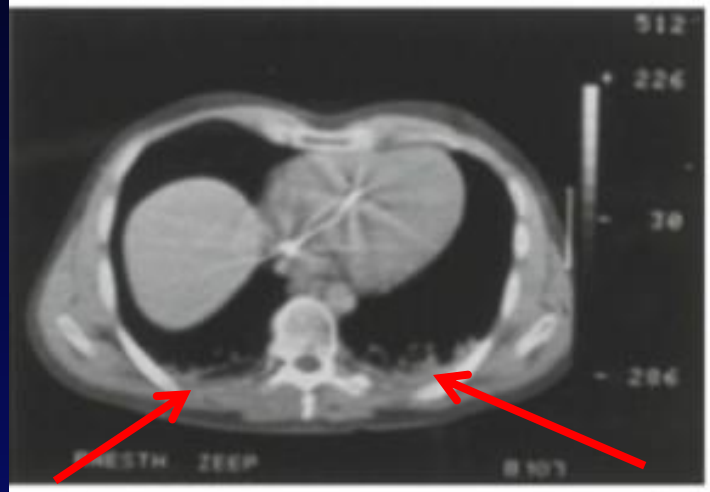
- Anesthesiology - Volume 98, Issue 1 January 2003

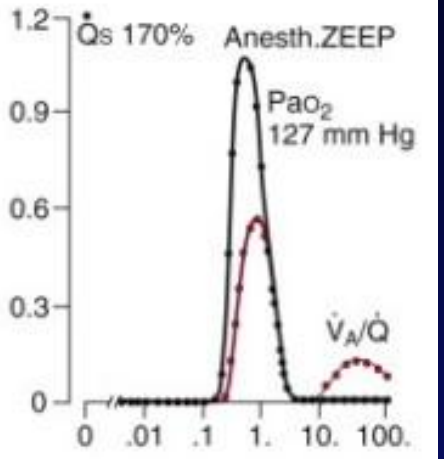
Atelectasia induzida pela VM

- Mistura de Gases
  - FiO2 100%: aumenta shunt pulmonar
    - 100%: shunt aumenta de 0.3% to 6.5%.
      - 8cm2 de atelectasia
    - 30%: shunt aumenta para apenas 2.1%,
      - 0.2 cm2
  - Lesão oxidativa.


512
226
30
286
RUKE
B 10'1


Awake
1.0
0.6
0.2
0
Pa_{O_2}
92 mm Hg
$\dot{V}_A/\dot{Q}$
0 .01 .1 1. 10. 100.


512
226
30
286
ANESTH ZEEP
B 10'1


1.2
$\dot{Q}_S$ 170%
Anesth.ZEEP
0.9
0.6
0.3
0
Pa_{O_2}
127 mm Hg
$\dot{V}_A/\dot{Q}$
0 .01 .1 1. 10. 100.


512
226
30
286
ANESTH PEEP
B 10'1
PVM

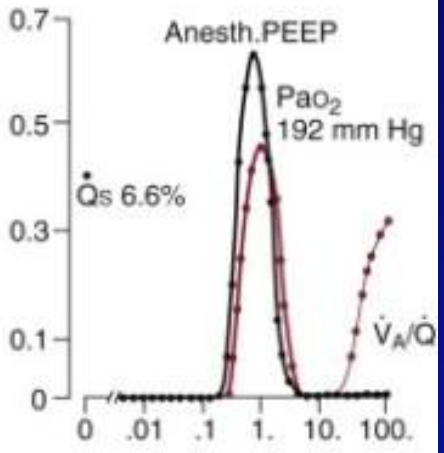
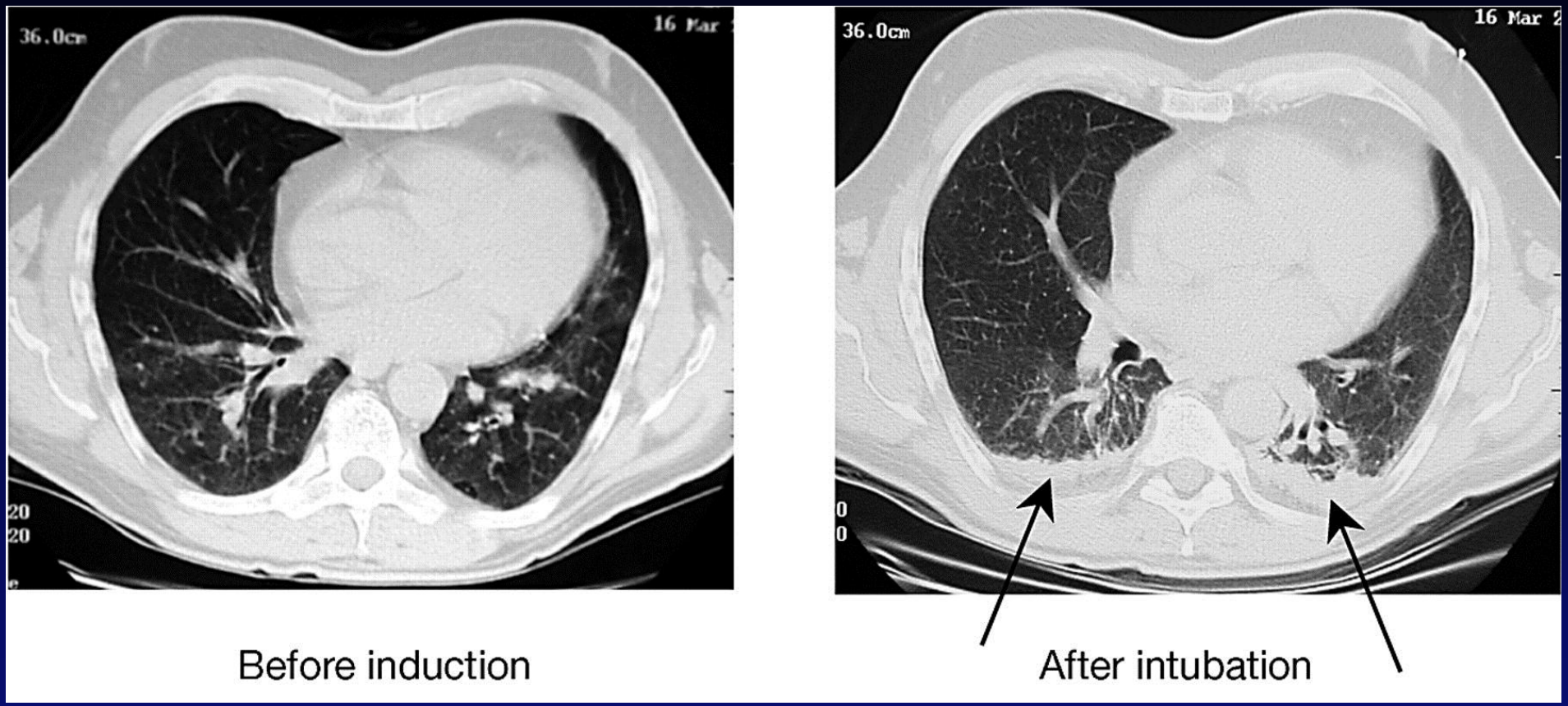

0.7
Anesth.PEEP
0.5
0.3
0.1
0
Pa_{O_2}
192 mm Hg
$\dot{Q}_S$ 6.6%
$\dot{V}_A/\dot{Q}$
0 .01 .1 1. 10. 100.

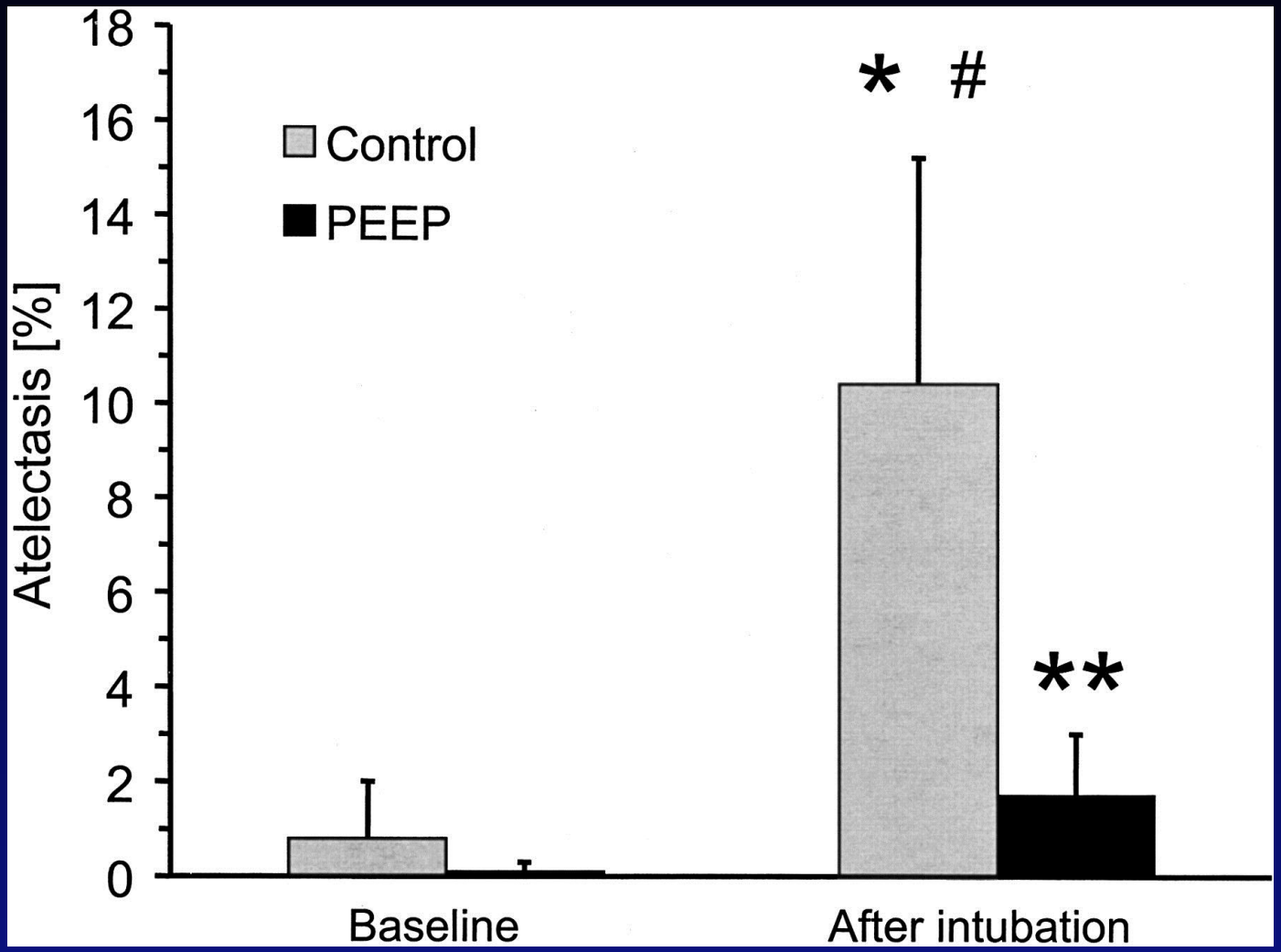
Fig 1 Examples of CT scans of a patient with healthy lungs, before and after induction of anaesthesia.



Magnusson L , Spahn D R Br. J. Anaesth. 2003;91:61-72

BJA British Journal of Anaesthesia

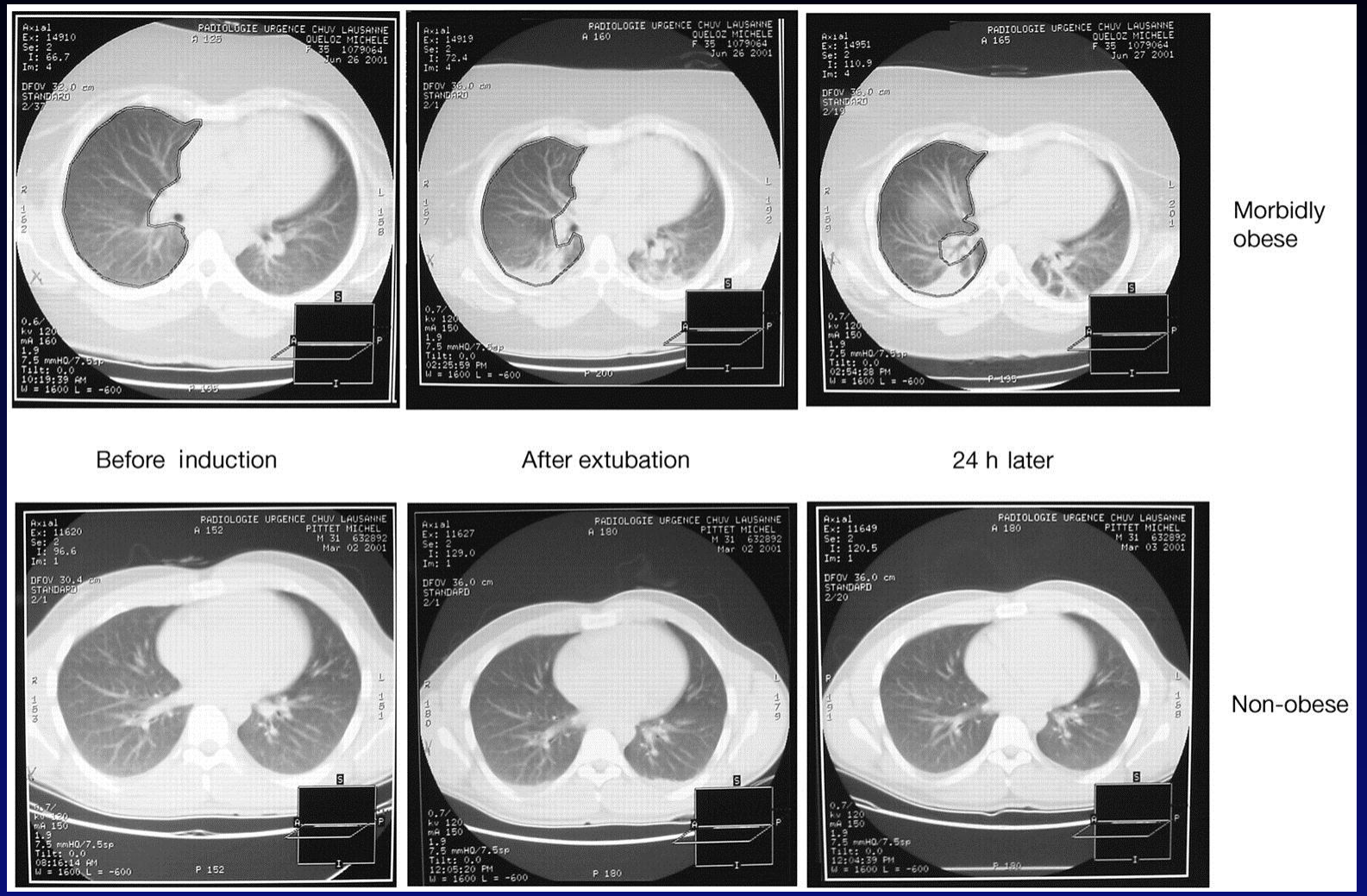
Figure 2. Percentage of pulmonary atelectasis at baseline and after the anesthesia induction in control and positive end-expiratory pressure (PEEP) patients. #P < 0.0001 compared with the PEEP group; *P = 0.0001 compared with baseline; **P = 0.006 compared ...



Coussa M et al. Anesth Analg 2004;98:1491-1495

ANESTHESIA & ANALGESIA

Fig 6 Samples of CT scans of a morbidly obese and a non-obese patient before anaesthesia, after extubation and 24 h later.



Magnusson L , Spahn D R Br. J. Anaesth. 2003;91:61-72

BJA British Journal of Anaesthesia

Atelectasia induzida pela VM

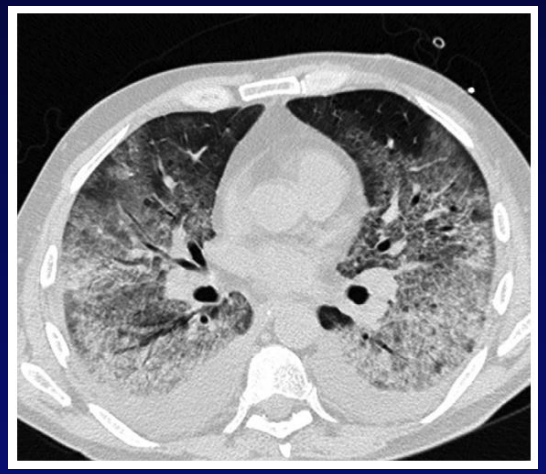
- Disfunção do sistema surfactante
  - Surfactante
    - Grande agregados x pequenos agregados
    - Reduz tensão alveolar → estabiliza o alvéolo → previne colapso alveolar
  - Volutrauma

Atelectasia induzida pela VM

- Disfunção do sistema surfactante
  - Volume corrente elevado
    - Alteração na área de superfície
    - Atividade aumentada de protease no espaço aéreo
  - Aumenta propensão a colapso
  - Expansão desigual aumenta estresse regional
  - Aumento da pressão de filtração vascular promove formação de edema

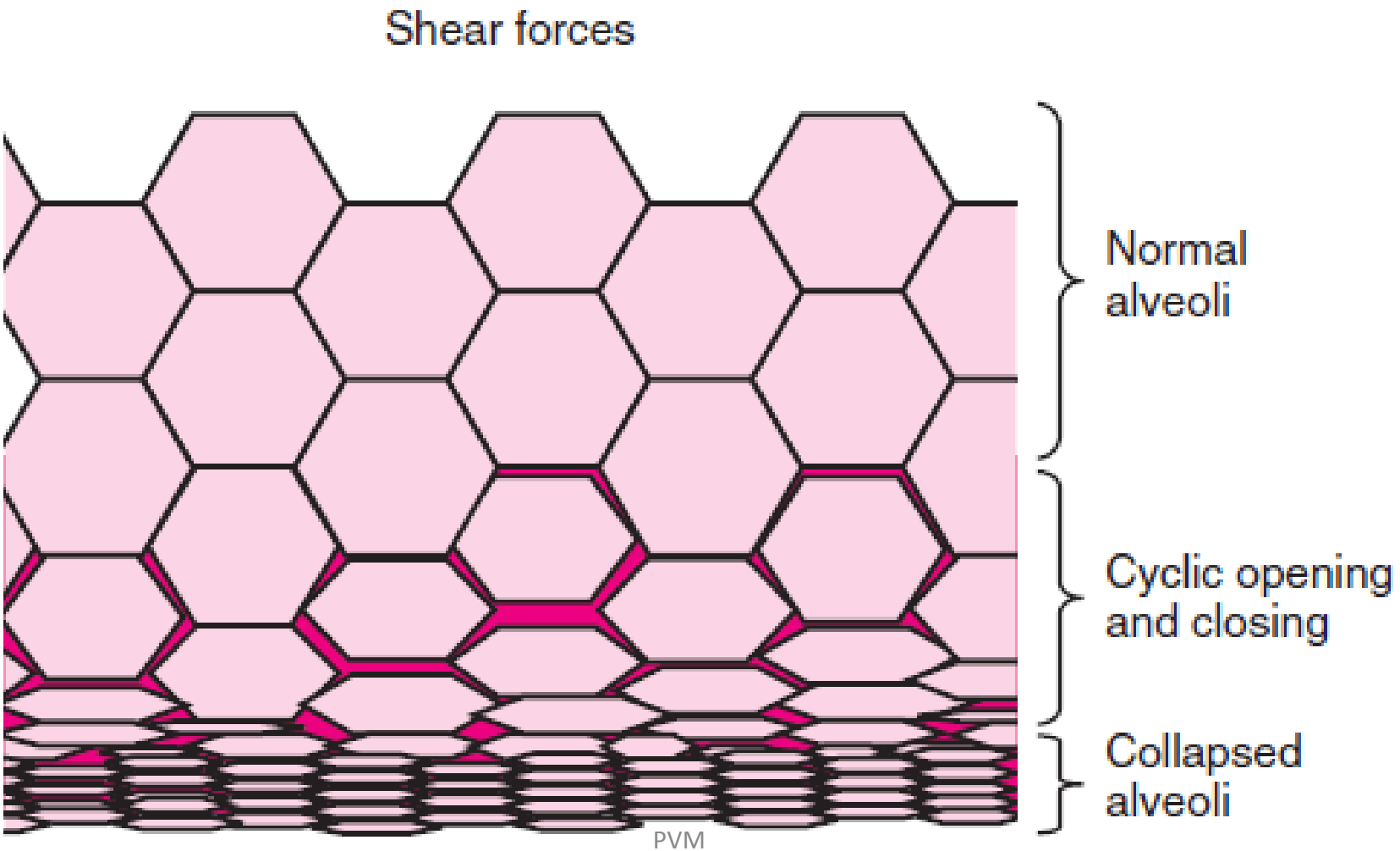
Atelectasia induzida pela VM

- Ateletrauma nas áreas colapsadas
- Diminuição da complacência
- Volutrauma e barotrauma nas regiões não colapsadas
- Hipoxemia
- Aumento da RVP



INFLAMAÇÃO

Atelectasia induzida pela VM

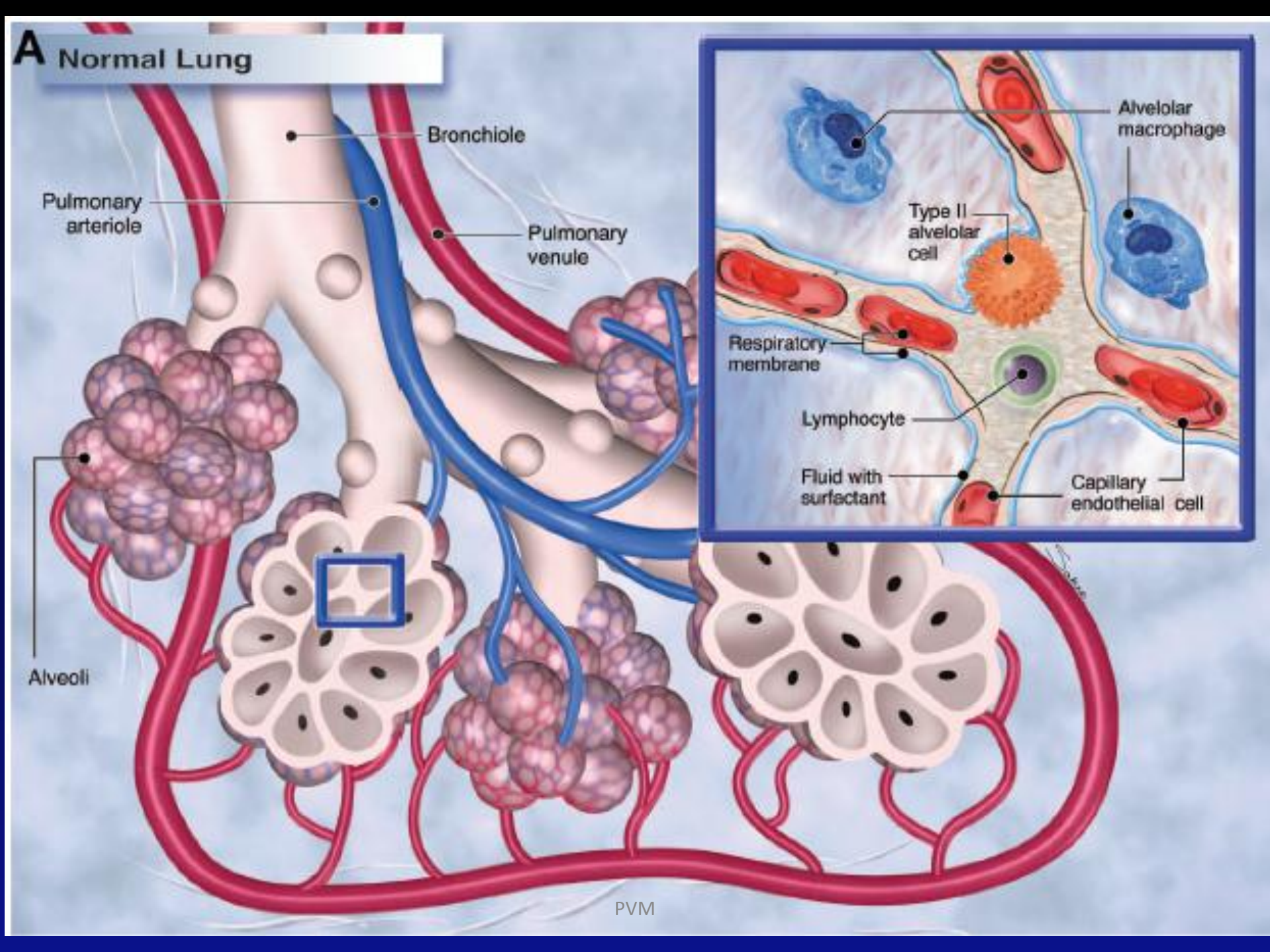


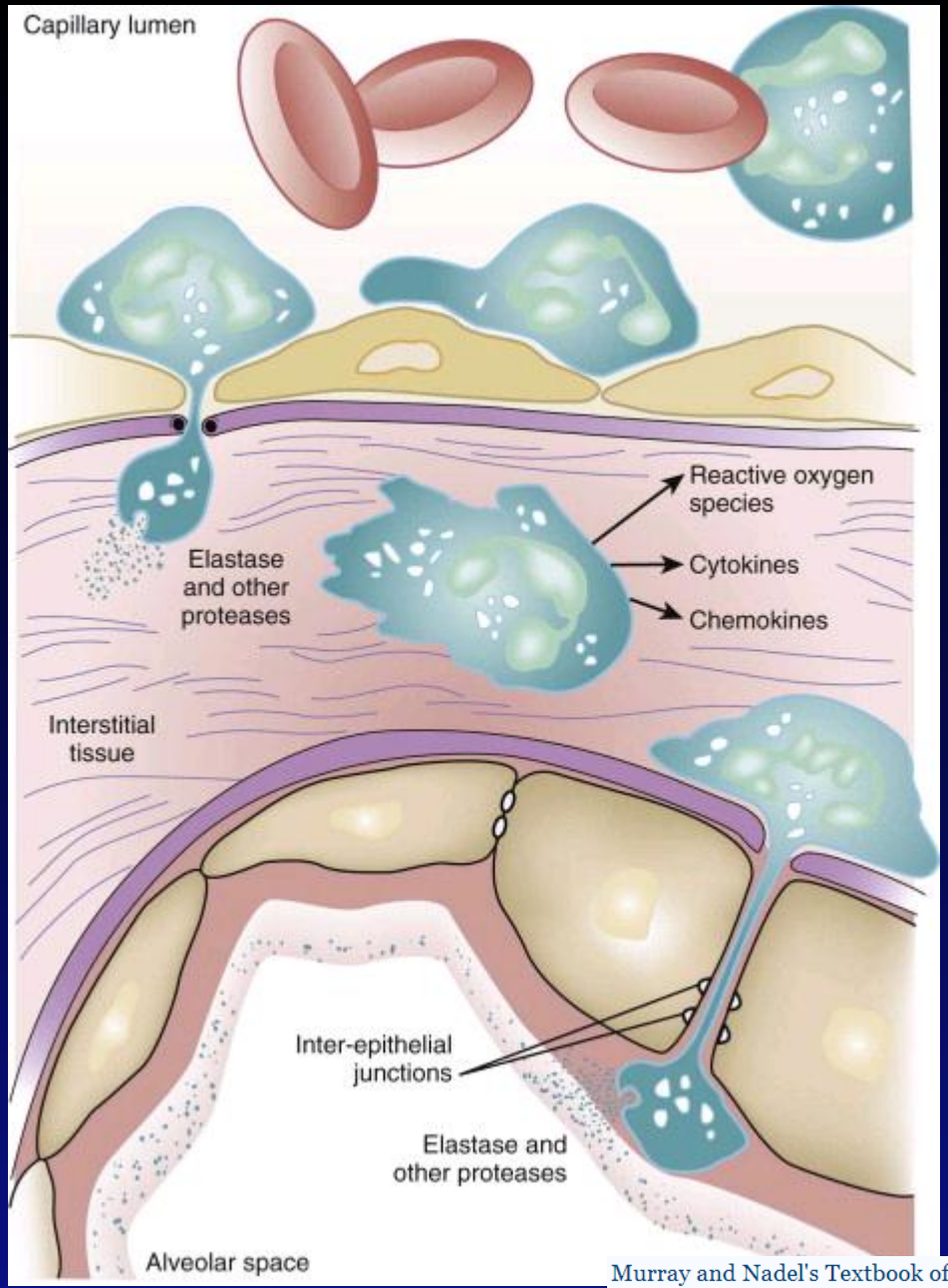
Mecanismos da Disfunção Pulmonar

- Atelectrauma
  - Recrutamento repetido
  - Estresse por cisalhamento

- Barotrauma: ruptura dos espaços aéreos e fuga de ar: Pneumomediastino / Enfisema subcutâneo / Pneumotórax

- Volutrauma: lesão por volume corrente alto
  - Grau de insuflação parece ser mais importe que os níveis de pressão


A Normal Lung
Bronchiole
Pulmonary arteriole
Pulmonary venule
Alveoli
Alvelolar macrophage
Type II alvelolar cell
Respiratory membrane
Lymphocyte
Fluid with surfactant
Capillary endothelial cell

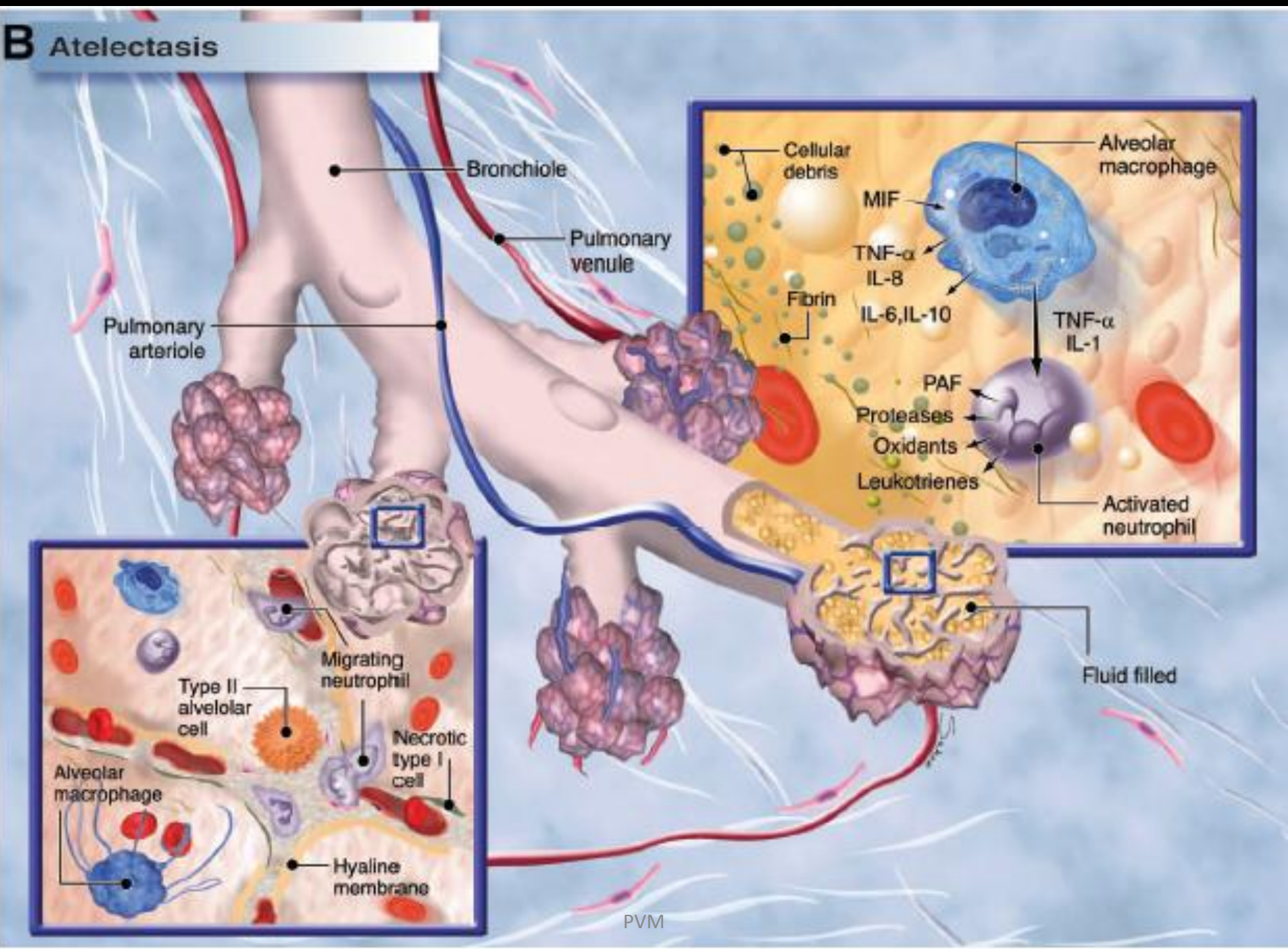


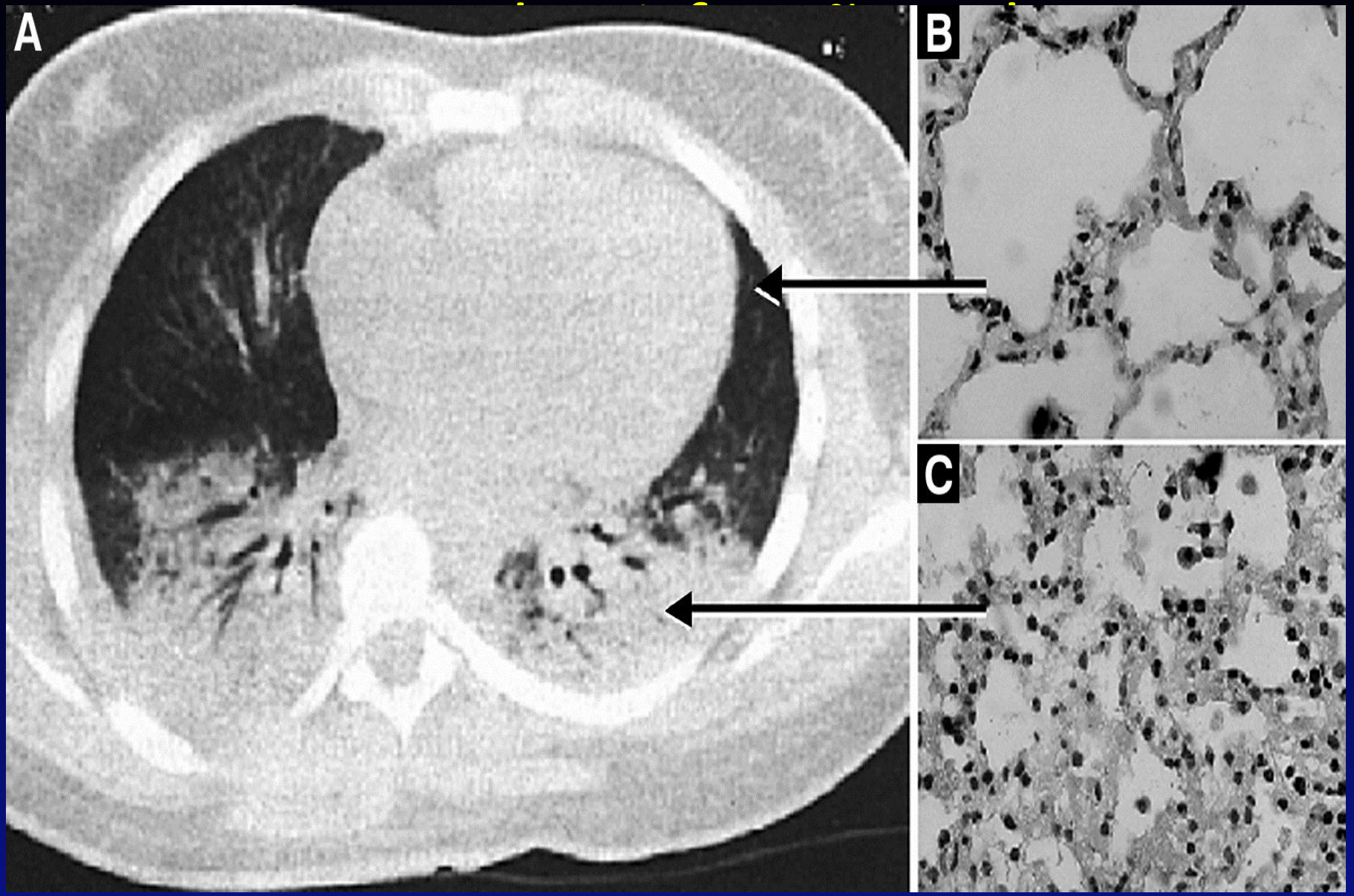
Murray and Nadel's Textbook of Respiratory Medicine , Fifth Edition

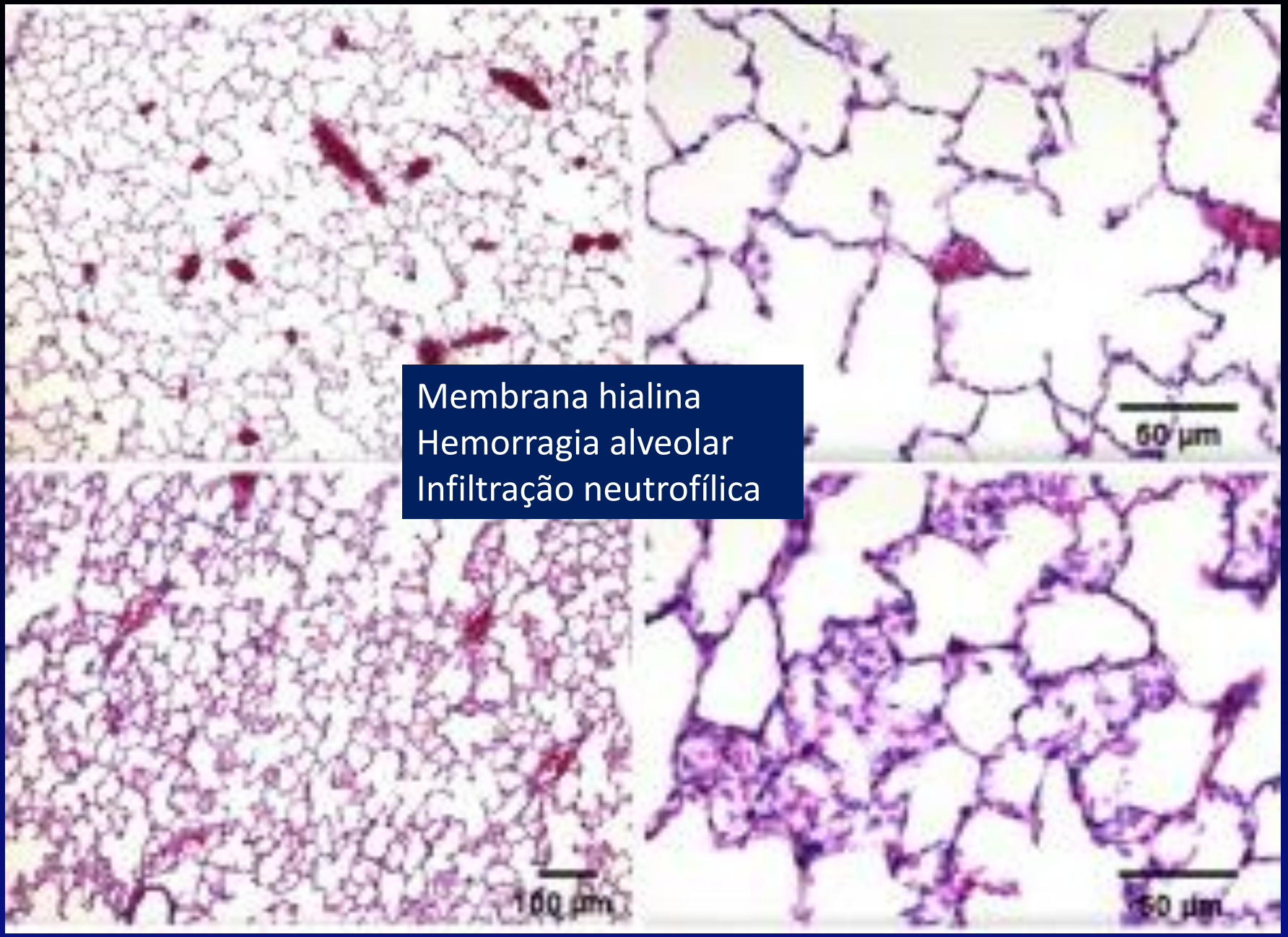
Robert J. Mason, V. Courtney Broaddus, Thomas R. Martin, Talmadge E. King, Dean E. Schraufnagel, John F. Murray, and Jay A. Nadel

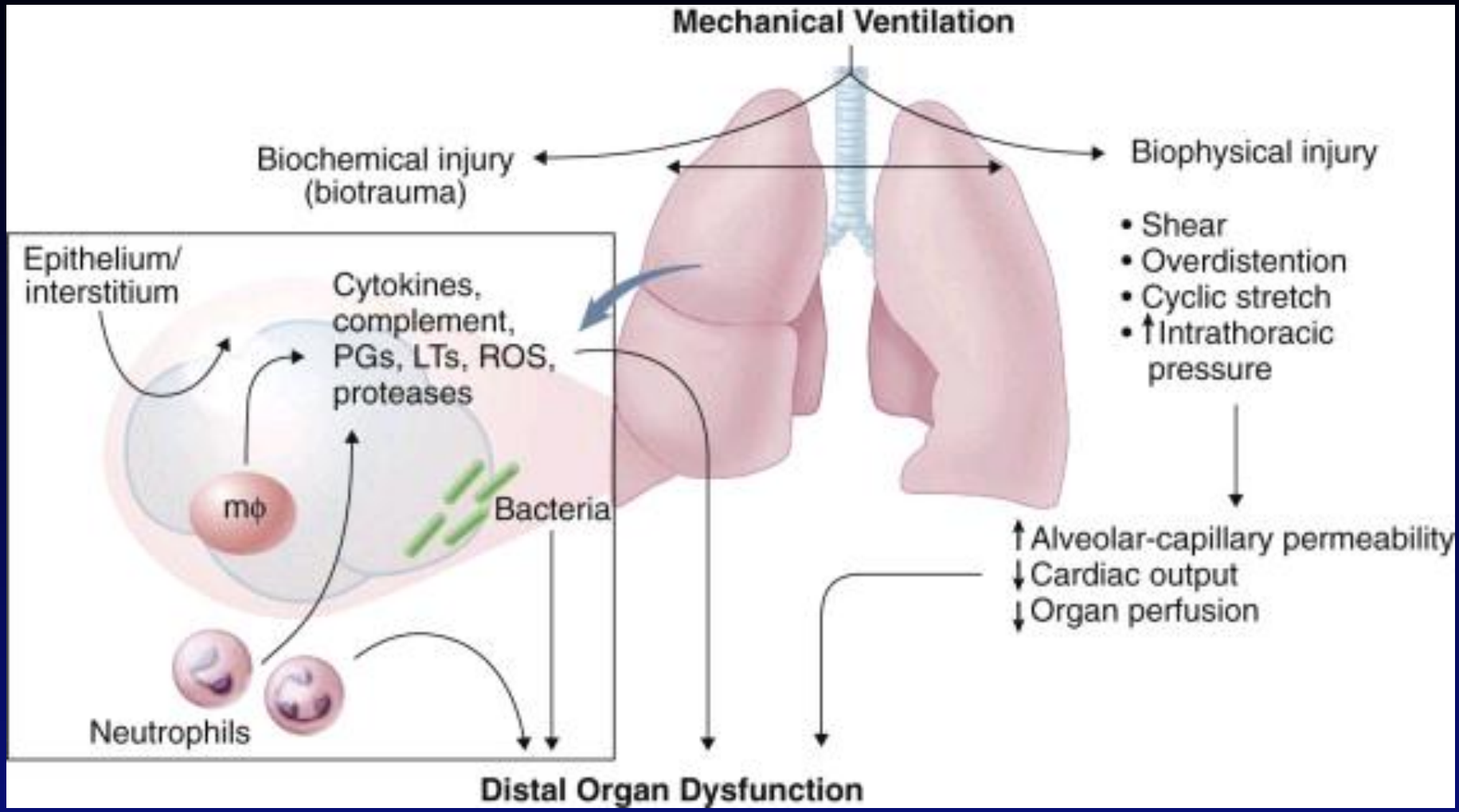
Chapter 90, 2104-2129

Copyright © 2010 by Saunders, an imprint of Elsevier Inc.


B Atelectasis
Bronchiole
Pulmonary venule
Pulmonary arteriole
Cellular debris
Alveolar macrophage
MIF
TNF-α
IL-8
IL-6,IL-10
Fibrin
TNF-α
IL-1
PAF
Proteases
Oxidants
Leukotrienes
Activated neutrophil
Migrating neutrophil
Type II alveolar cell
Necrotic type I cell
Alveolar macrophage
Hyaline membrane
Fluid filled

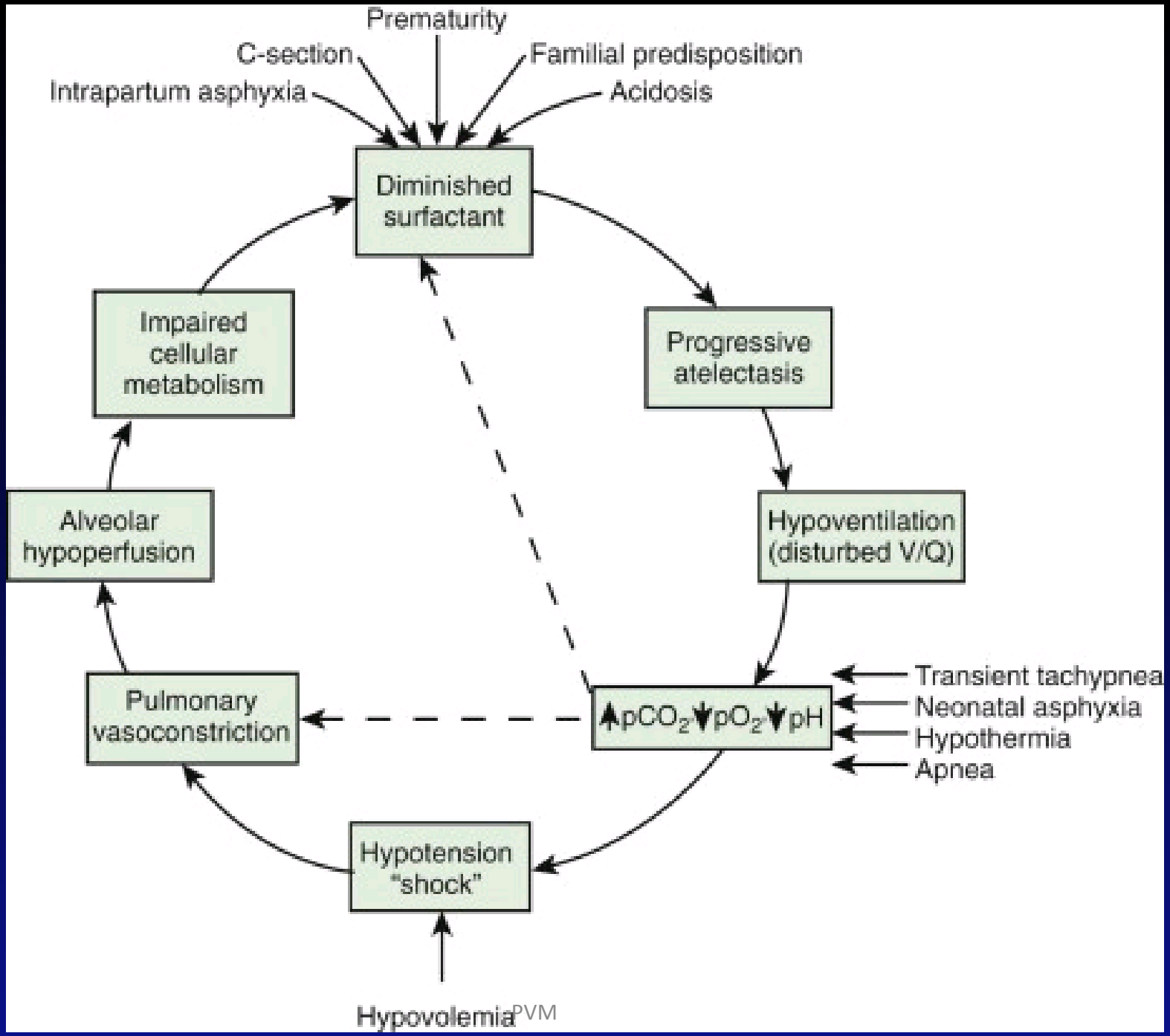

A
B
C

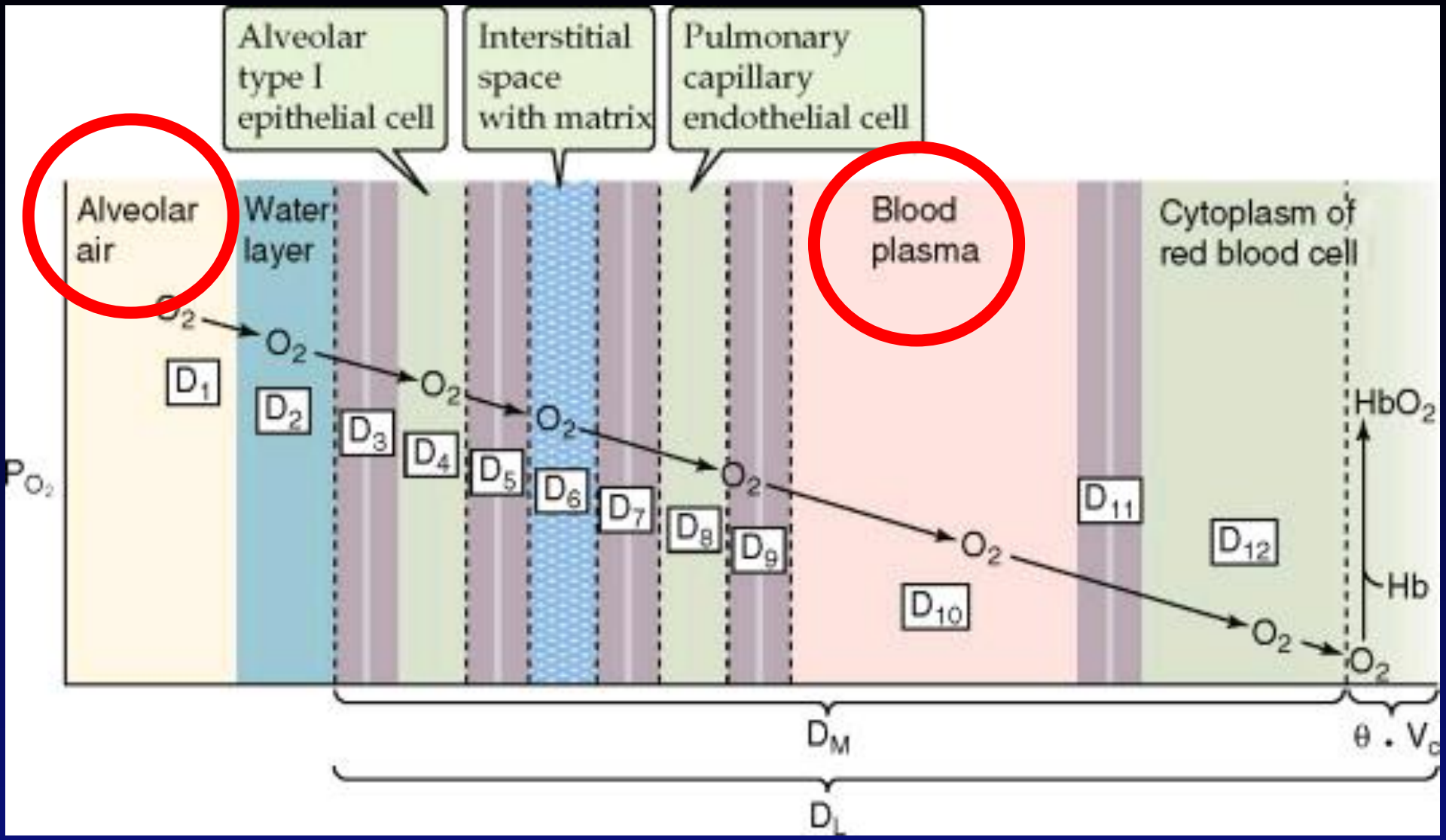

Membrana hialina
Hemorragia alveolar
Infiltração neutrofílica
50 µm
100 µm
50 µm

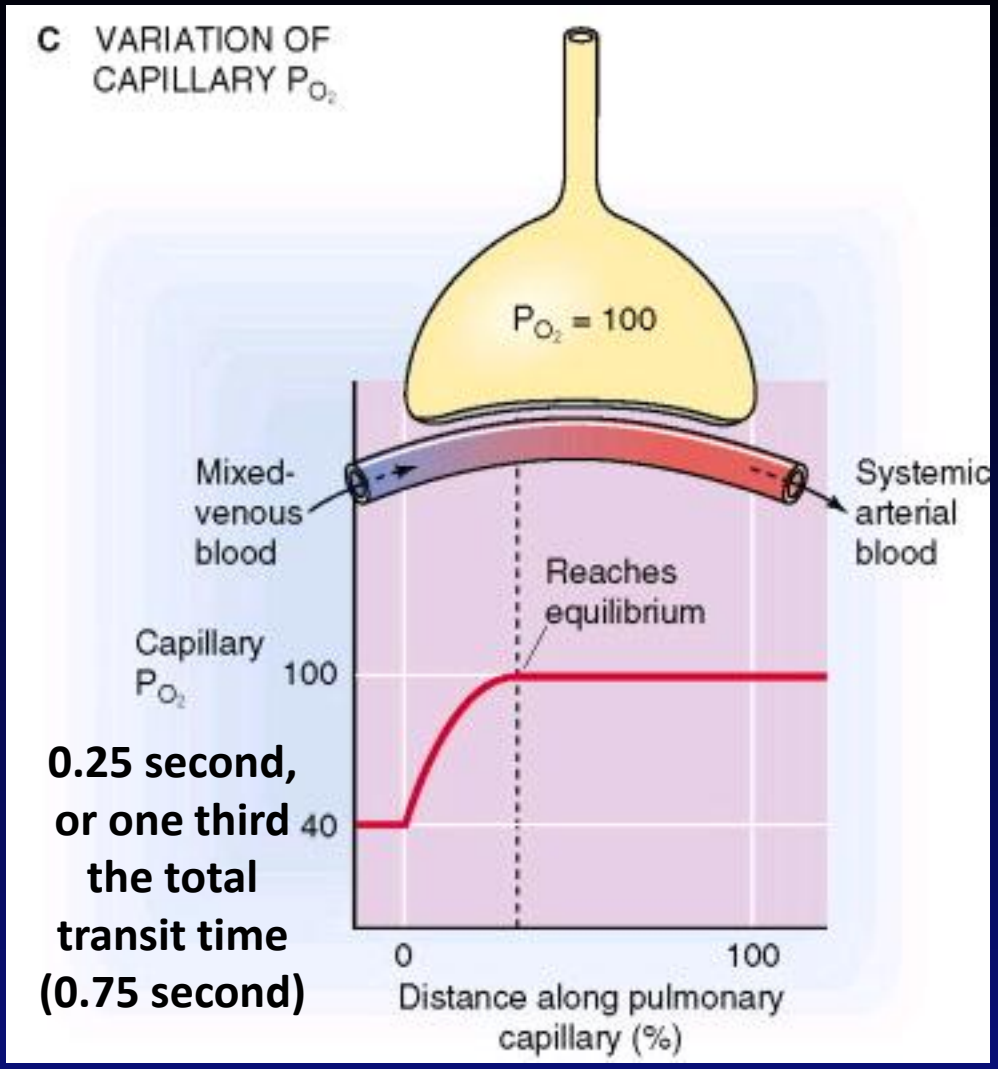


Goldman's Cecil Medicine , Twenty-Fourth Edition

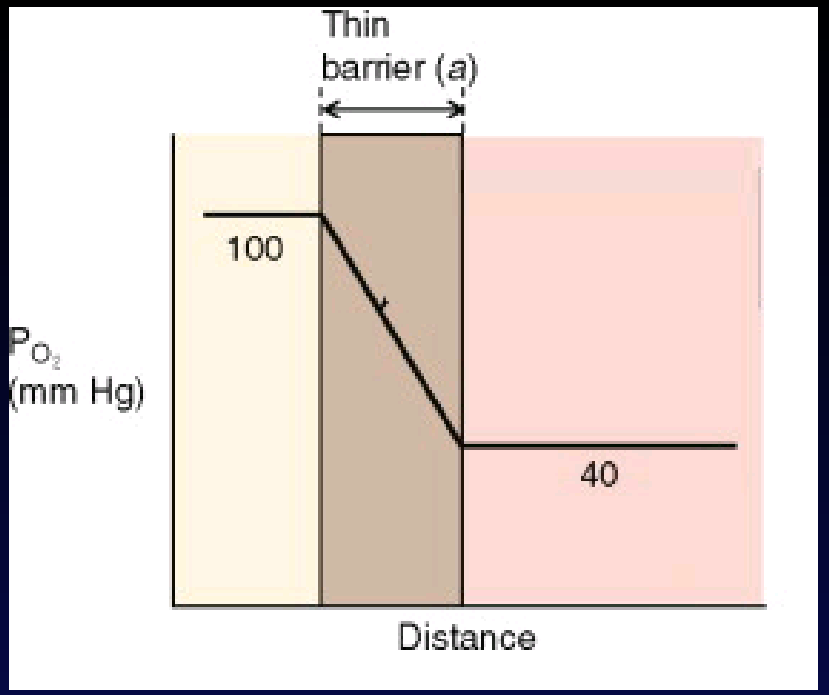
Lee Goldman, and Andrew I. Schafer

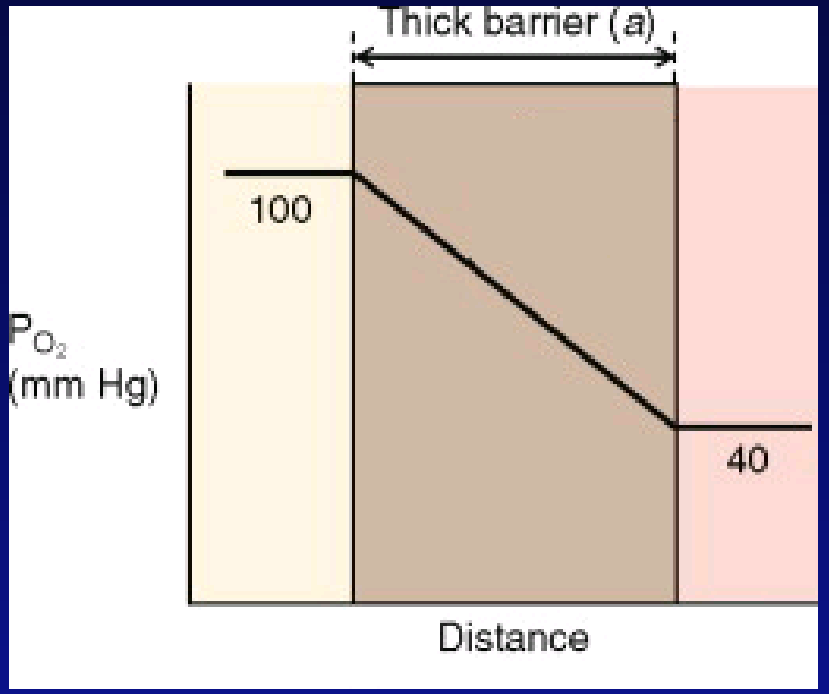

Prematurity
C-section
Familial predisposition
Intrapartum asphyxia
Acidosis
Diminished surfactant
Impaired cellular metabolism
Progressive atelectasis
Alveolar hypoperfusion
Hypoventilation (disturbed V/Q)
Pulmonary vasoconstriction
↑pCO2 ↓pO2 ↓pH
Transient tachypnea
Neonatal asphyxia
Hypothermia
Apnea
Hypotension "shock"
Hypovolemia
PVM


Alveolar type I epithelial cell
Interstitial space with matrix
Pulmonary capillary endothelial cell
Alveolar air
Water layer
Blood plasma
Cytoplasm of red blood cell
O_2
D_1
D_2
D_3
D_4
D_5
D_6
D_7
D_8
D_9
D_{10}
D_{11}
D_{12}
HbO_2
Hb
P_{O_2}
D_M
$\theta \cdot V_c$
D_L



0.25 second, or one third the total transit time (0.75 second)





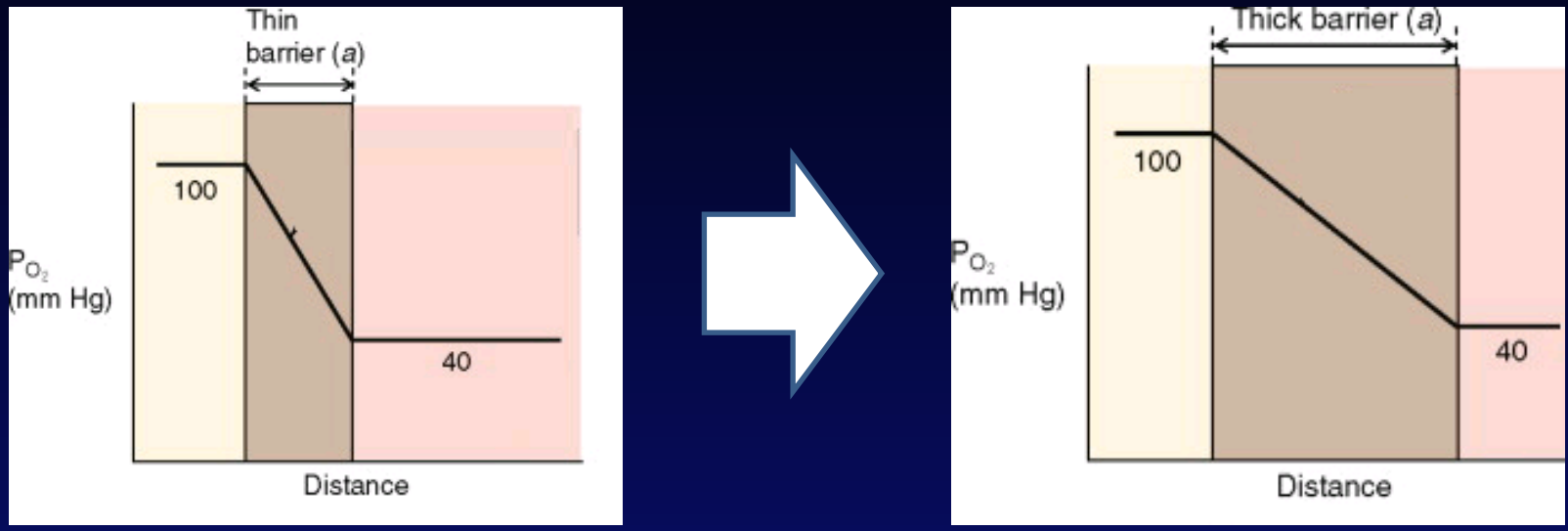
Medical Physiology , Updated Second Edition

Walter F. Boron, and Emile L. Boulpaep

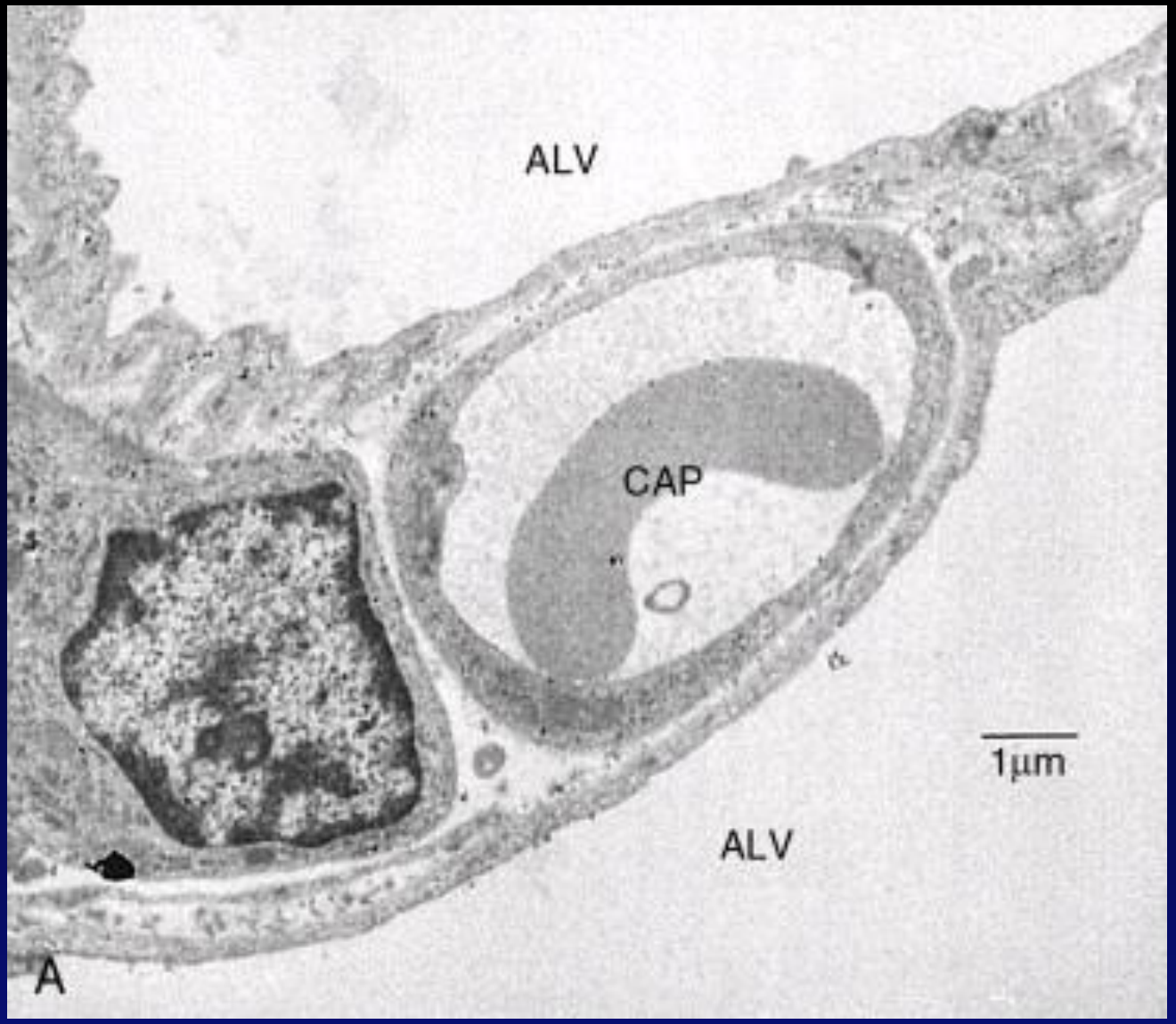
CHAPTER 30, 685-699

PVM

Inflamação

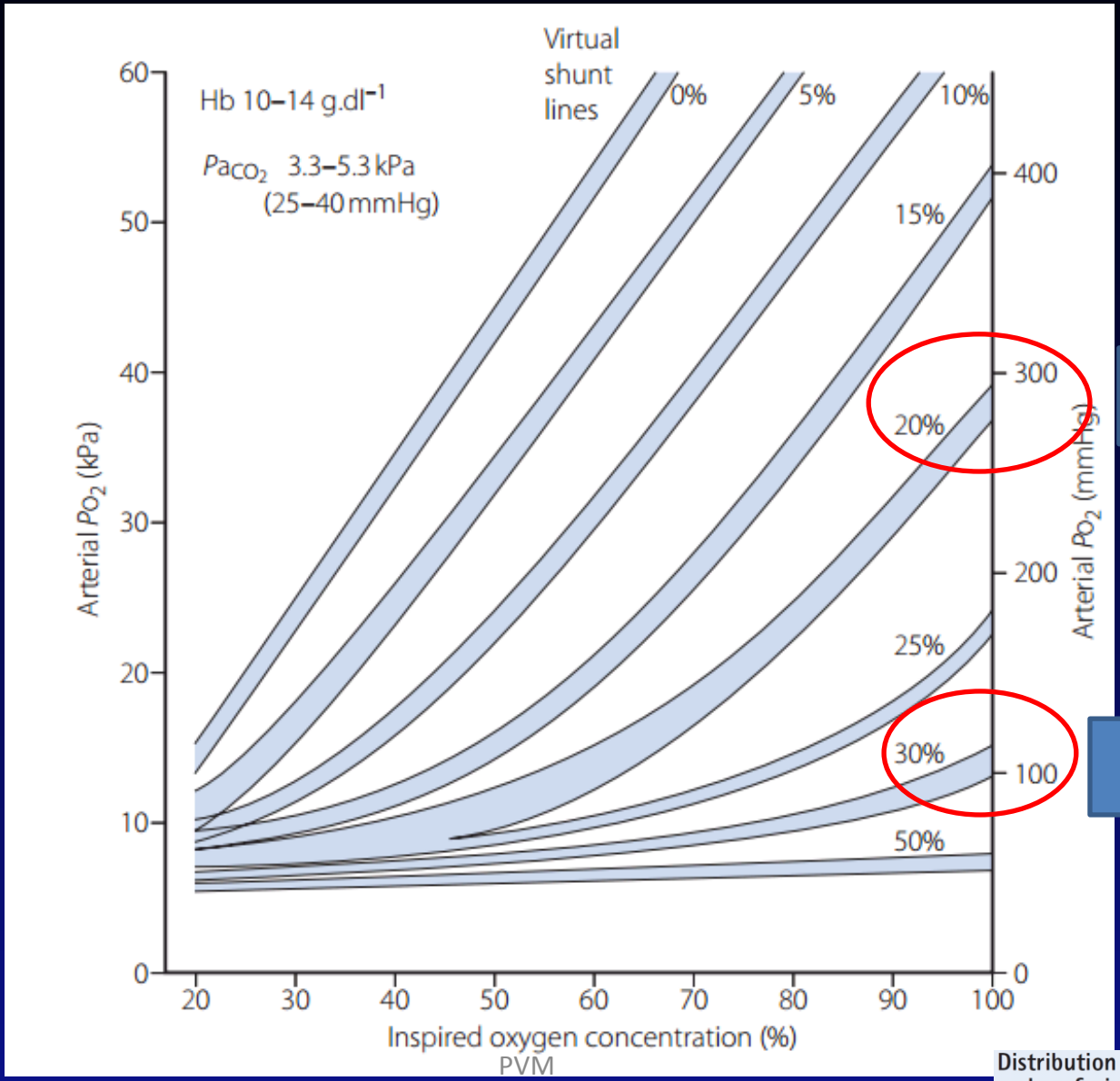


- Peep, FiO2, I/E, Aumentar fluxo, Pausa Ins.



A, Electrophotomicrograph of a type I pneumocyte. Note the thin alveolar-arterial interface.

Distribution of pulmonary ventilation and perfusion



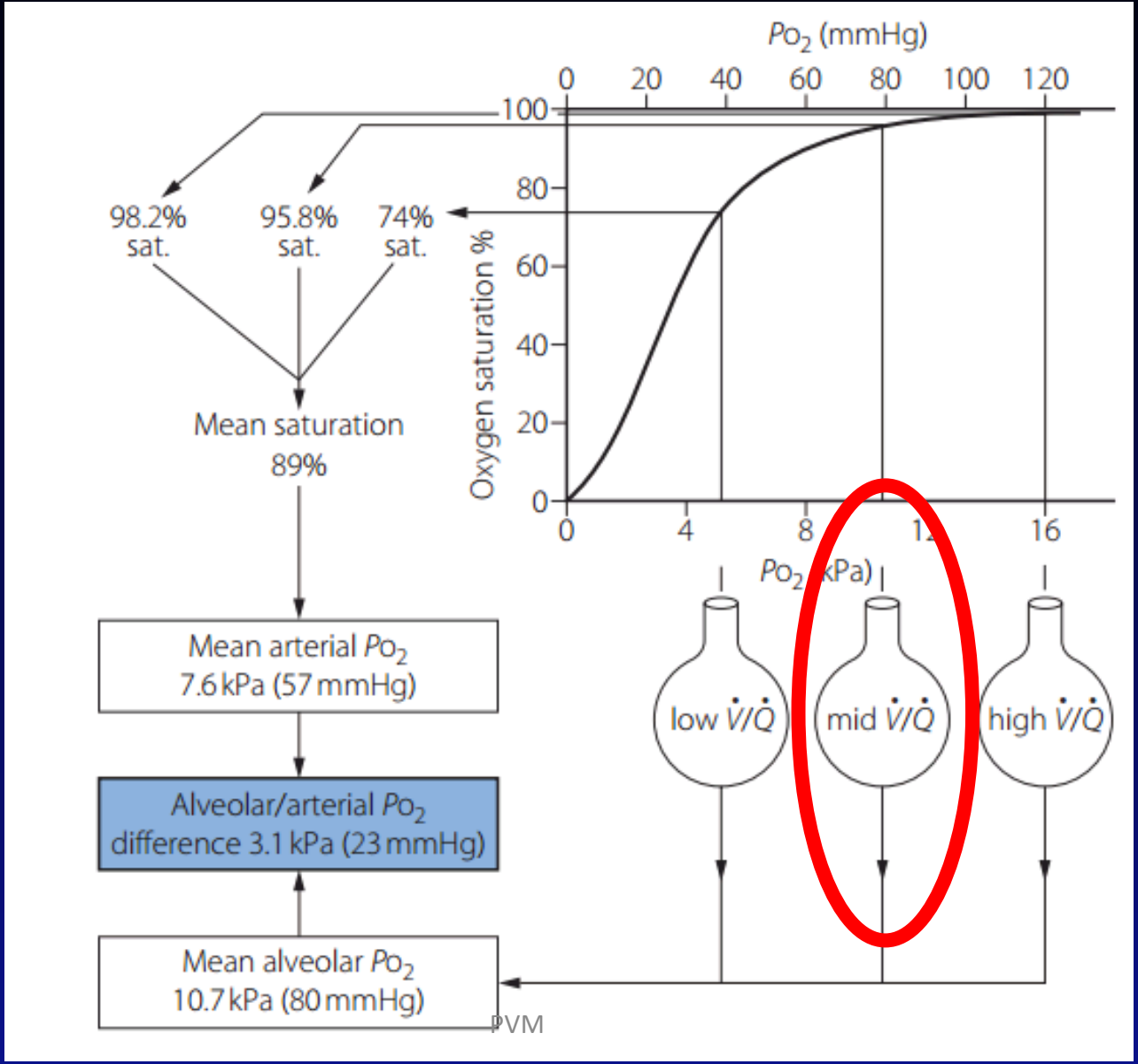
P/F = 285

P/F = 100

PVM

Distribution of pulmonary ventilation and perfusion

Distribution of pulmonary ventilation and perfusion

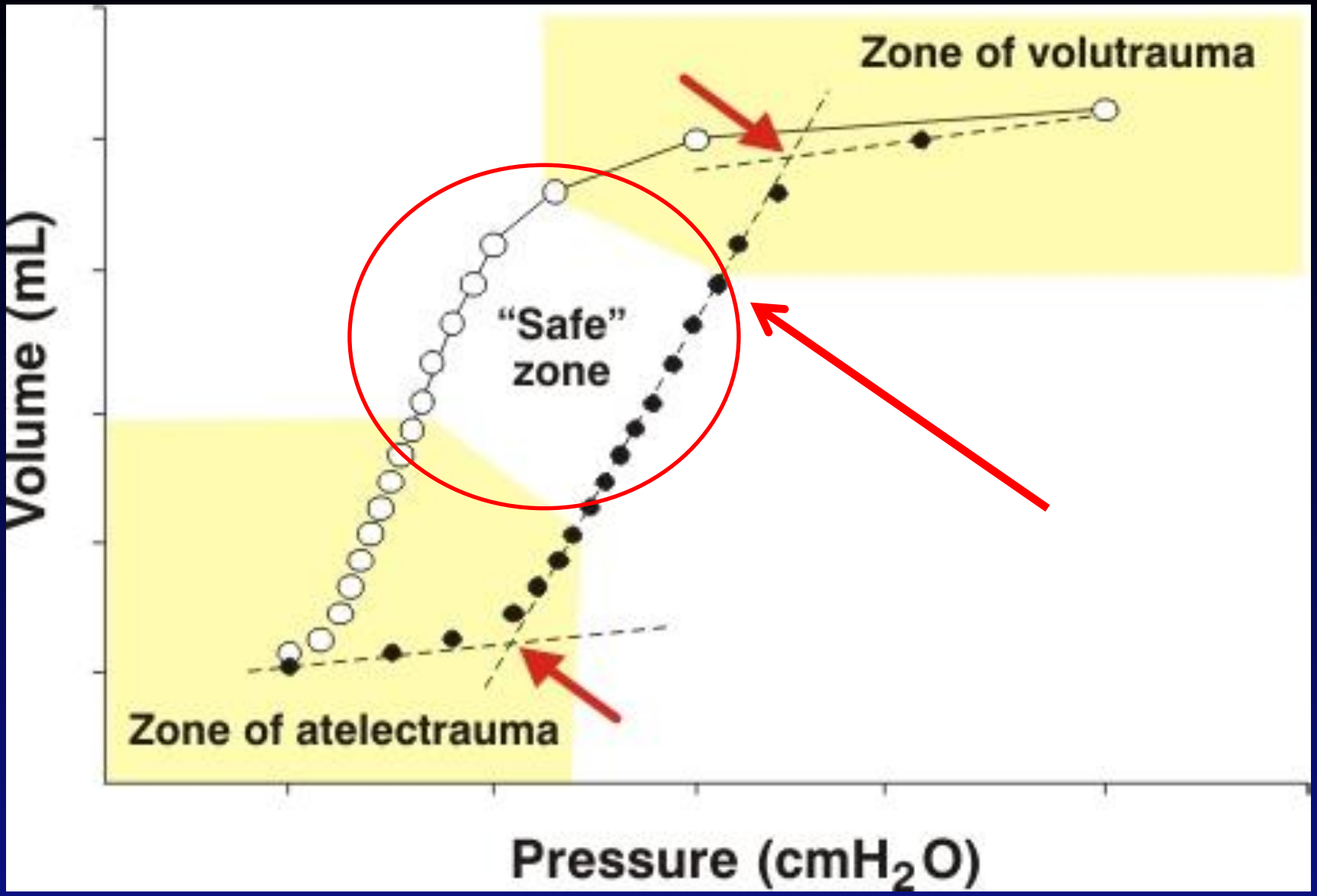


Abordagem da Disfunção Pulmonar

PEEP IDEAL

+

PARÂMETROS MÍNIMOS DE VENTILAÇÃO


Zone of volutrauma
"Safe" zone
Zone of atelectrauma
Volume (mL)
Pressure (cmH_2O)

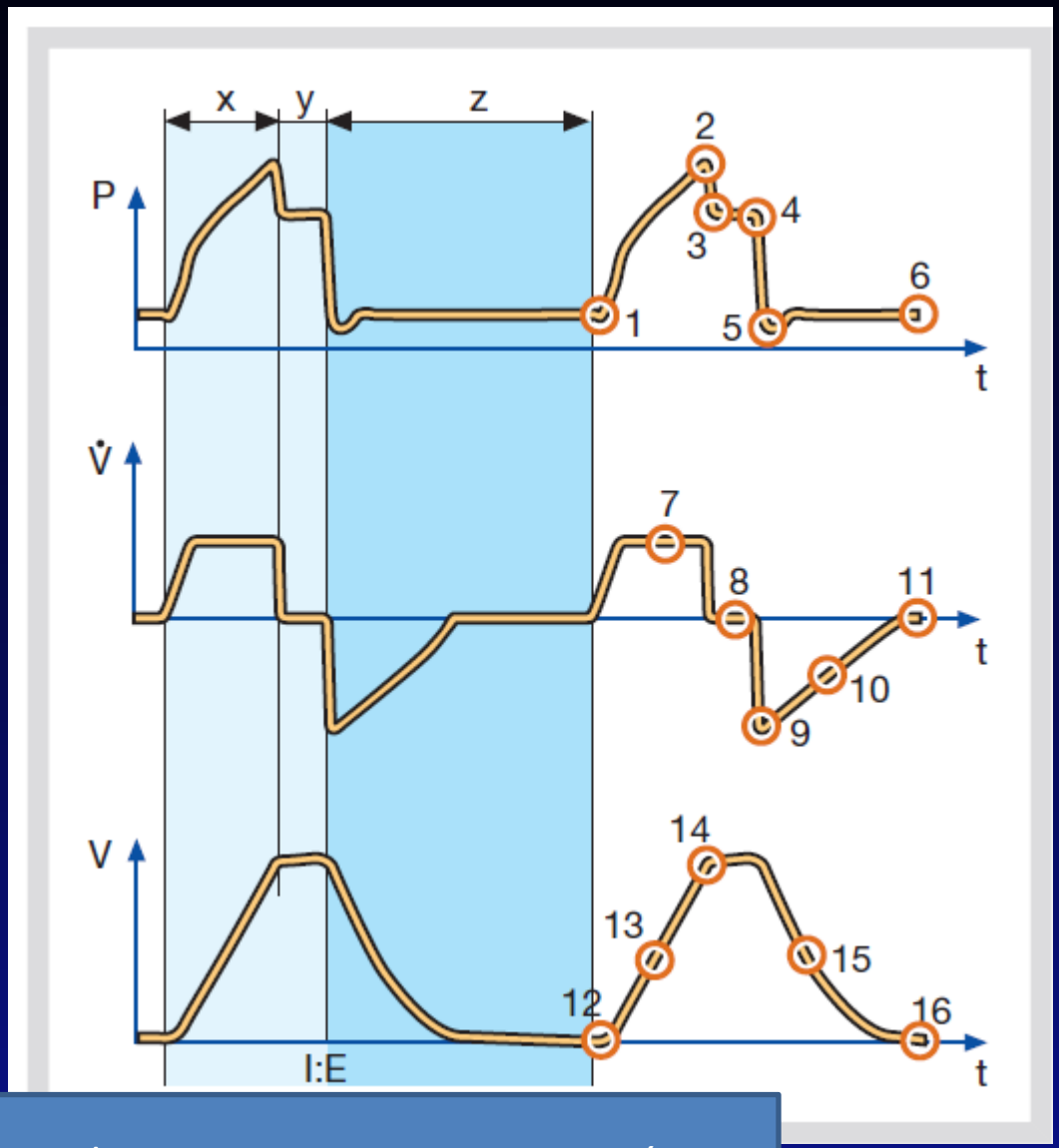
Objetivos da VM

- Manter troca gasosa com o mínimo de lesão pulmonar e lesão hemodinâmica
- Reduzir o trabalho respiratório

- Evidência esmagadora de que o volume corrente é o principal determinante da injuria pulmonar

Volume corrente, FR, I:E

Disparo: Tempo Ex FR 30/min➔ 1ciclo/2seg
Ciclagem: volume. Pode adicionar platô.



Fluxo: calculado baseado no Vt e no tempo inspiratório.

Ciclo a volume

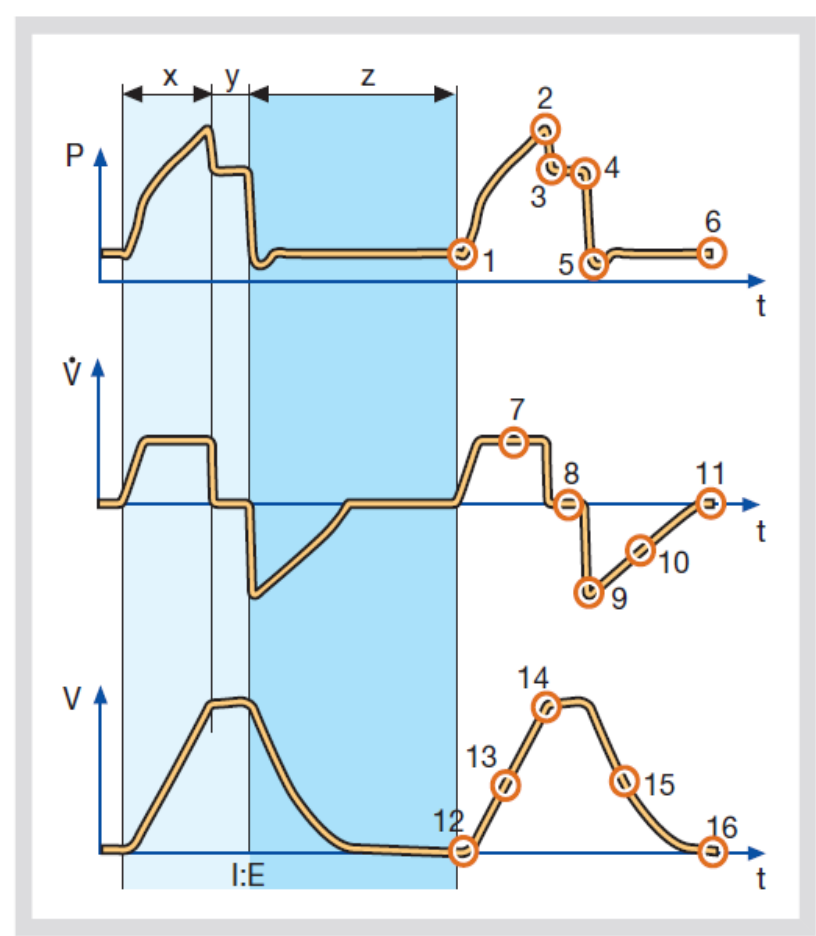
- Ex: FR 10; I:E 1:2; Vt 500ml

60segundos:10= 6segundos/ciclo

I:E 1:2 2:4

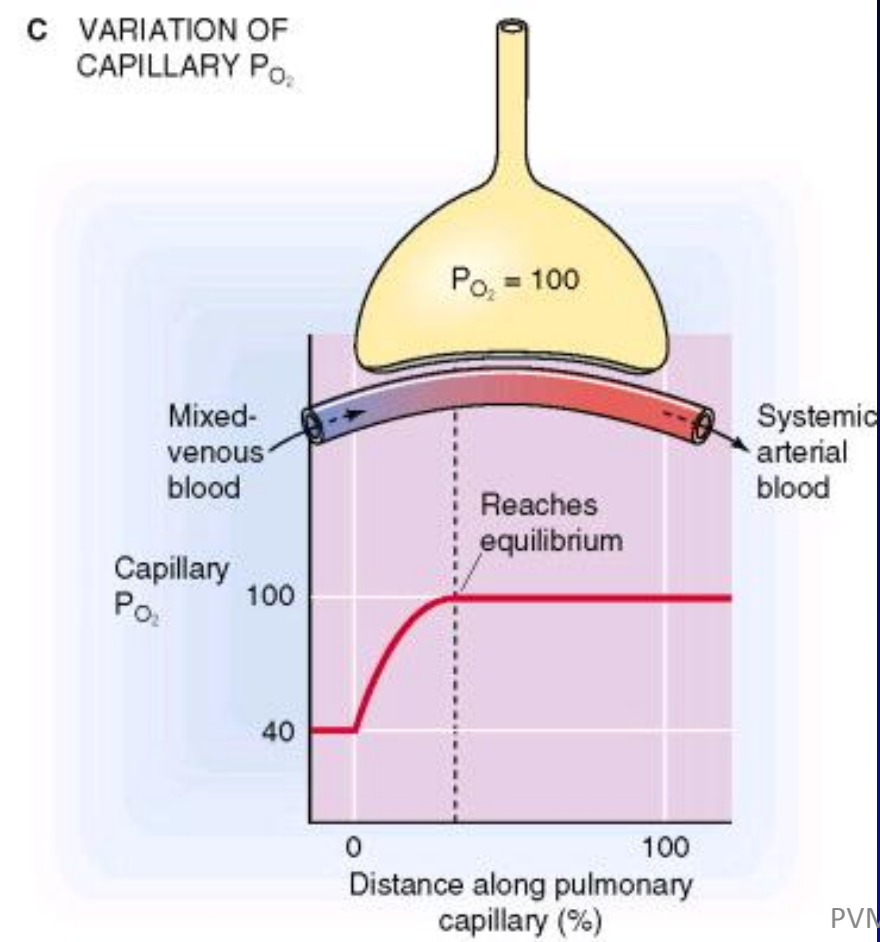
500ml/2= 150ml/s

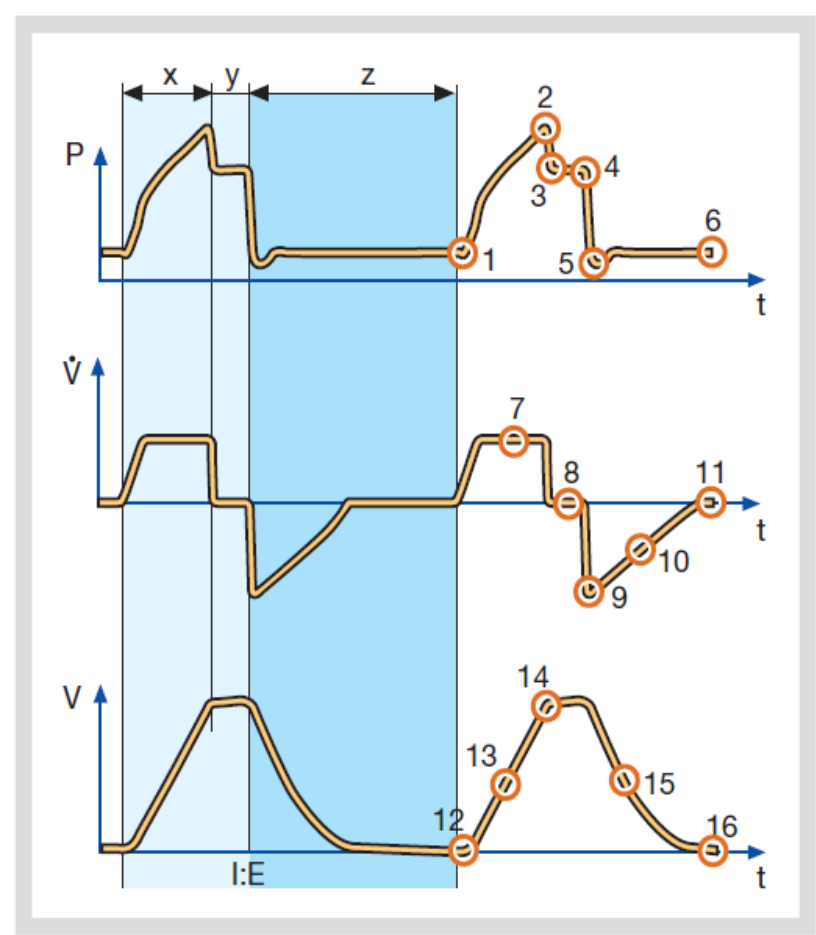
50%de pausa: 500ml/1s= 500ml/s



Ciclo a volume

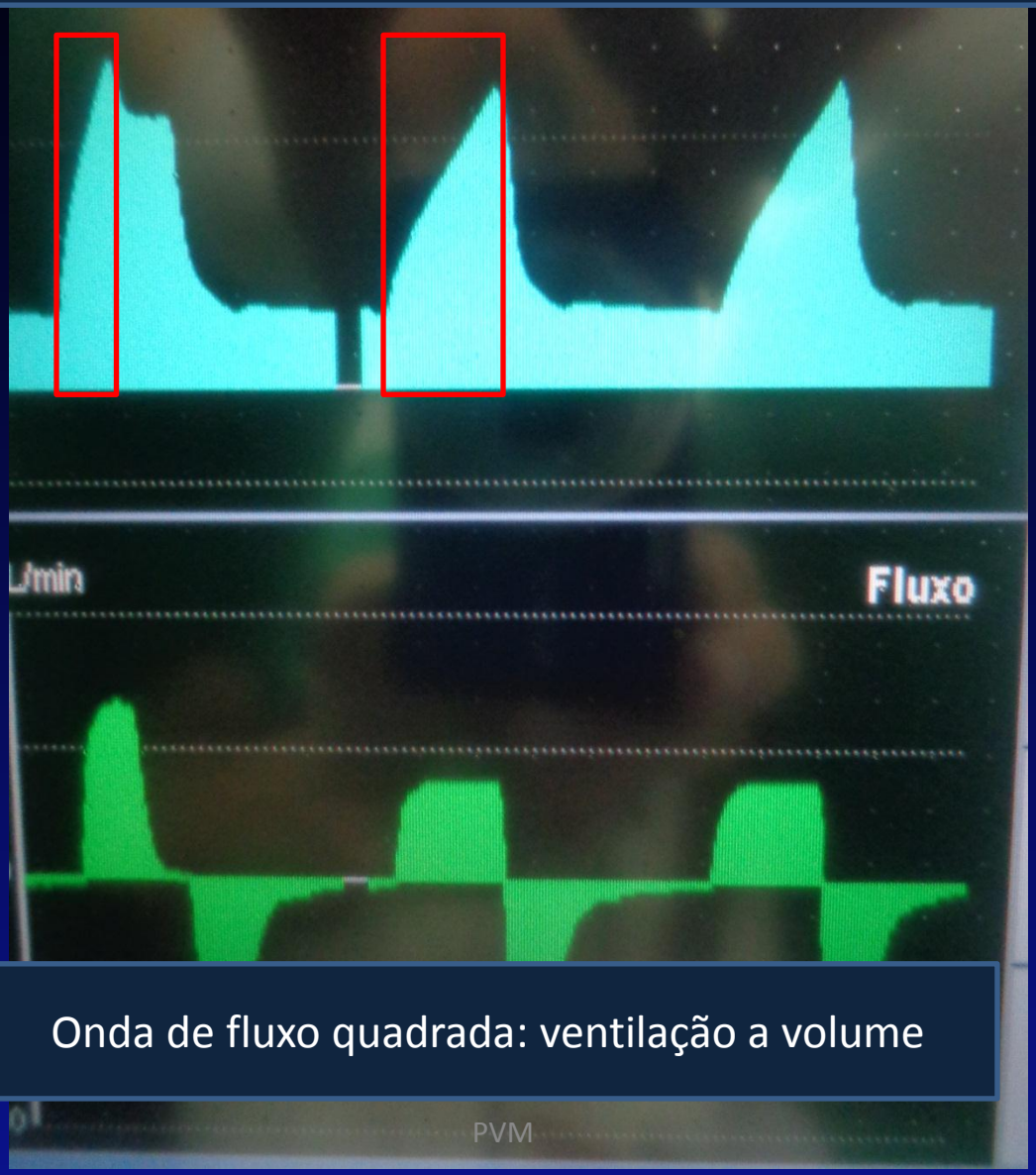
- Pausa inspiratória





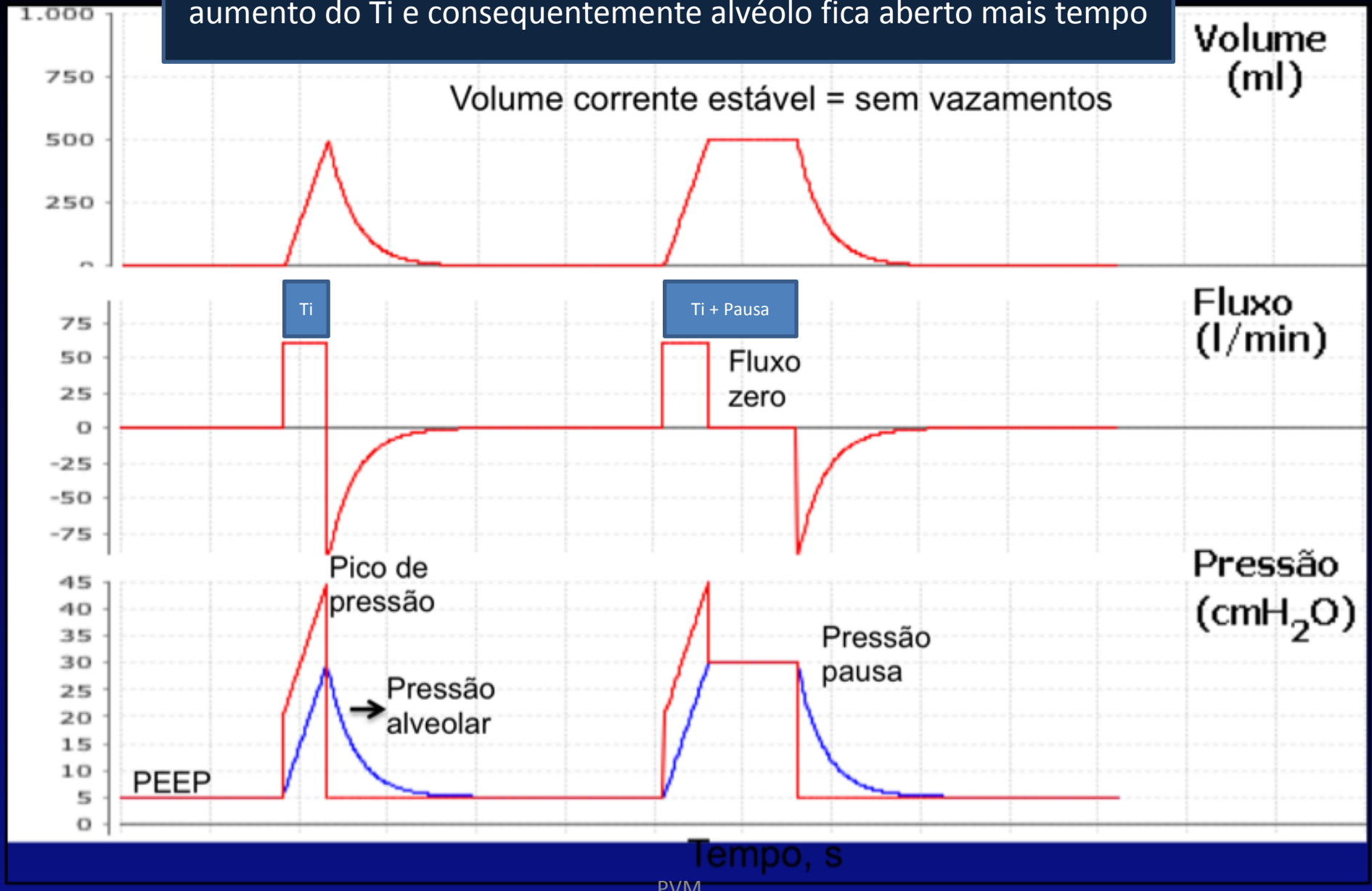

H2O
Pva
L/min
Fluxo
PVM

Pausa inspiratória de 50%(1): Vt é oferecido em metade do Ti.
Sem pausa(2) Vt é oferecido durante todo o Ti.
A pausa permite enchimento alveolar mais rápido.

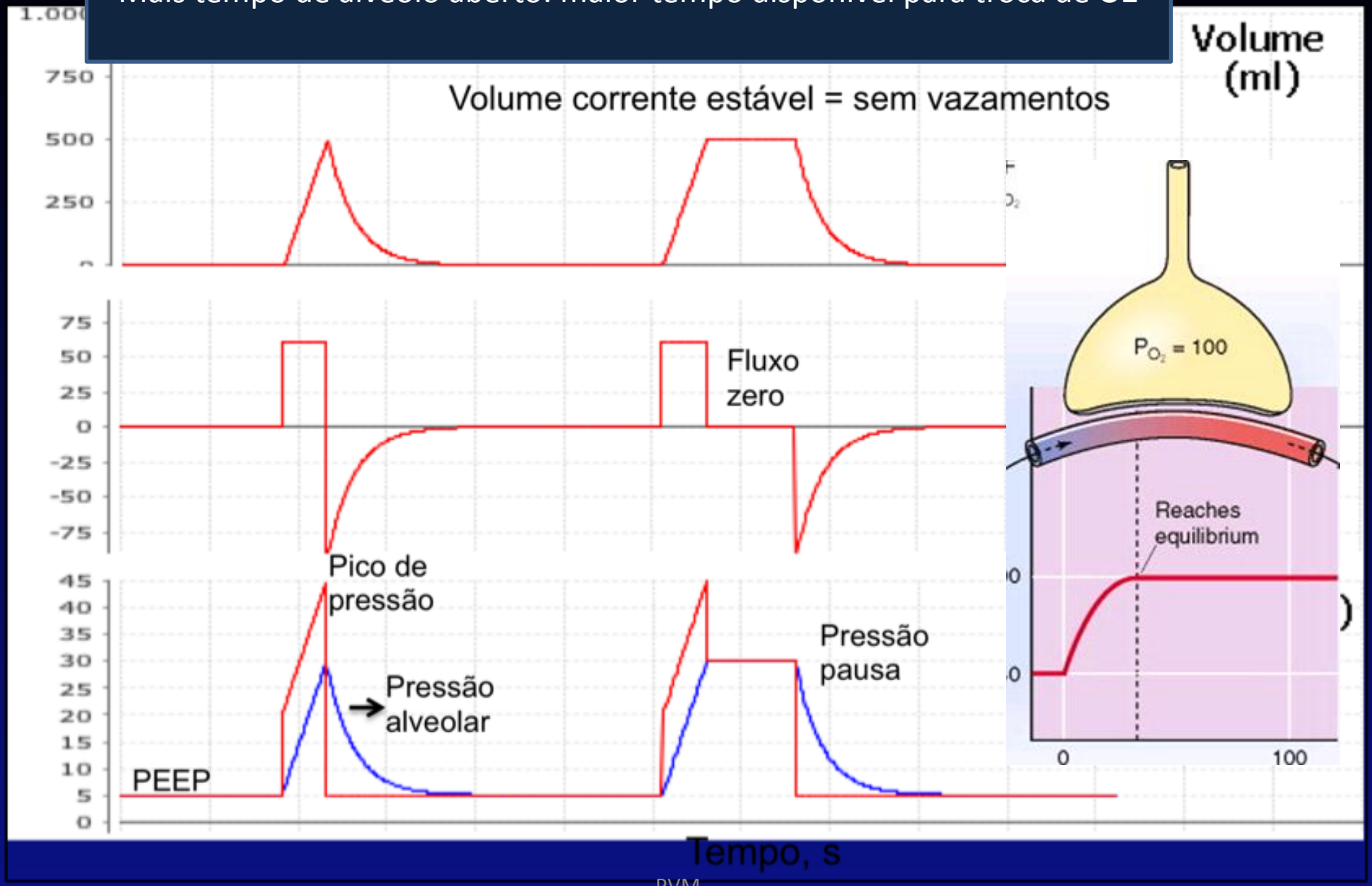


Onda de fluxo quadrada: ventilação a volume

Onda de fluxo quadrada: ciclo a volume. Pausa inspiratória: observe aumento do Ti e consequentemente alvéolo fica aberto mais tempo



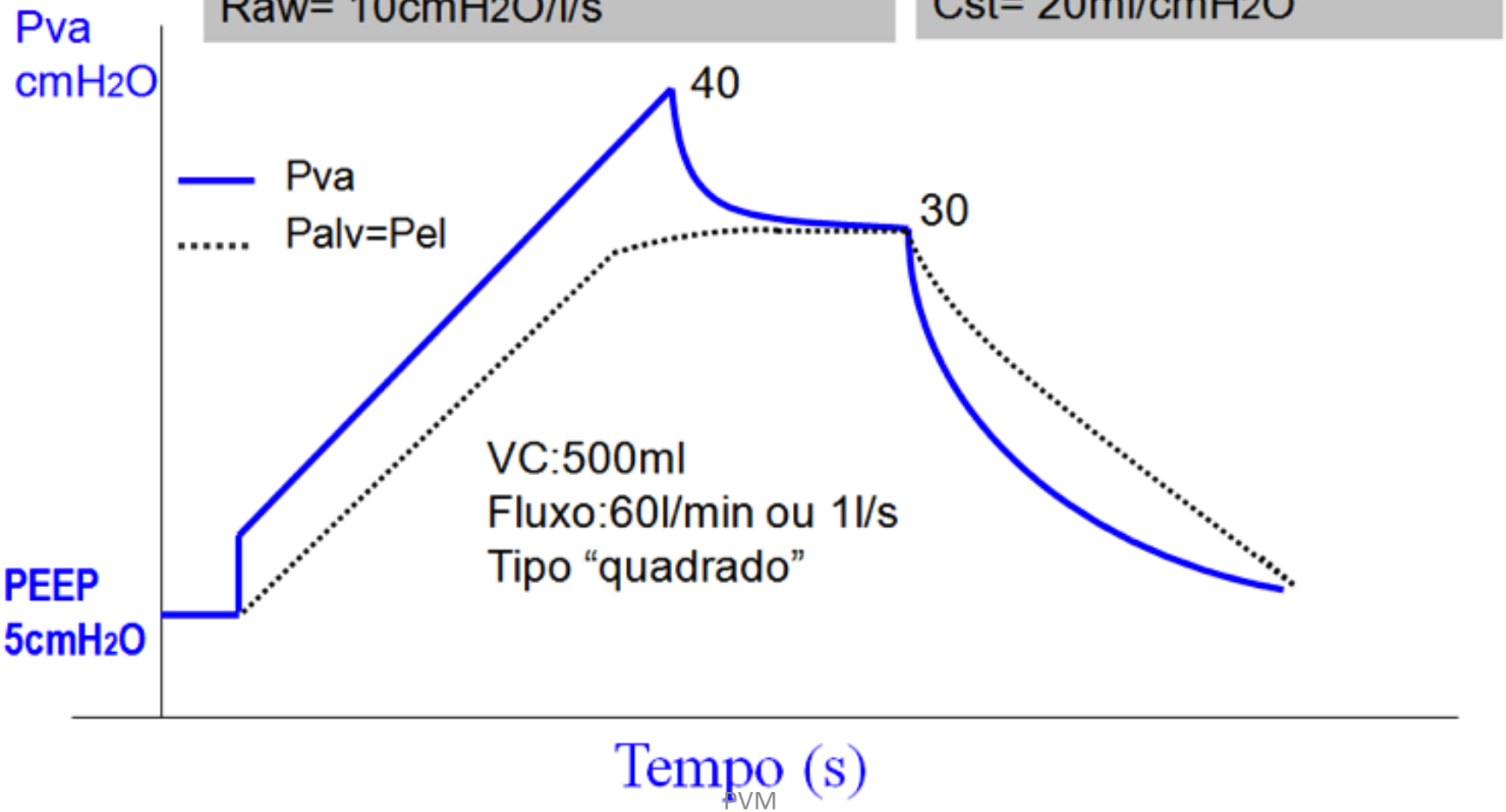
Mais tempo de alvéolo aberto: maior tempo disponível para troca de O2



Mensuração da resistência de vias aéreas (Raw) e da complacência estática (Cst) do sistema respiratório na VCV, modo controlado

Raw= (Ppressão – Pausa)/Fluxo
Raw= 40-30/1
Raw= 10cmH2O/l/s

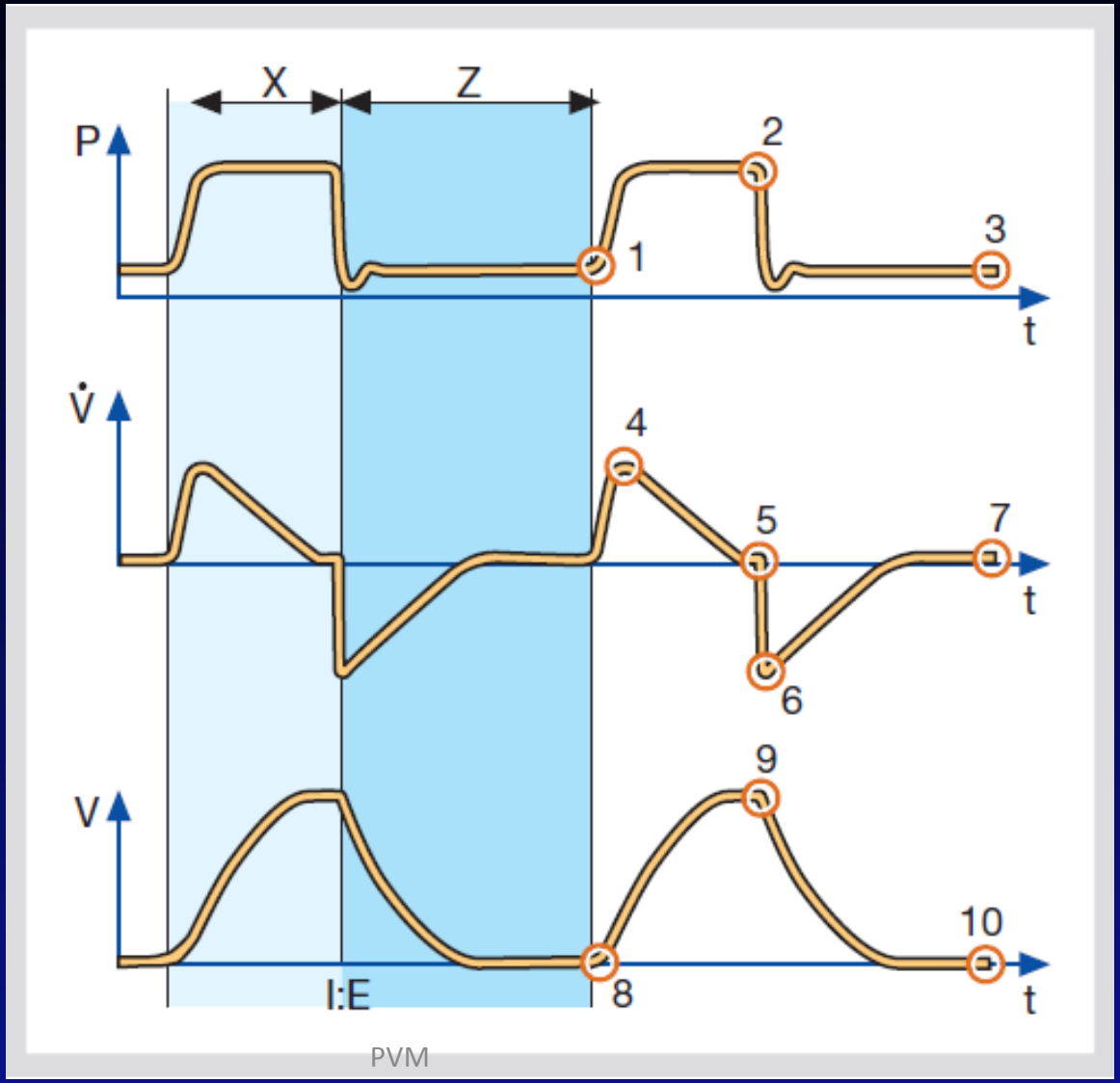
Cst= VC/ (Ppausa – PEEP)
Cst= 500/30-5
Cst= 20ml/cmH2O



Pressão inspiratória, FR, I:E

Disparo: Tempo Ex FR 30/min➔ 1ciclo/2seg
Ciclagem: tempo (pressão alvo controlada).

Fluxo: descendente.



Ciclo a Pressão

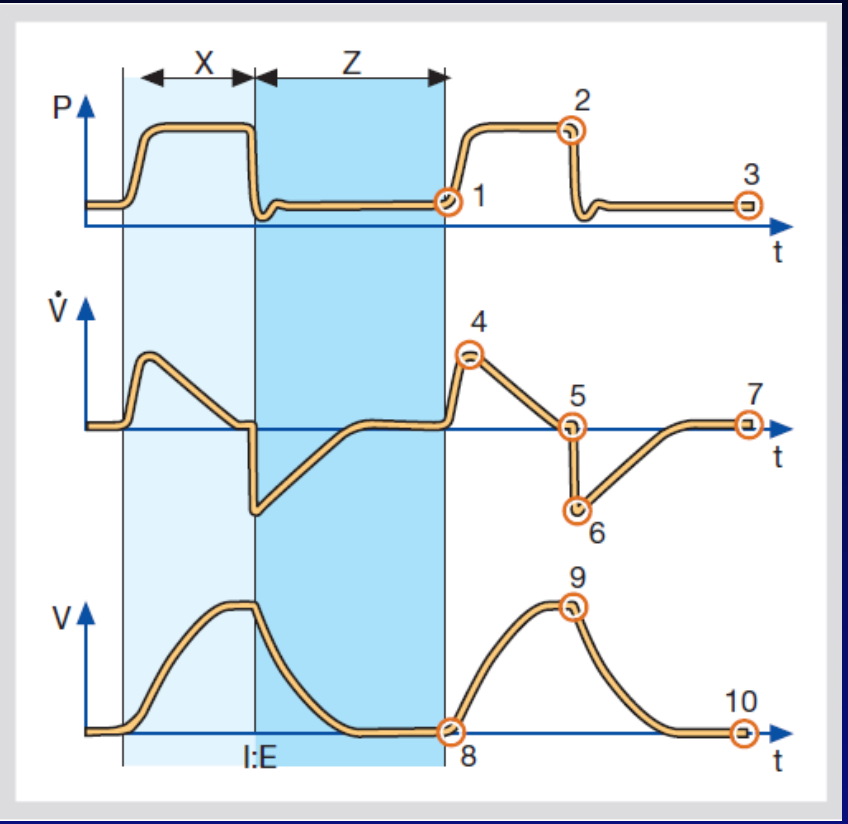
- Ex: FR 40; I:E 1:2; Pi 20

60segundos:40= 1,5segundos/ciclo

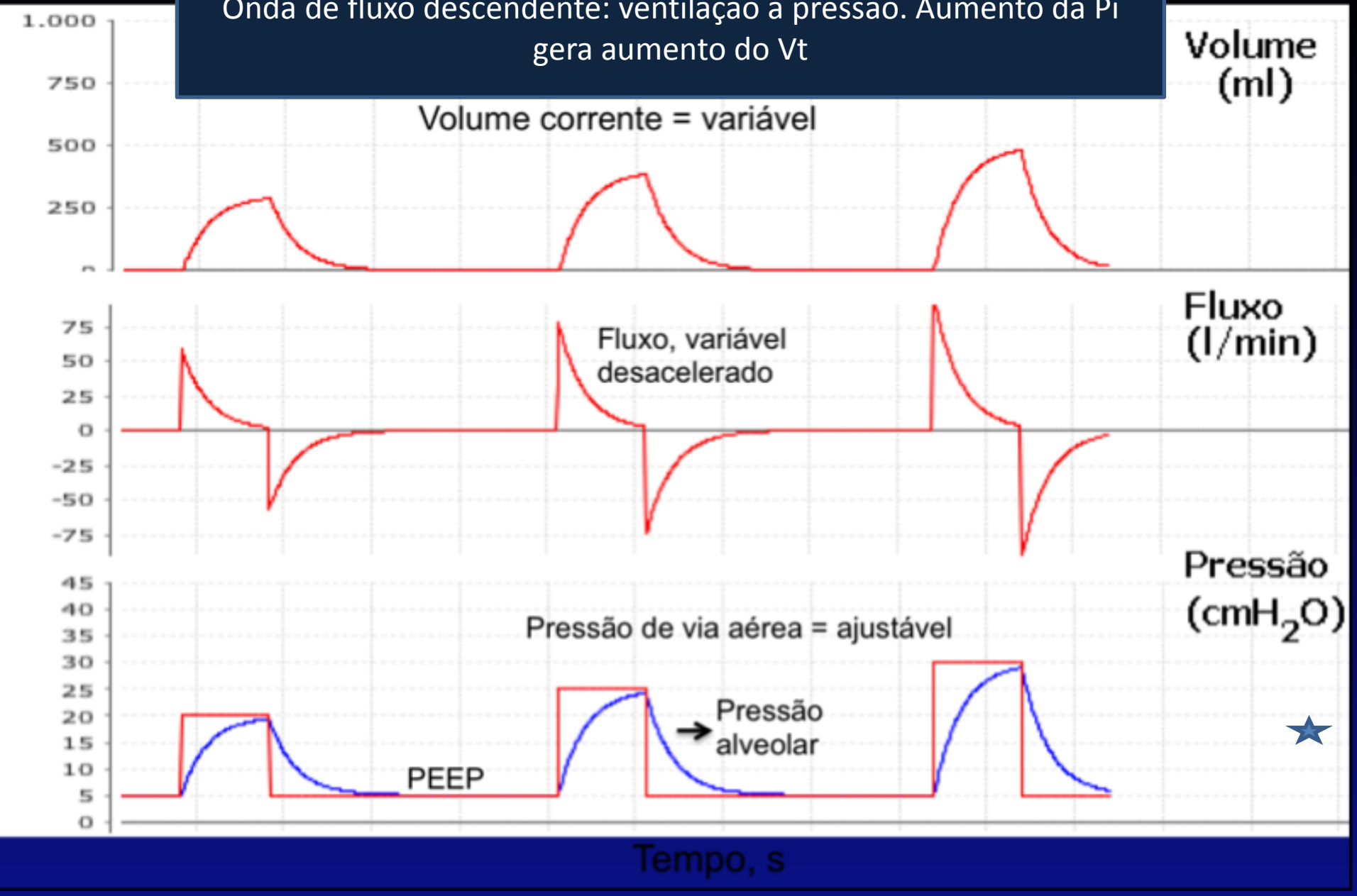
I:E 1:2 0,5:1

Ajusta fluxo para manter pressão

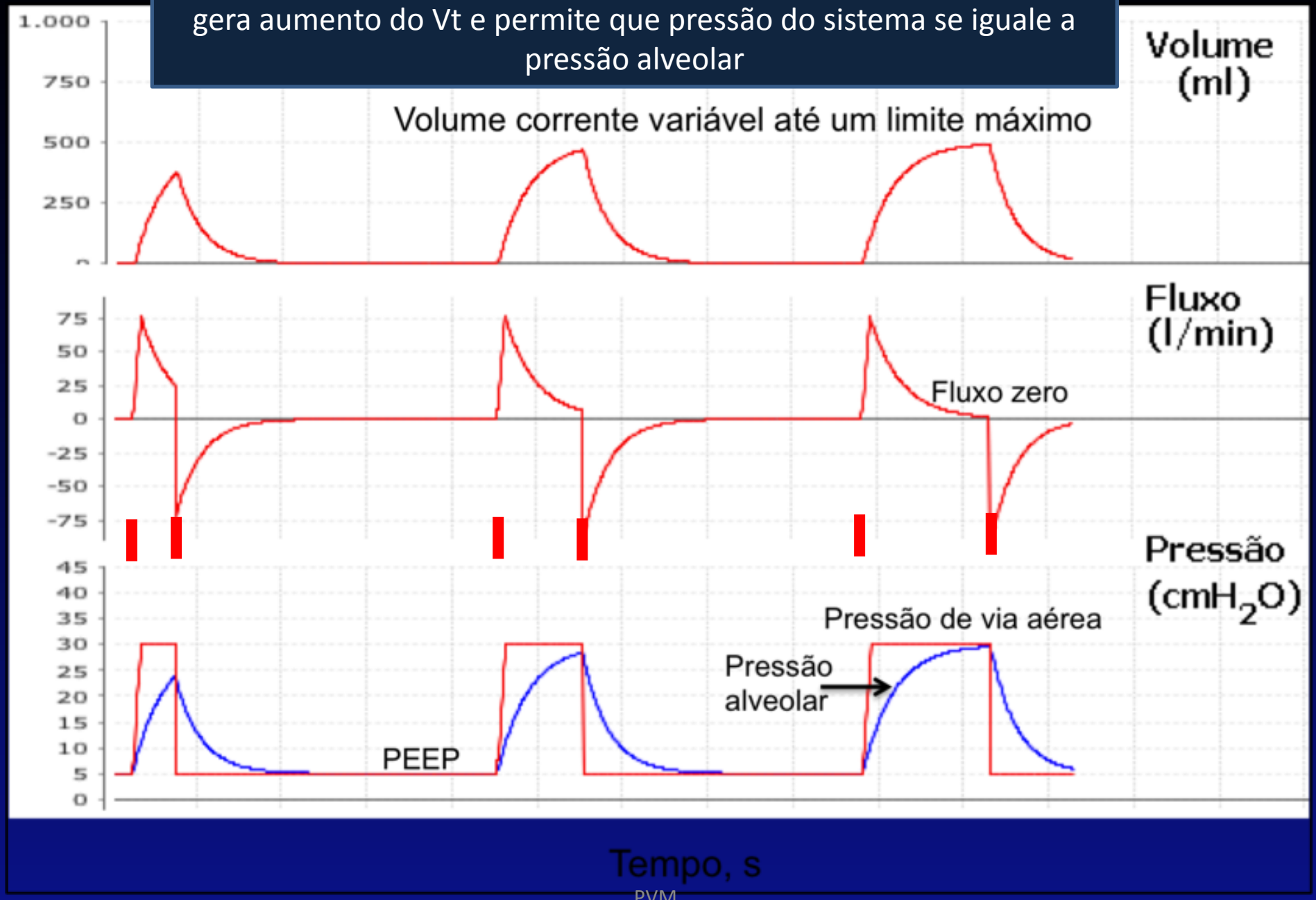
Sempre em 20cmH20

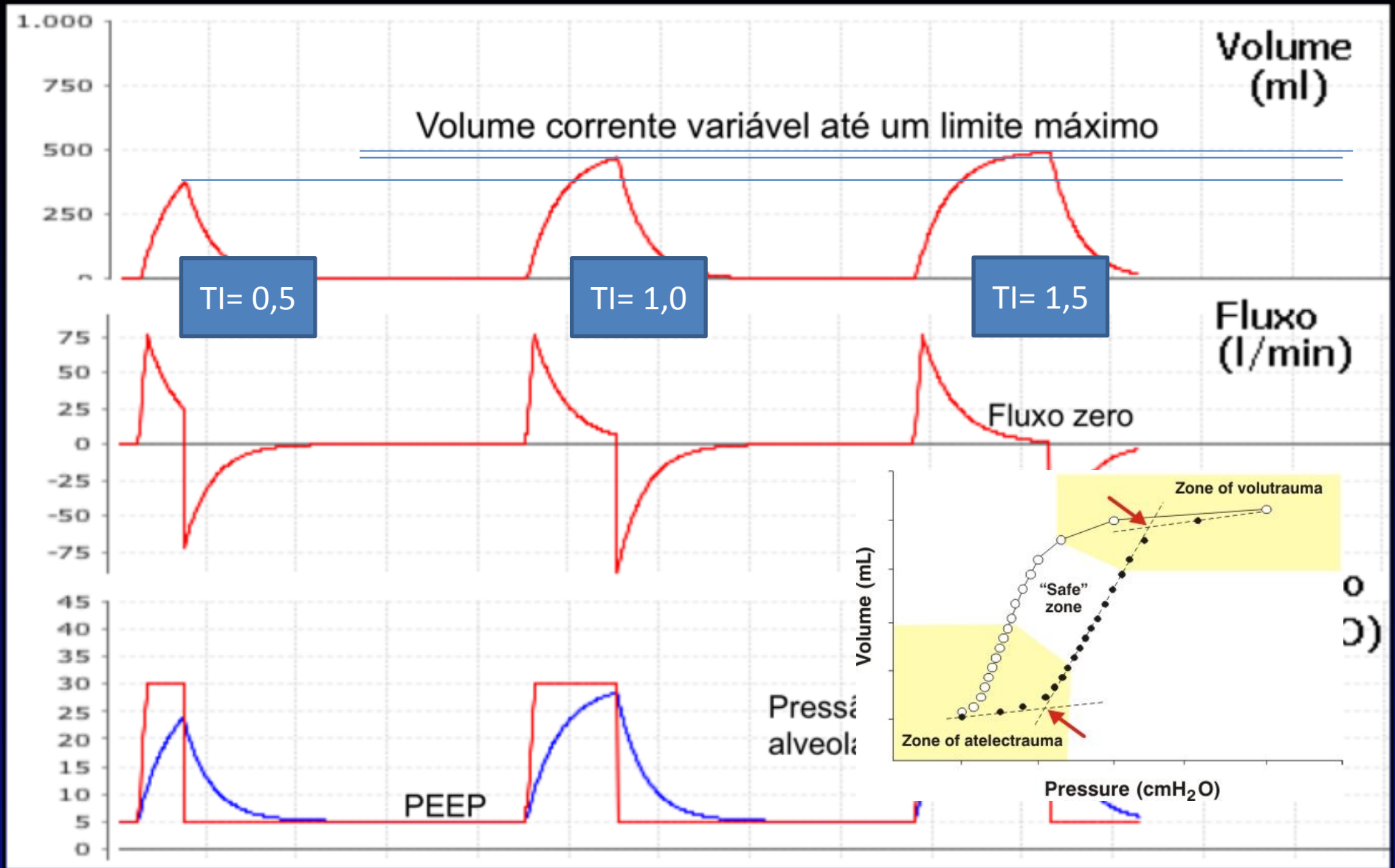


Onda de fluxo descendente: ventilação a pressão. Aumento da Pi gera aumento do Vt

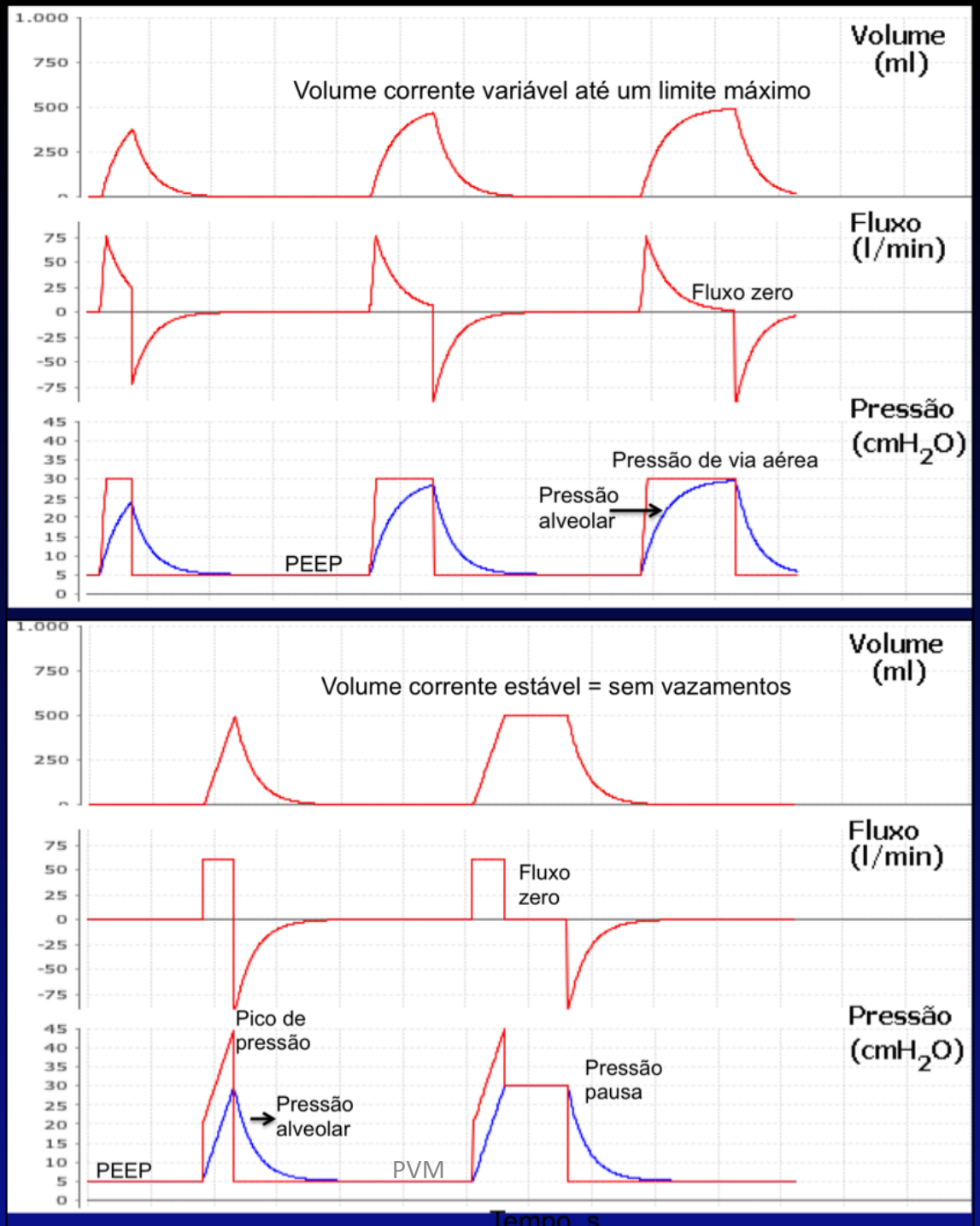


Onda de fluxo descendente: ventilação a pressão. Aumento do Ti gera aumento do Vt e permite que pressão do sistema se iguale a pressão alveolar

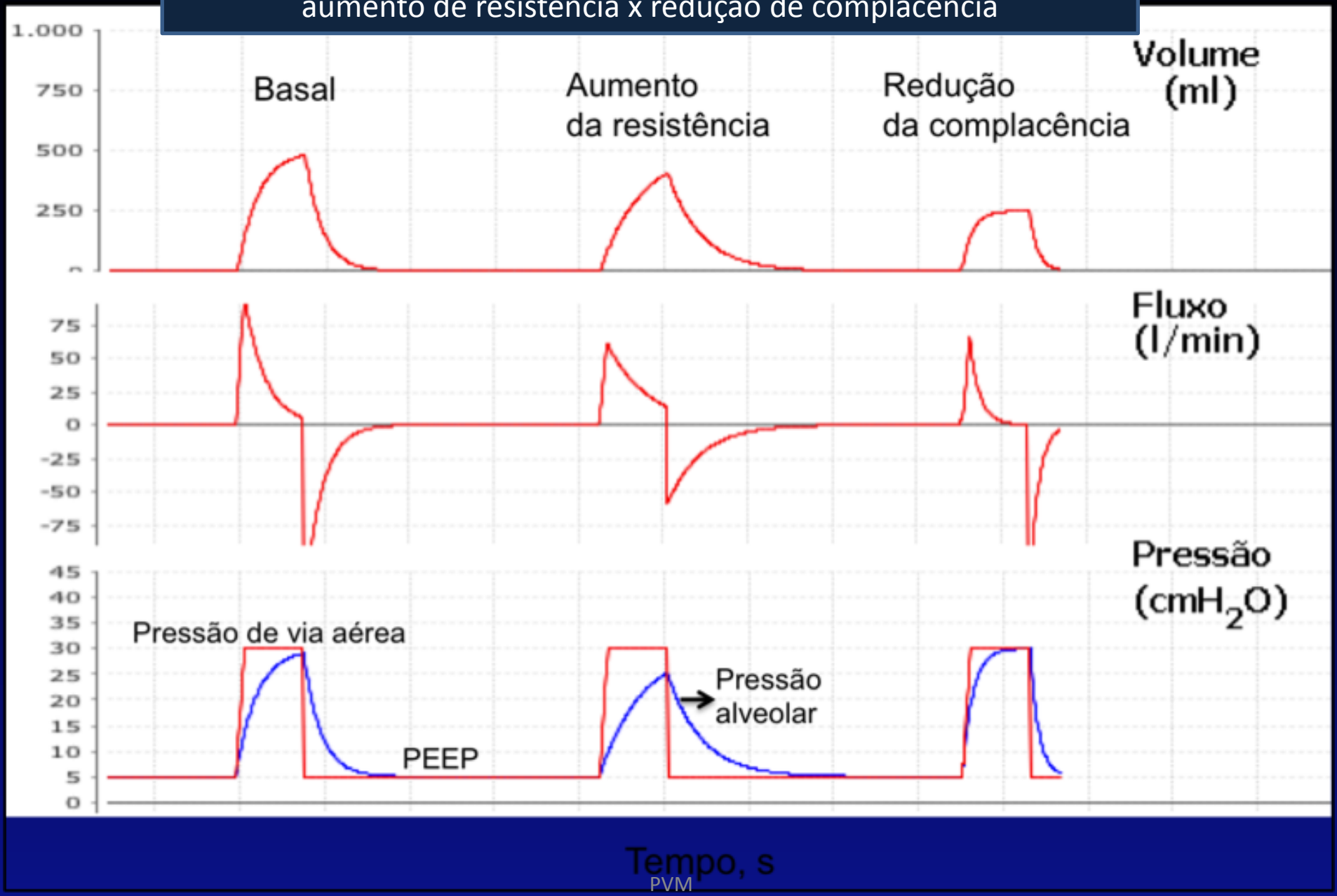



1.000
750
500
250
0
Volume
(ml)
Volume corrente variável até um limite máximo
TI= 0,5
TI= 1,0
TI= 1,5
75
50
25
0
-25
-50
-75
Fluxo
(l/min)
Fluxo zero
45
40
35
30
25
20
15
10
5
0
PEEP
Pressã
alveola
Zone of volutrauma
"Safe"
zone
Zone of atelectrauma
Volume (mL)
Pressure (cmH2O)
Tempo, s

X


Volume (ml)
Volume corrente variável até um limite máximo
Fluxo (l/min)
Fluxo zero
Pressão (cmH_2O)
Pressão de via aérea
Pressão alveolar
PEEP
Volume (ml)
Volume corrente estável = sem vazamentos
Fluxo (l/min)
Fluxo zero
Pressão (cmH_2O)
Pico de pressão
Pressão alveolar
Pressão pausa
PEEP
PVM
Tempo, s

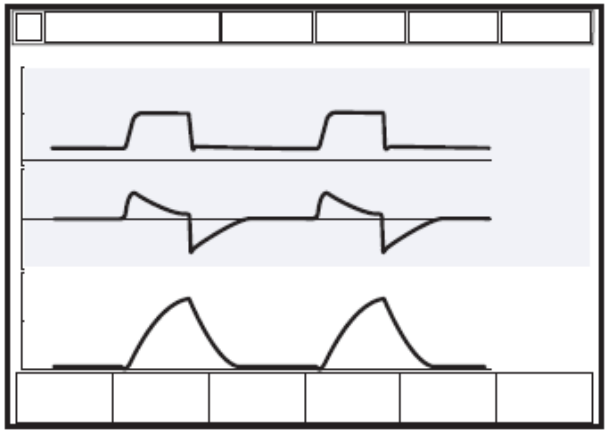
Onda de fluxo descendente: ventilação a pressão. Observe efeito de aumento de resistência x redução de complacência



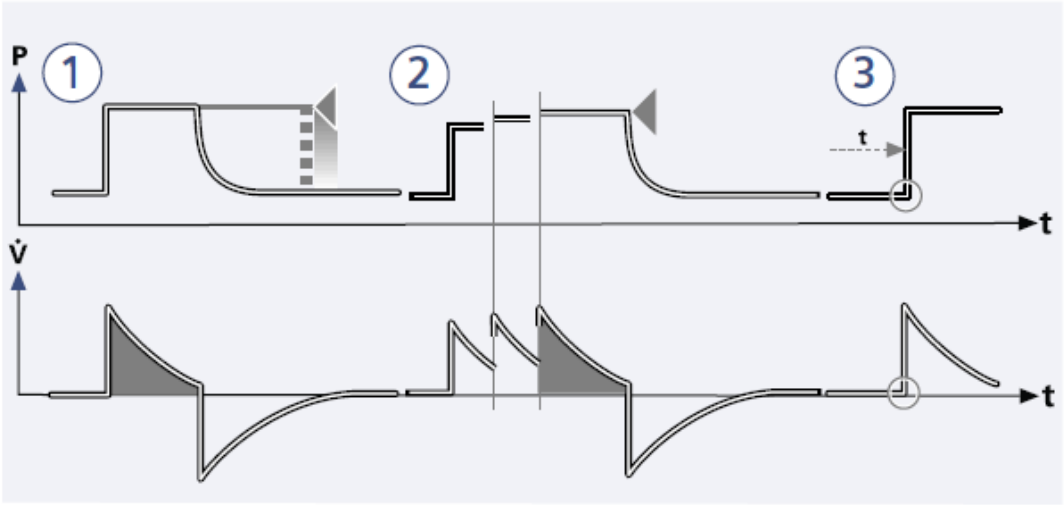
Ciclo a pressão com volume alvo

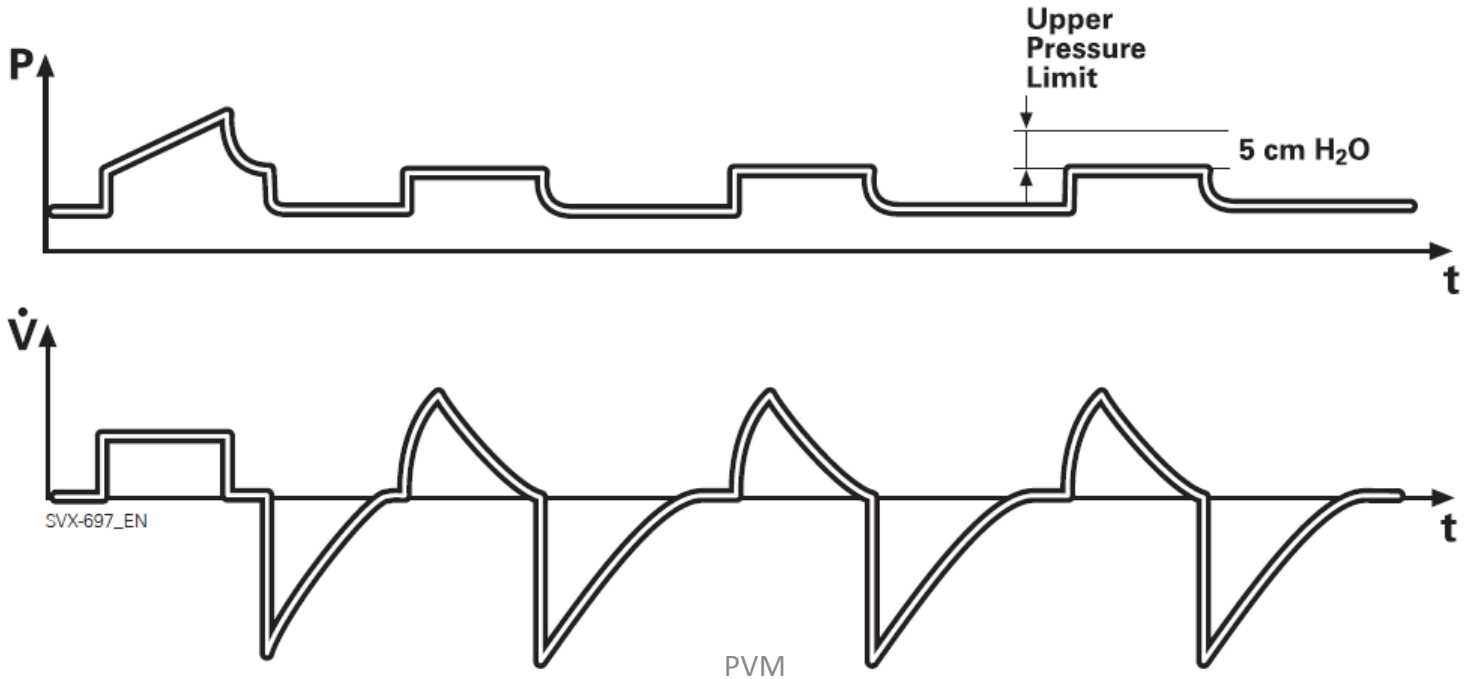
- Servo 300 and Servo-I (Maquet Critical Care, Bridgewater, NJ.
  - PRVC (Pressure-regulated volume control)
  - Limitado a pressão, ciclado a tempo
  - Capaz de ajustar a pressão inspiratória baseada no volume corrente
  - Ajusta automático na pressão não passa de 5cmH2O
  - Vazamentos, dificuldade em medir o VT

6.4.2 PRVC IN DETAIL



SVX-9006_XX





Ciclo a pressão com volume alvo

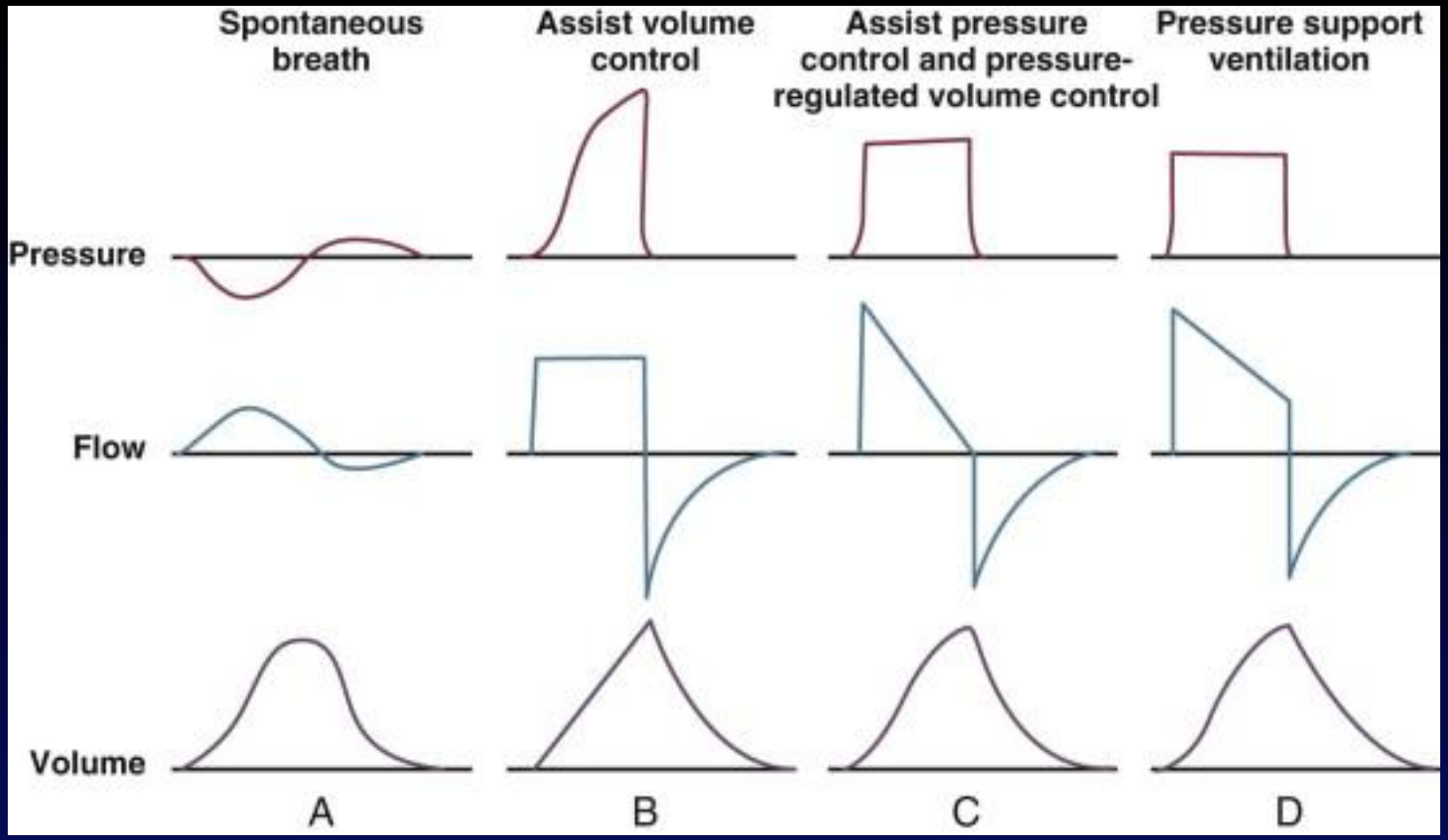
- Bird VIP Gold (Viasys Healthcare, Palm Springs, CA)
  - Modo hibrido
  - PS com volume assegurado
  - Limitado a pressão, ciclado a tempo
  - Se Vt não é atingido: ciclo passa a fluxo e aumenta a PI
  - Não ajusta para garantir Vt pequeno se complacência melhora.

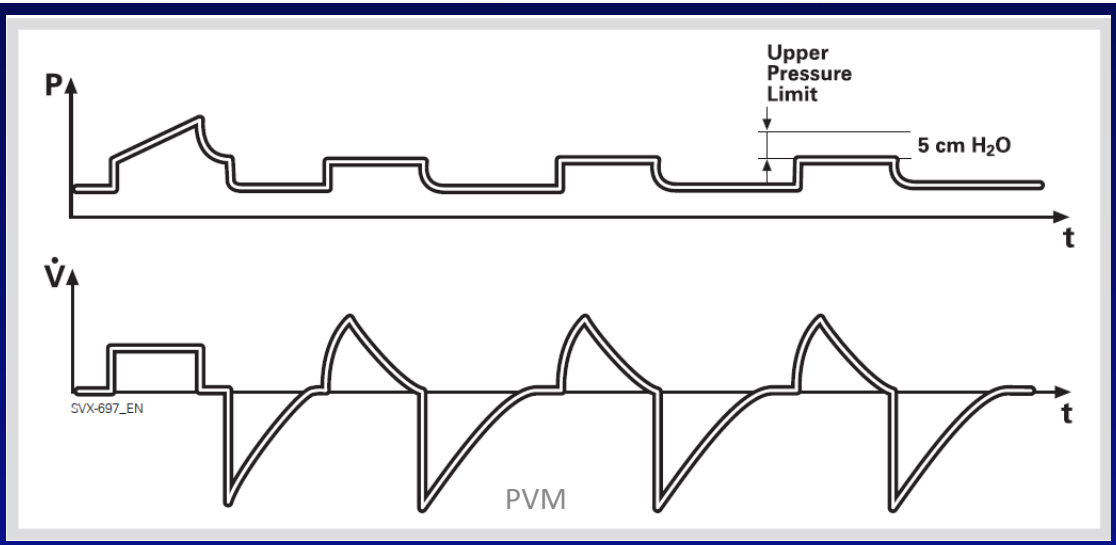
Ciclo a pressão com volume alvo

- Avea
  - Modo hibrido
  - PS com volume assegurado
  - Função de desarme da inspiração de Vt passa do limite preestabelecido.
  - Falta desarme automático da pressão inspiratória

Ciclo a pressão com volume alvo

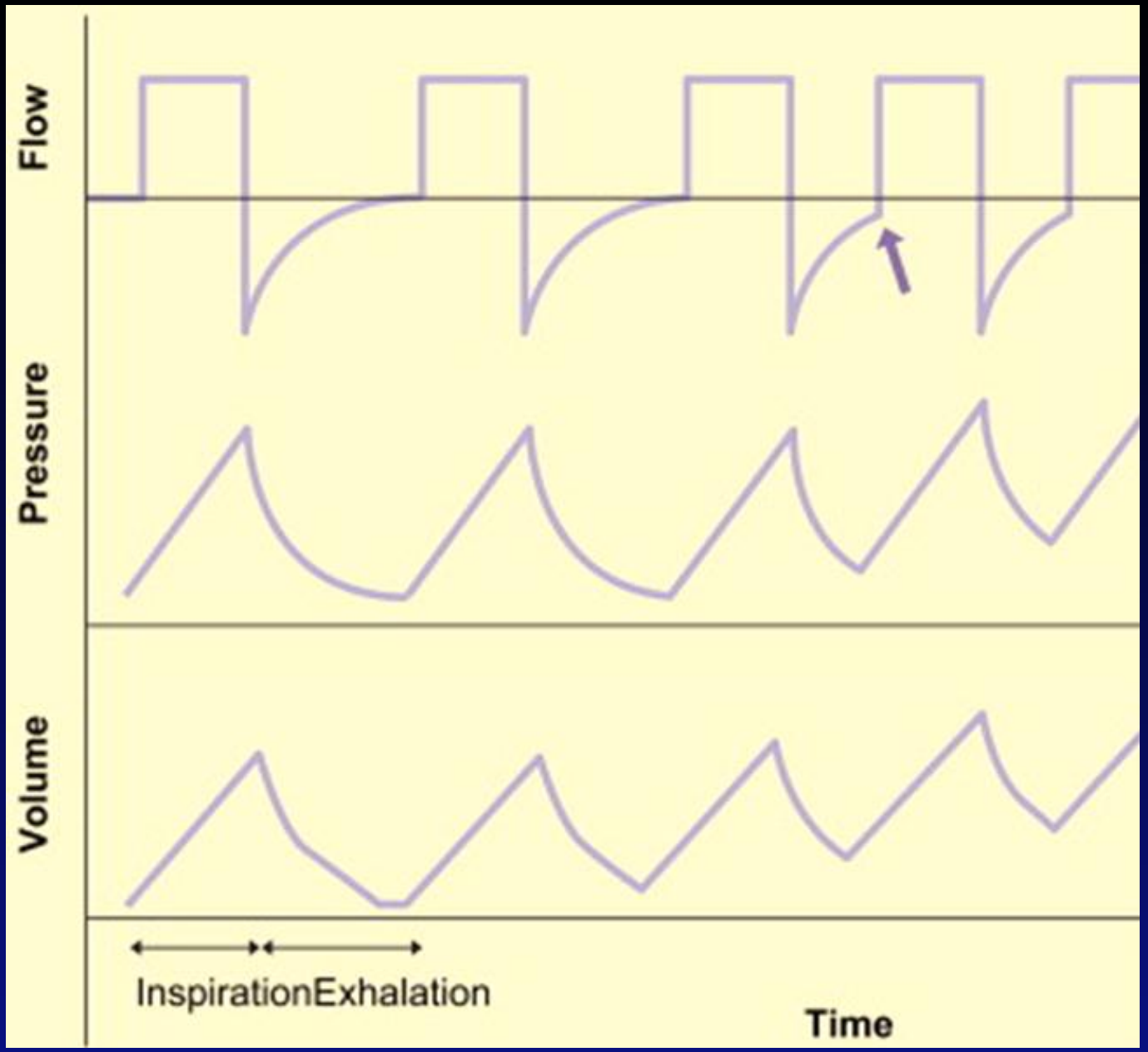
- Draeger Babylog (Draeger, Inc., Lubeck, Germany)
  - Usa Vt exalado
  - Ajusta PI baseada no Vt do ultimo ciclo
  - Algorítimo limita aumento grande na PI
  - Algoritimo corrige rapidamente Vt grande


Spontaneous breath
Assist volume control
Assist pressure control and pressure-regulated volume control
Pressure support ventilation
Pressure
Flow
Volume
A
B
C
D


P
Upper Pressure Limit
5 cm H_2O
t
$\dot{V}$
SVX-697_EN
t
PVM

Abordagem da Disfunção Pulmonar

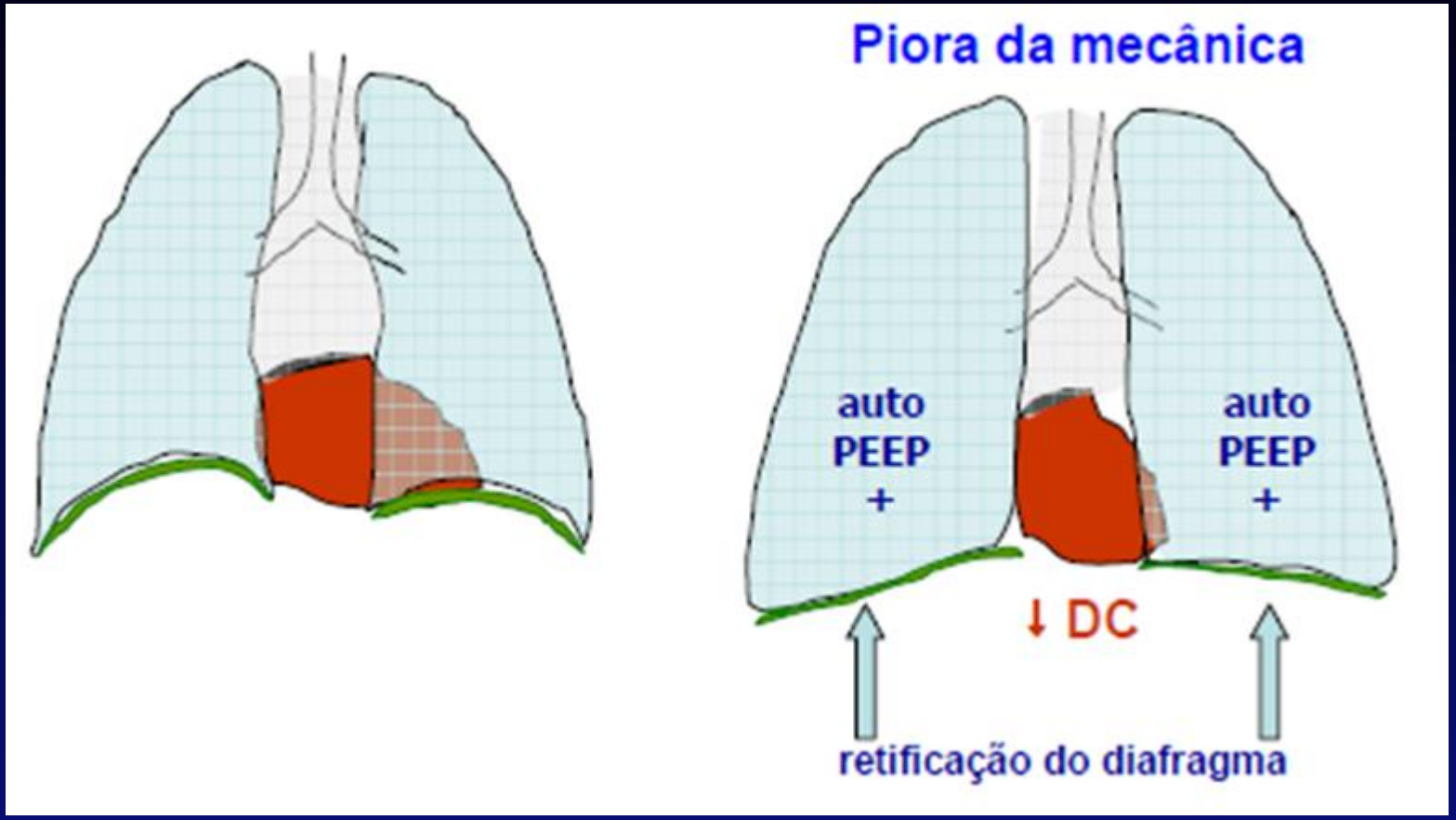
- Controle da Ventilação
  - Monitorização adequada.
  - Intervenção adequada.



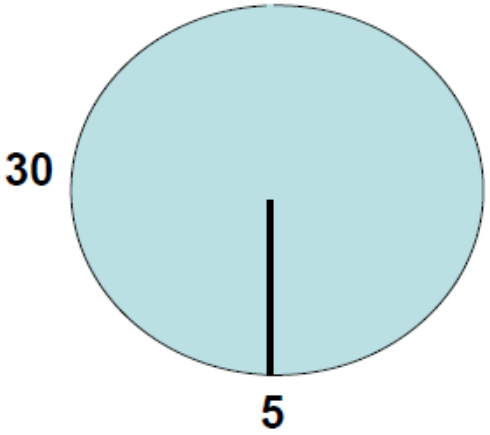
Respiratory monitoring during mechanical ventilation

Robinder G Khemani, Robert D Bart, and Christopher JL Newth

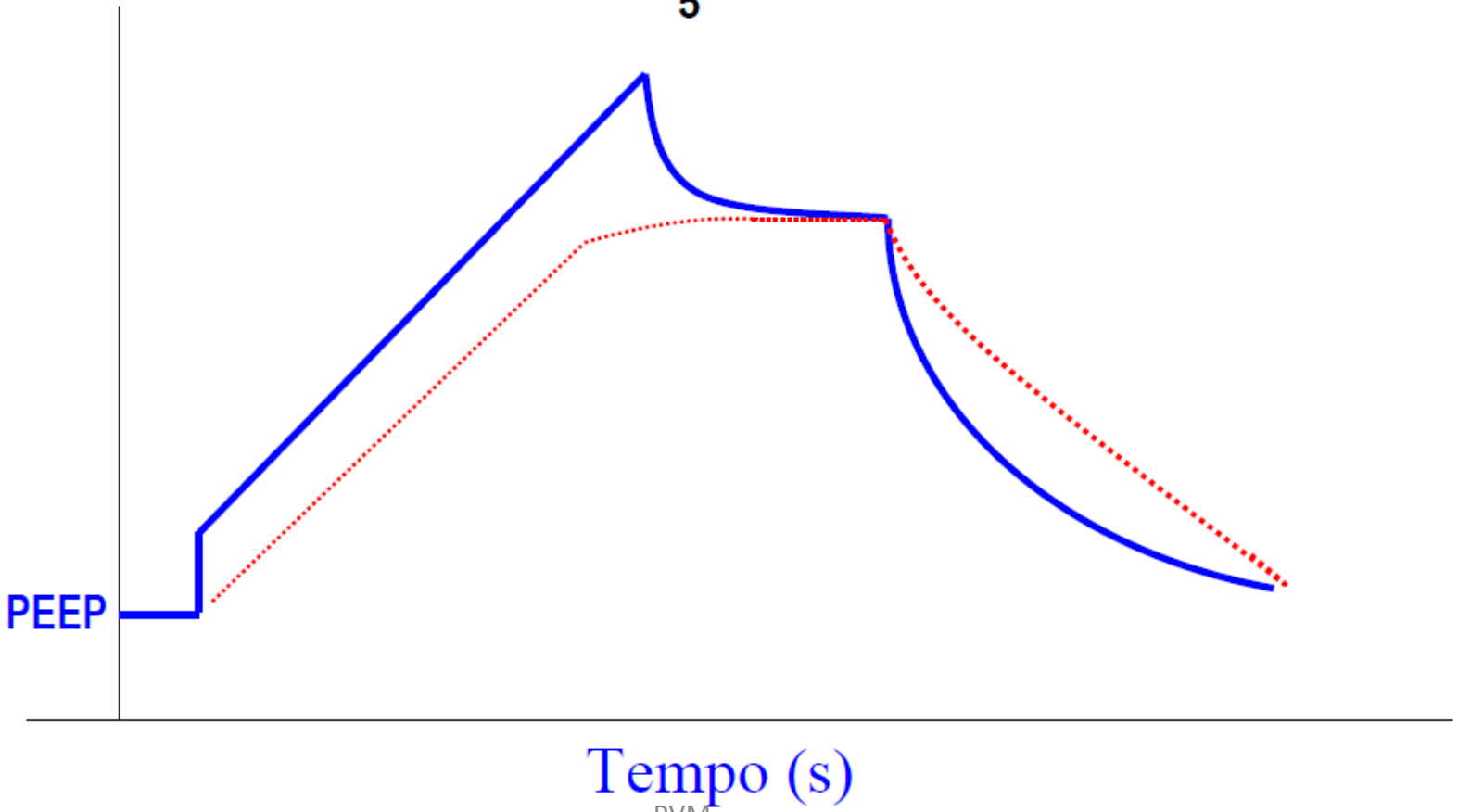
Paediatrics and Child Health, 2007-05-01, Volume 17, Issue 5, Pages 193-201


Piora da mecânica
auto
PEEP
+
auto
PEEP
+
↓ DC
retificação do diafragma

Mensuração da P alveolar

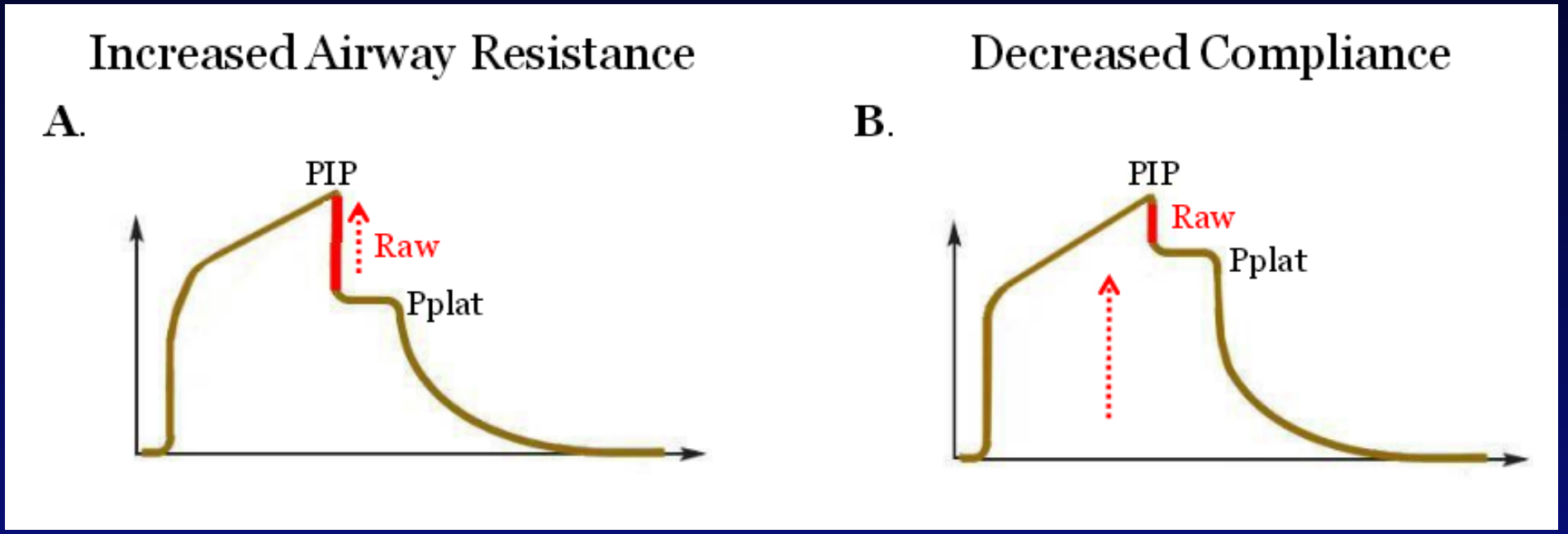


P via aérea

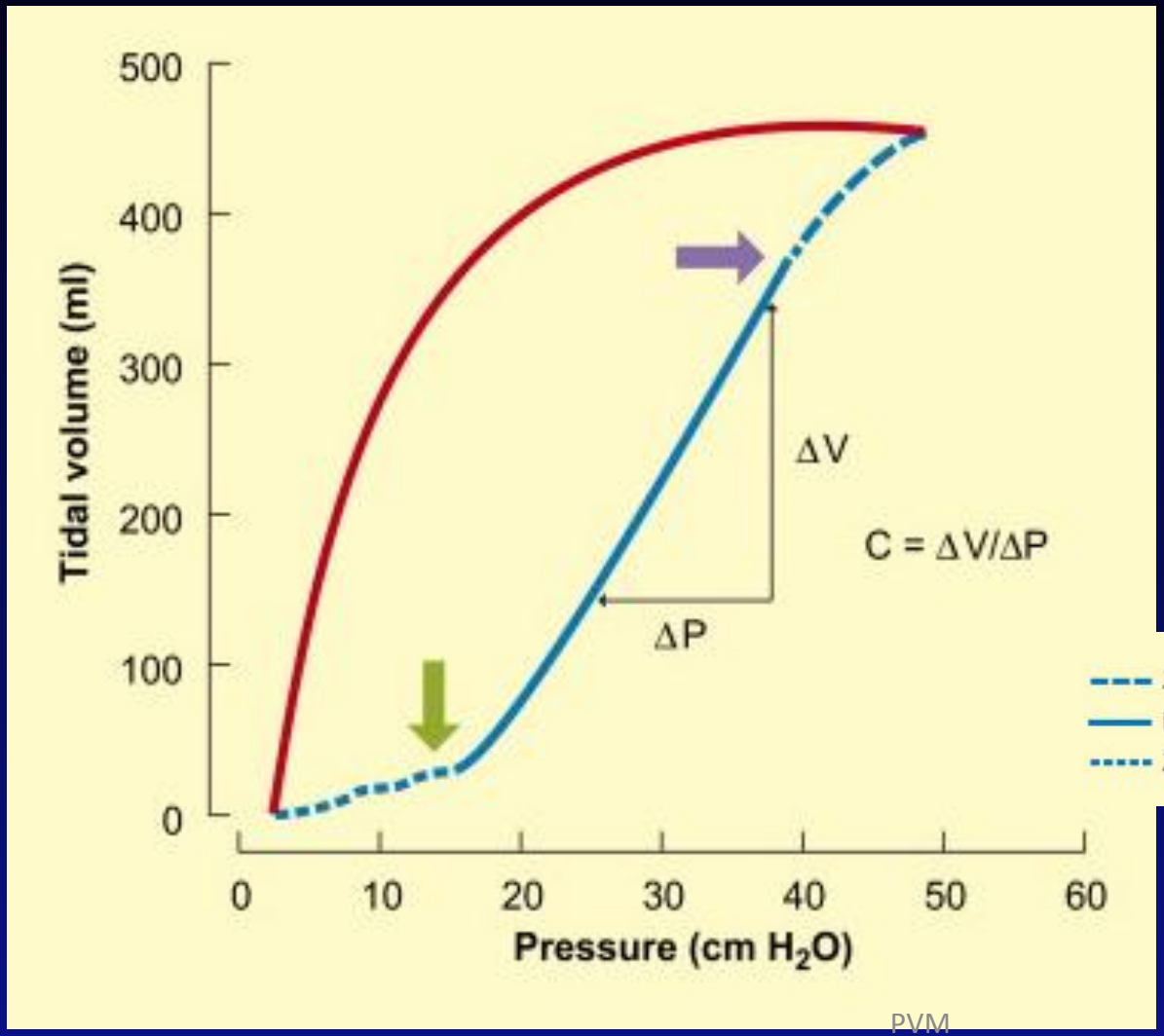


Monitorização

- Discutir obstrução x piora da complacência



Monitorização



Curva

Pressão Volume

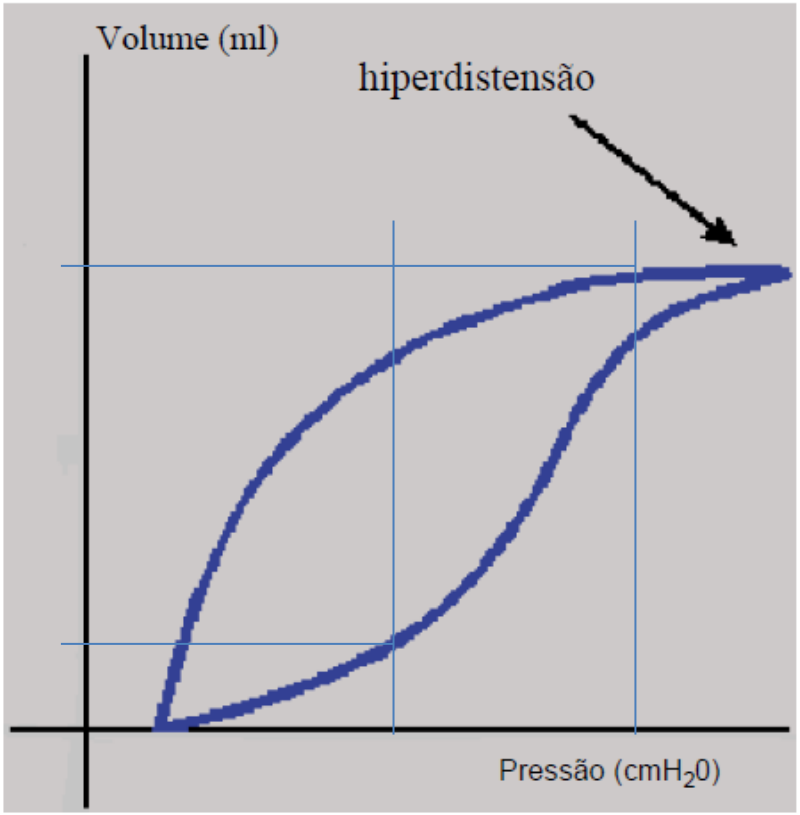
Respiratory monitoring during mechanical ventilation

Robinder G Khemani, Robert D Bart, and Christopher JL Newth

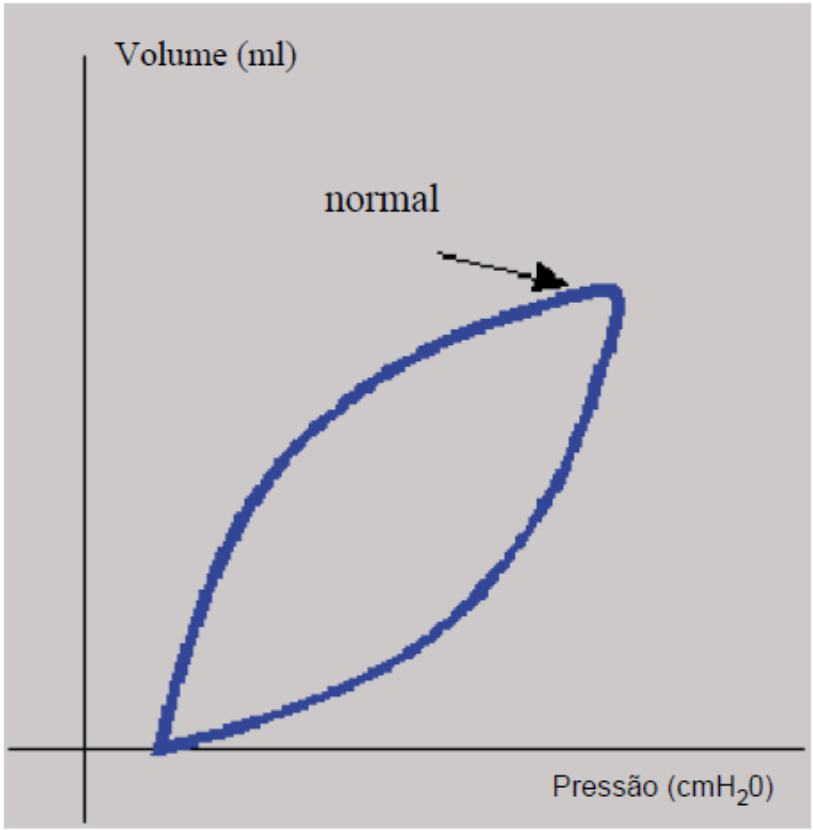
Paediatrics and Child Health, 2007-05-01, Volume 17, Issue 5, Pages 193-201

Monitorização

Traçado alterado → Traçado corrigido



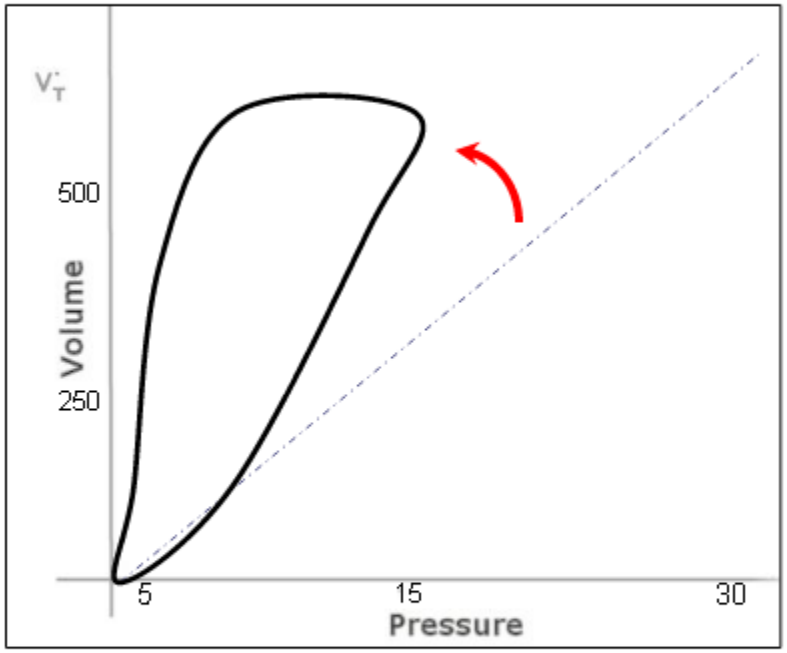
PIP: 26 cmH_2O



PIP: 22 cmH_2O

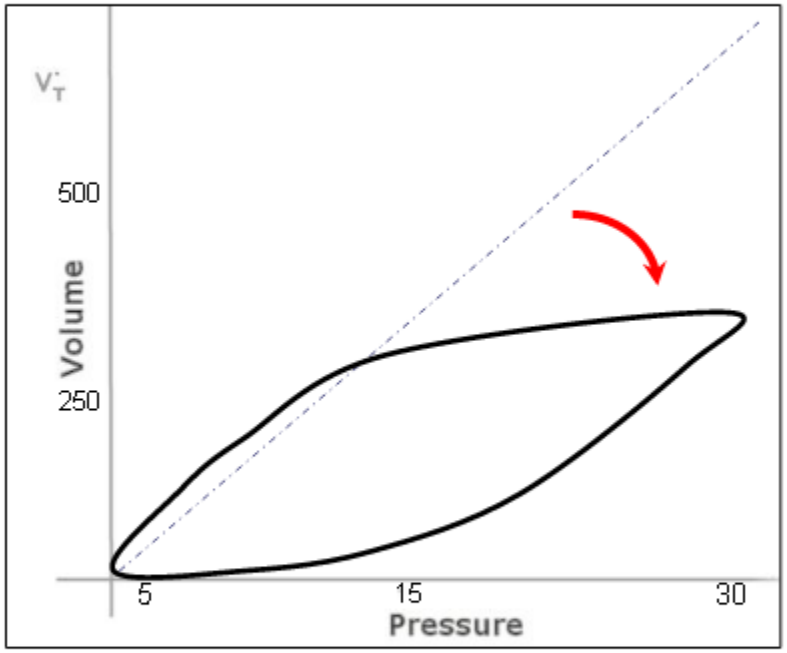
Monitorização

Increased Compliance



Example: Emphysema, Surfactant Therapy

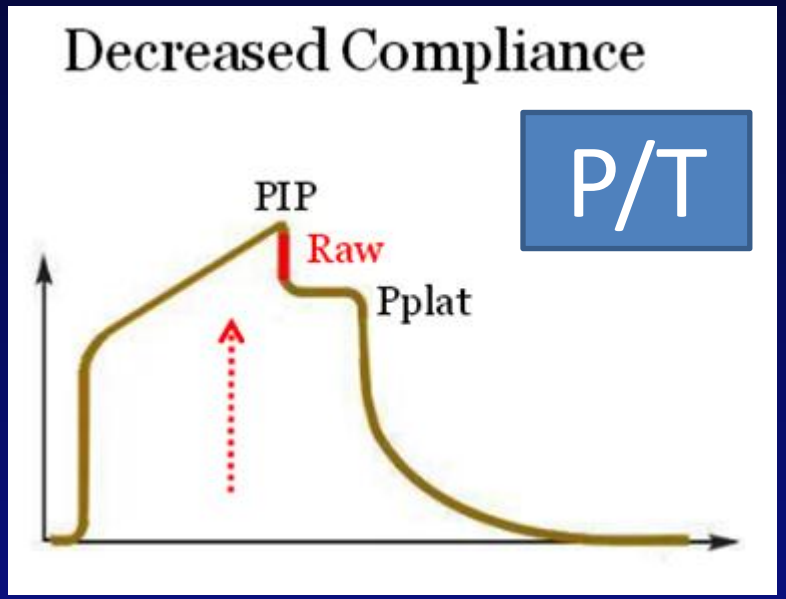
Decreased Compliance

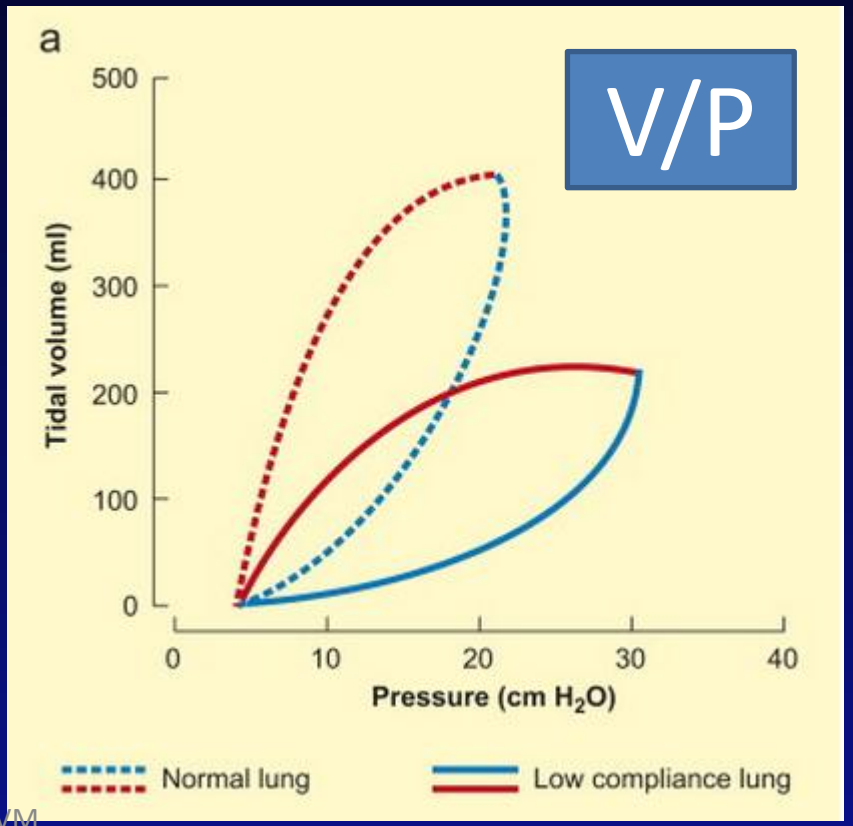


Example: ARDS, CHF, Atelectasis

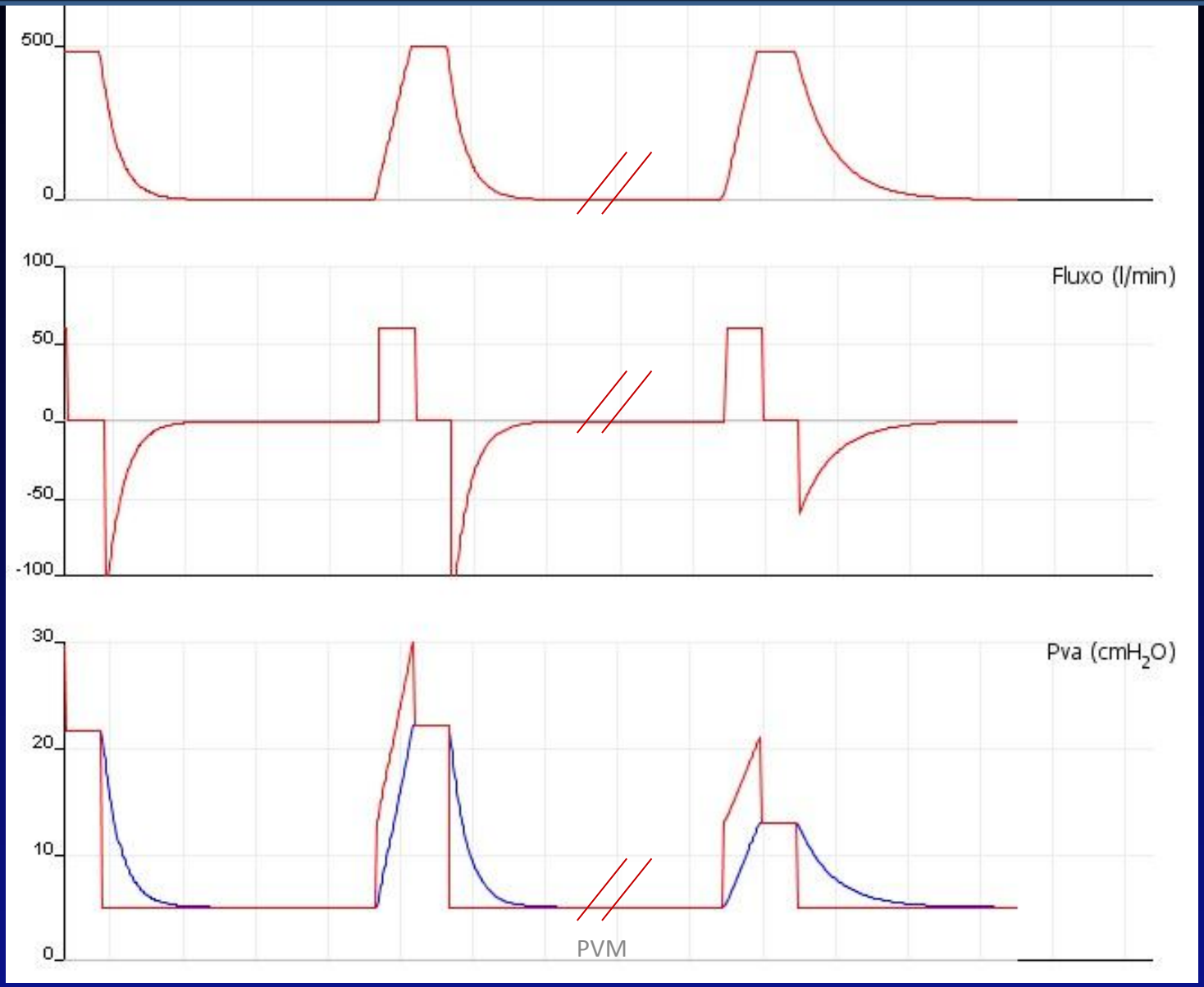
Monitorização

- Atelectasia

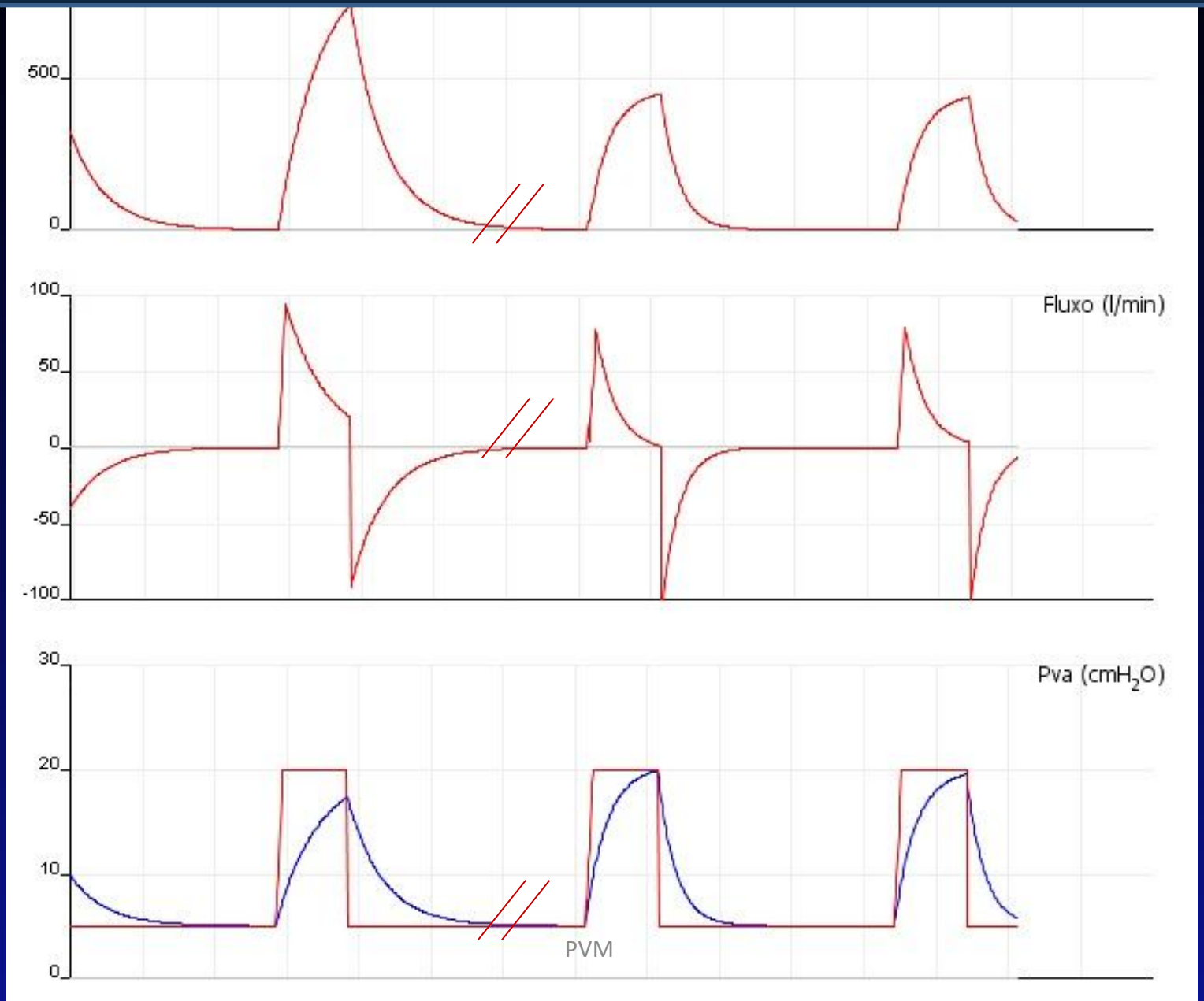




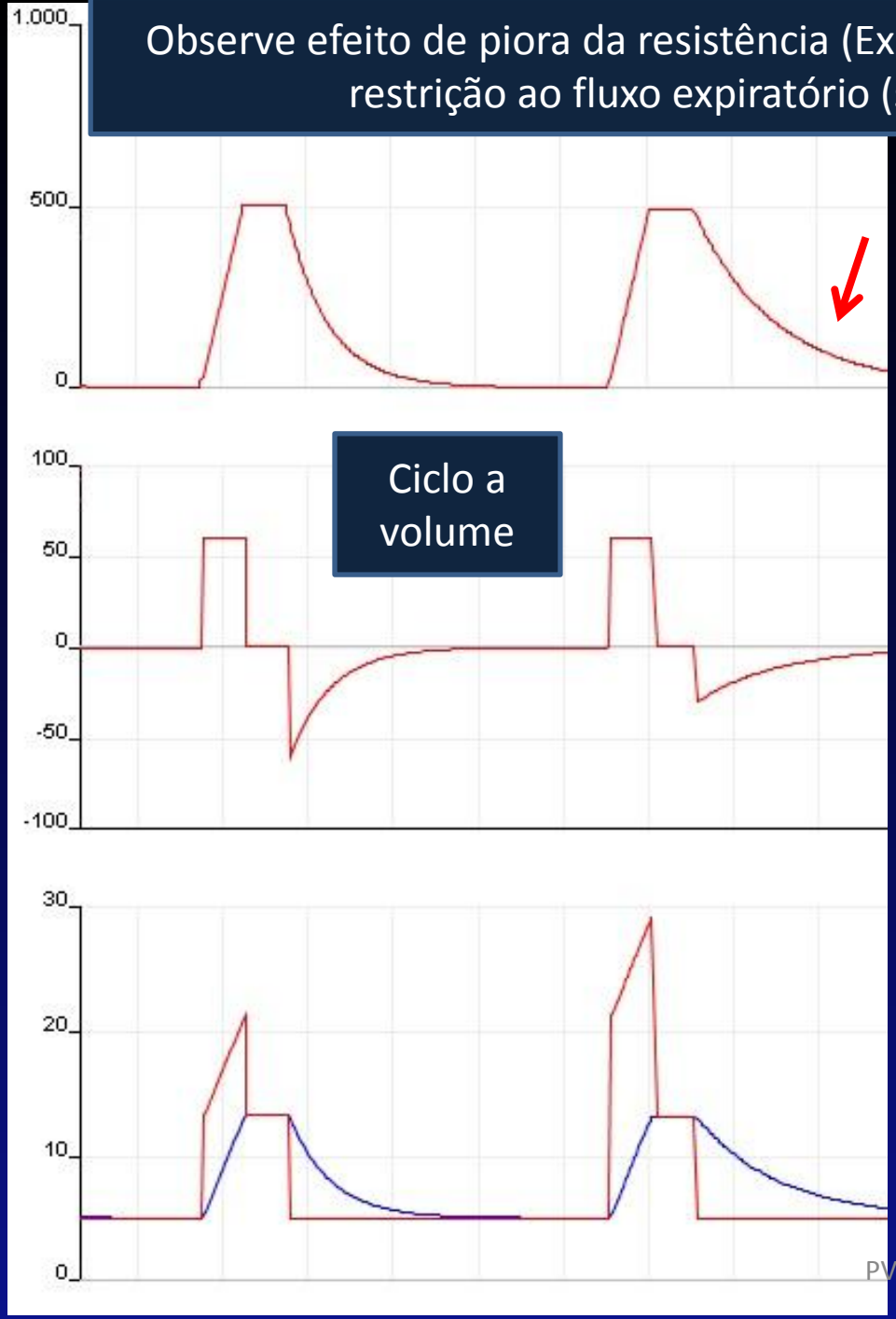
Onda de fluxo quadrada com pausa: ventilação a volume. Observe efeito de melhora da complacência (Ex. recrutamento de atelectasia, toracocentese de alívio no pneumotórax, tto da congestão pulmonar, etc...)



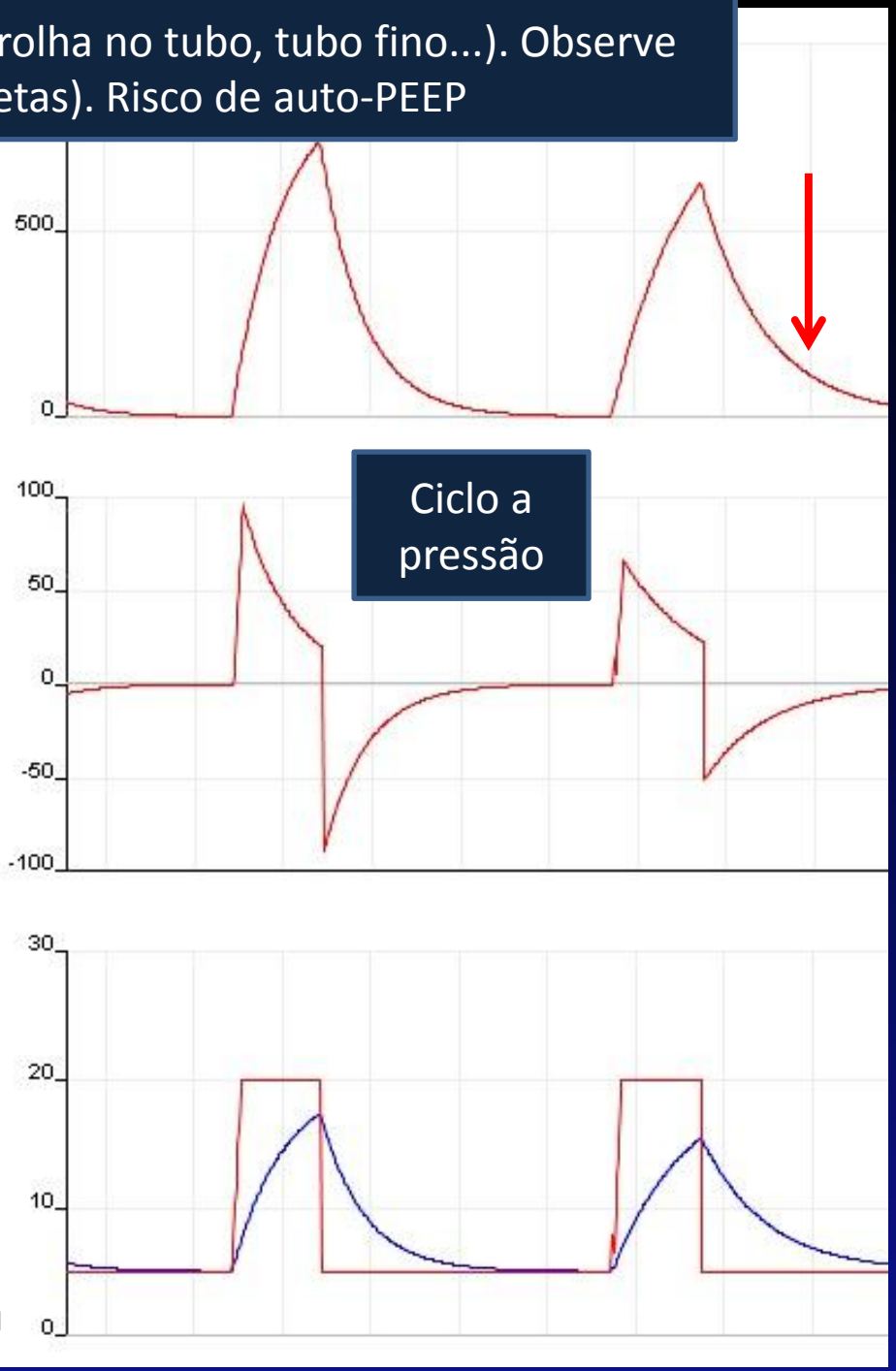
Onda de fluxo descendente: ventilação a pressão. Observe efeito de piora complacência (Ex. atelectasia, pneumotórax, congestão pulmonar, etc...)



Observe efeito de piora da resistência (Ex. rolha no tubo, tubo fino...). Observe restrição ao fluxo expiratório (setas). Risco de auto-PEEP

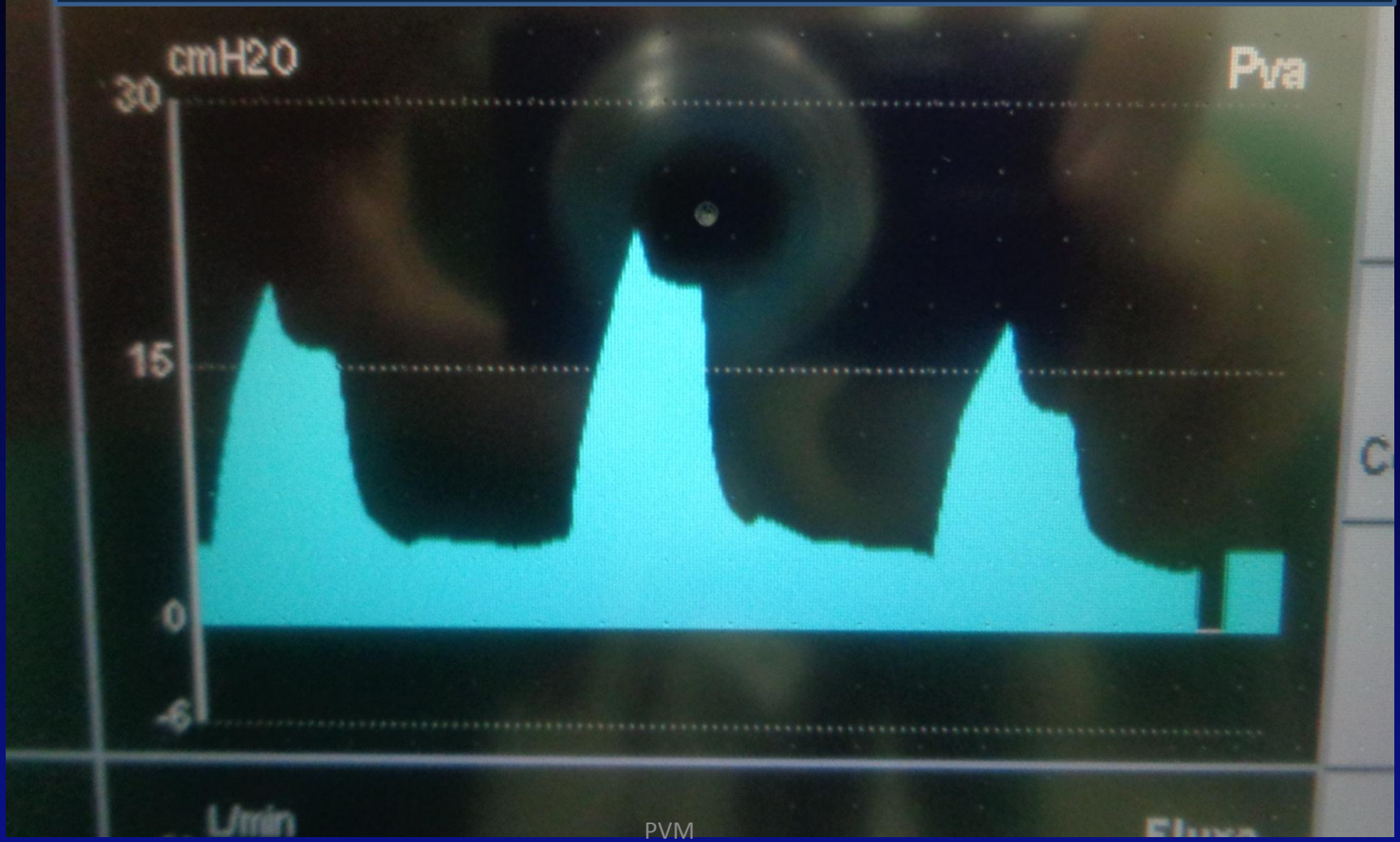


Ciclo a volume

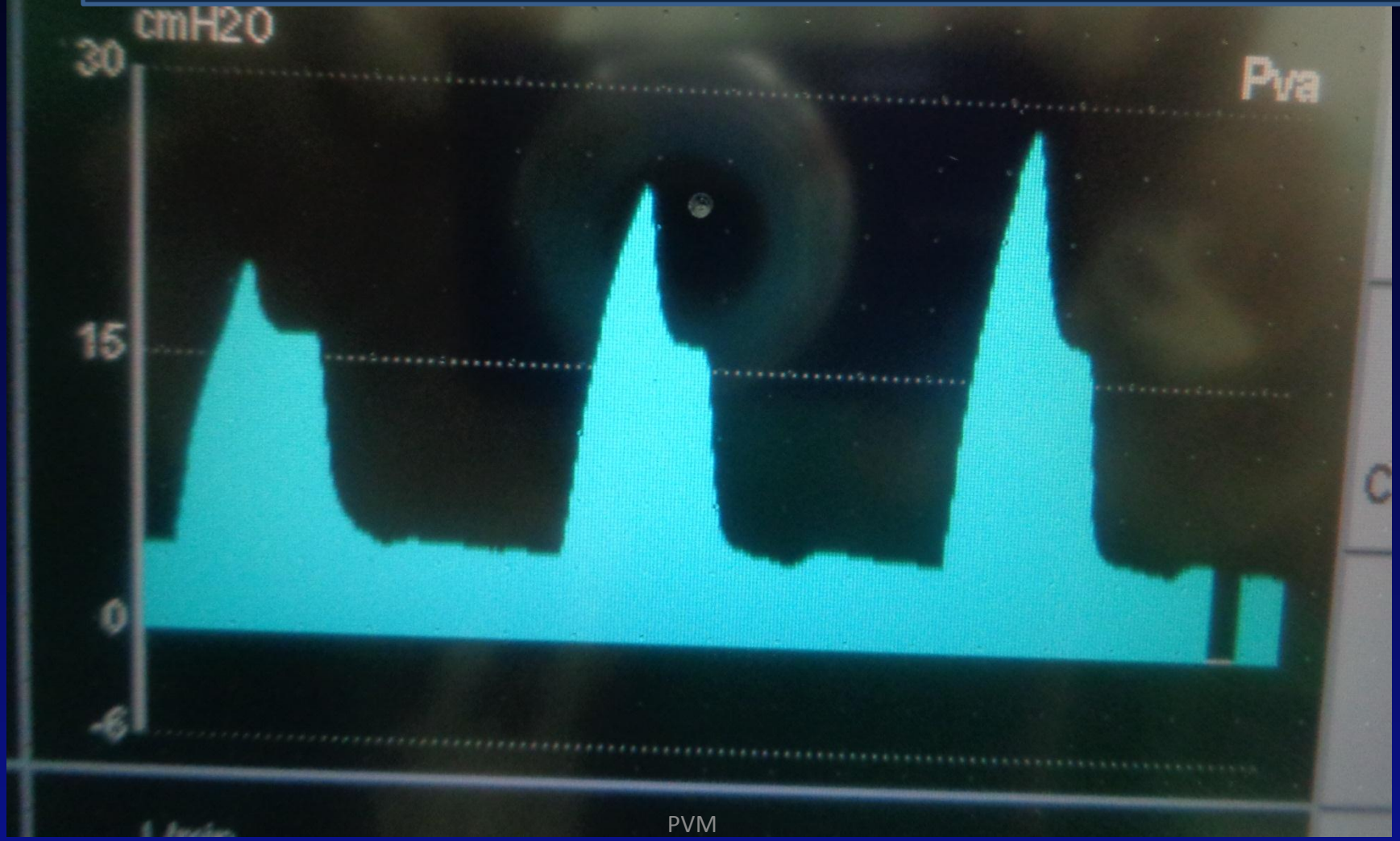


Ciclo a pressão

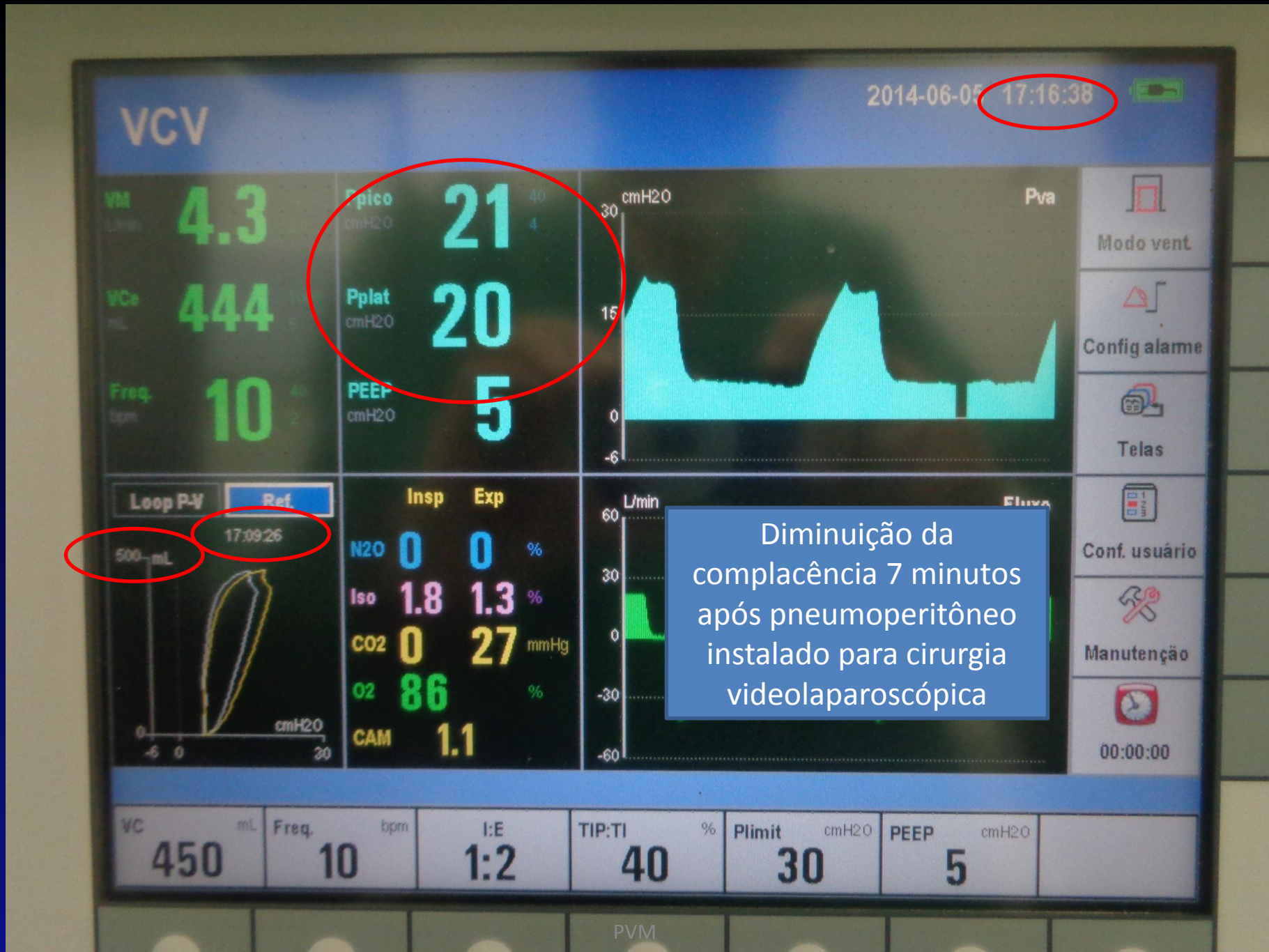
Ciclo a volume com pausa. Observe efeito de piora da complacência, com melhora no terceiro ciclo. Ocorre aumento da pressão de pico e platô, com manutenção da diferença entre as duas pressões.

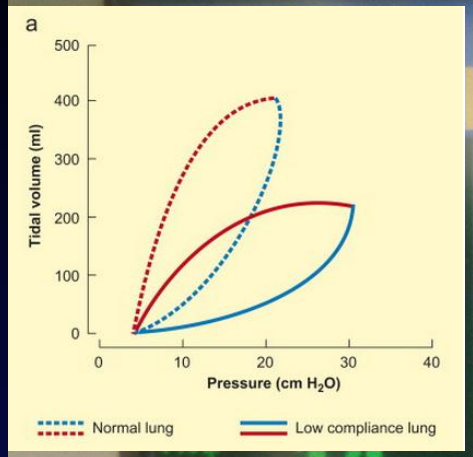


Ciclo a volume com pausa. Observe efeito de aumento da resistência. Ocorre aumento da pressão de pico e manutenção da pressão de platô.




VCV
** Filso muito alto
2014-06-05 17:09:5
VM
L/min
4.3
10.0
2.0
VCe
mL
426
1000
5
Freq.
bpm
10
40
2
Ppico
cmH2O
17
40
4
Pplat
cmH2O
15
PEEP
cmH2O
5
cmH2O
30
15
0
-6
Pva
Loop P-V
Ref.
17:09:26
500 mL
0
-6
0
cmH2O
30
Insp
Exp
N2O
0
0
%
Iso
2.4
1.5
%
CO2
0
26
mmHg
O2
84
%
CAM
1.3
L/min
60
30
0
-30
-60
Fluxo
VC
mL
450
Freq.
bpm
10
I:E
1:2
TIP:TI
%
40
Plimit
cmH2O
30
PEEP
cmH2O
5
PVM


VCV
2014-06-05 17:16:38
VM 4.3
VCe 444
Freq. 10
Ppico cmH2O 21
Pplat cmH2O 20
PEEP cmH2O 5
cmH2O
Pva
30
15
0
-6
Modo vent.
Config alarme
Telas
Conf. usuário
Manutenção
00:00:00
Loop P-V
Ref
17:09:26
500 mL
cmH2O
-6 0 30
Insp Exp
N2O 0 0 %
Iso 1.8 1.3 %
CO2 0 27 mmHg
O2 86 %
CAM 1.1
L/min
60
30
0
-30
-60
Diminuição da complacência 7 minutos após pneumoperitôneo instalado para cirurgia videolaparoscópica
VC 450 mL
Freq. 10 bpm
I:E 1:2
TIP:TI 40 %
Plimit 30 cmH2O
PEEP 5 cmH2O
PVM



2014-06-05 18:25:11

** FiN2O muito alto

Ppico 22 (40 / 4) cmH2O

Pplat 21 cmH2O

PEEP 5 cmH2O

cmH2O 30 15 0 -6 Pva

Modo vent

Config alarme

Telas

Loop P-V Ref.

17:09:26

1000 mL

cmH2O

0 -6 0 30

Insp Exp

N2O 50 %

Iso 1.1 0.9 %

CO2 0 49 mmHg

O2 37 %

CAM 1.3

L/mi 60 30 0 -30 -60

00:00:00

VC 450 mL | Freq. 14 bpm | I:E 1:2 | TIP:TI 40 % | Plimit 30 cmH2O | PEEP 5 cmH2O

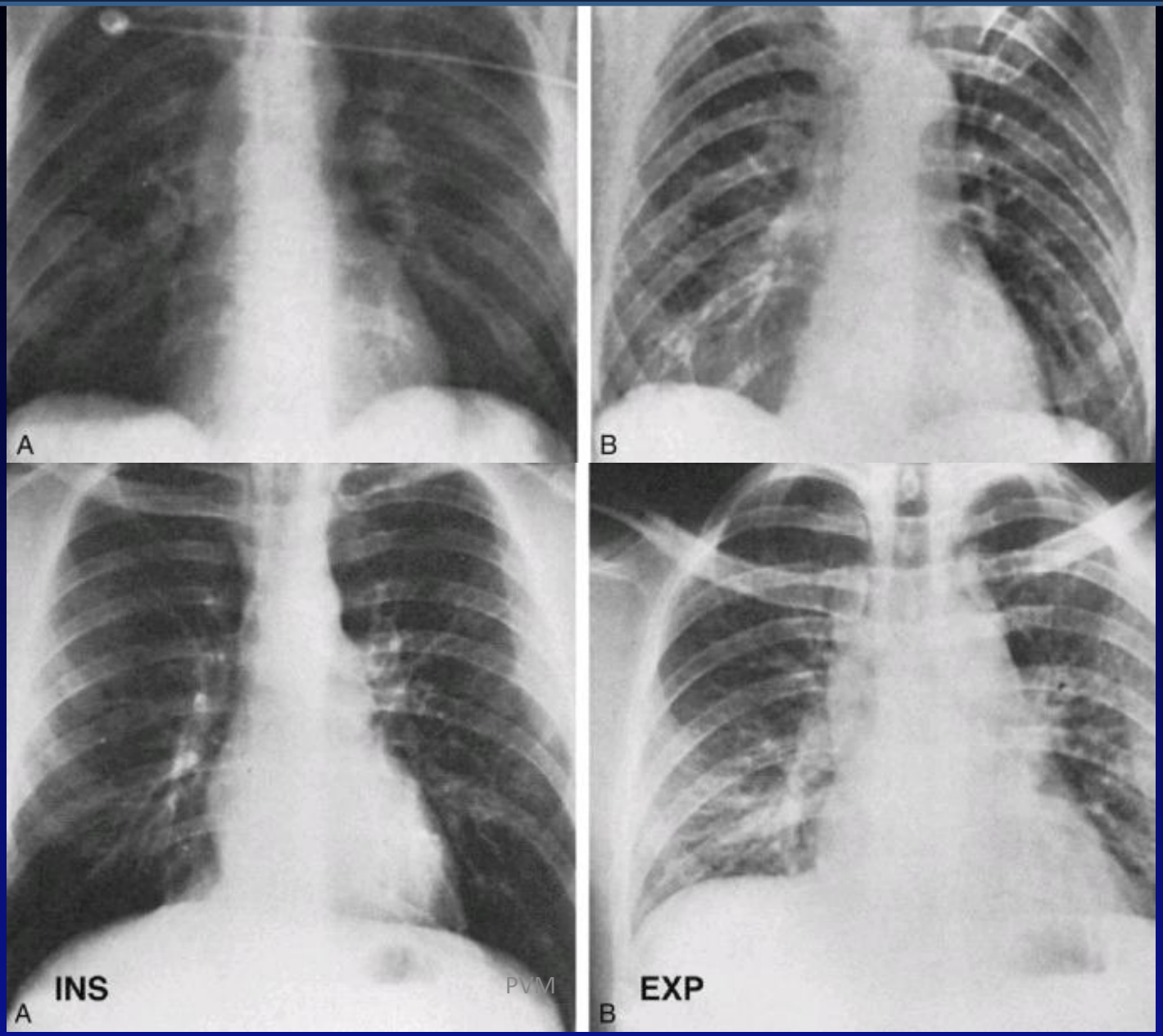
PVM

Diminuição mais acentuada da complacência 1h15mi após pneumoperitôneo instalado para cirurgia videolaparoscópica

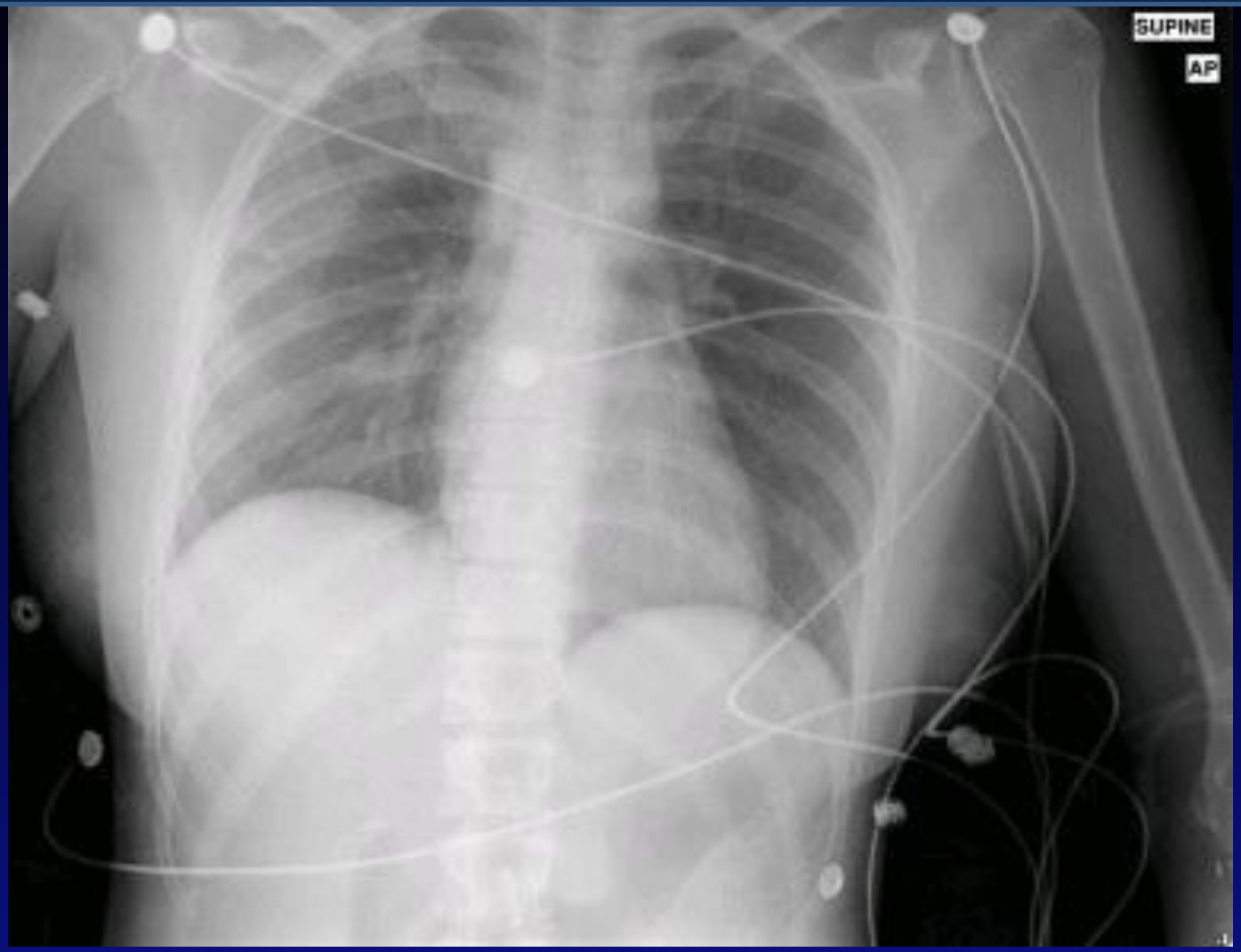
Mecanismos da Disfunção Pulmonar

- Atelectrauma
  - Recrutamento repetido
  - Estresse por cisalhamento
- Barotrauma: ruptura dos espaços aéreos e fuga de ar: Pneumomediastino / Enfisema subcutâneo / Pneumotórax
- Outros diagnósticos

Limitações da radiologia: qualidade do exame (topo – mesmo paciente, aparelhos diferente), técnica (inferior – mesmo paciente, um ins outro expirado)

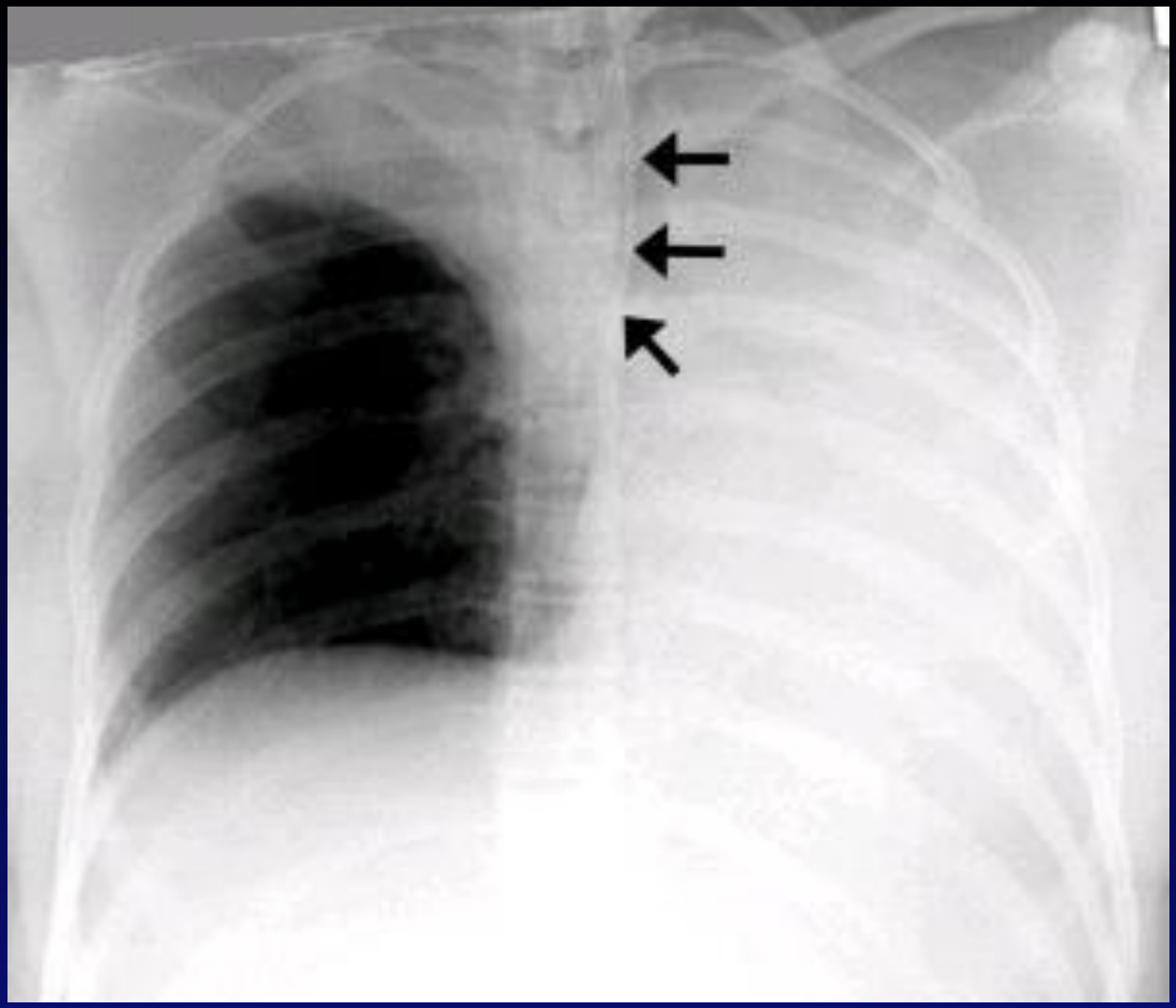


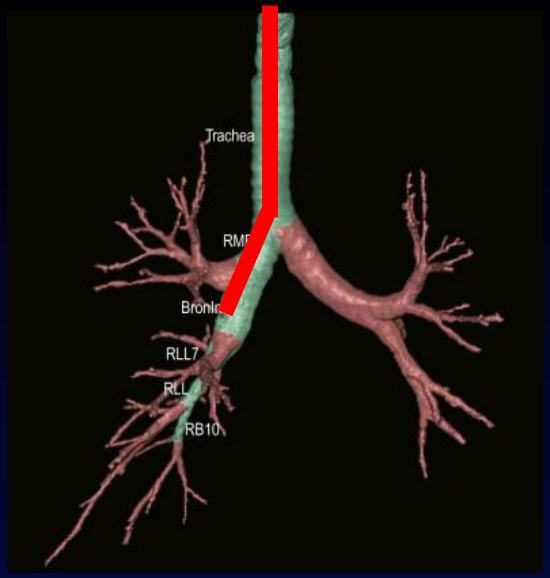
Curvas permitem diagnóstico: piora da complacência após acesso central, motivo foi hemotórax.

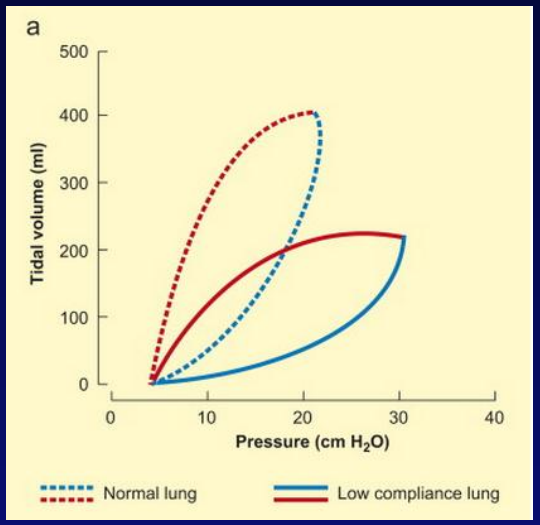


Hemothorax: Supine chest x-ray with a subtle density difference.

PVM

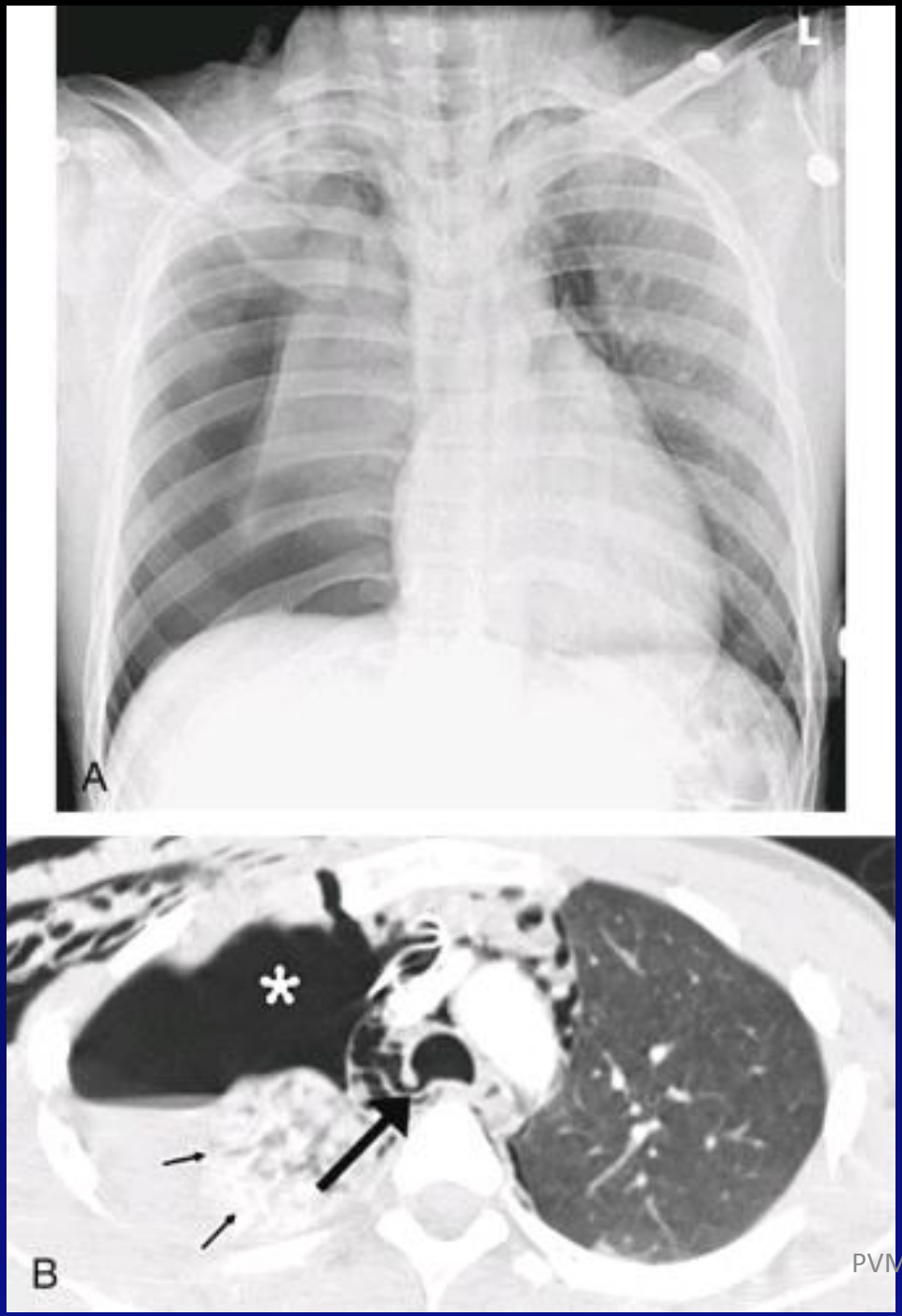




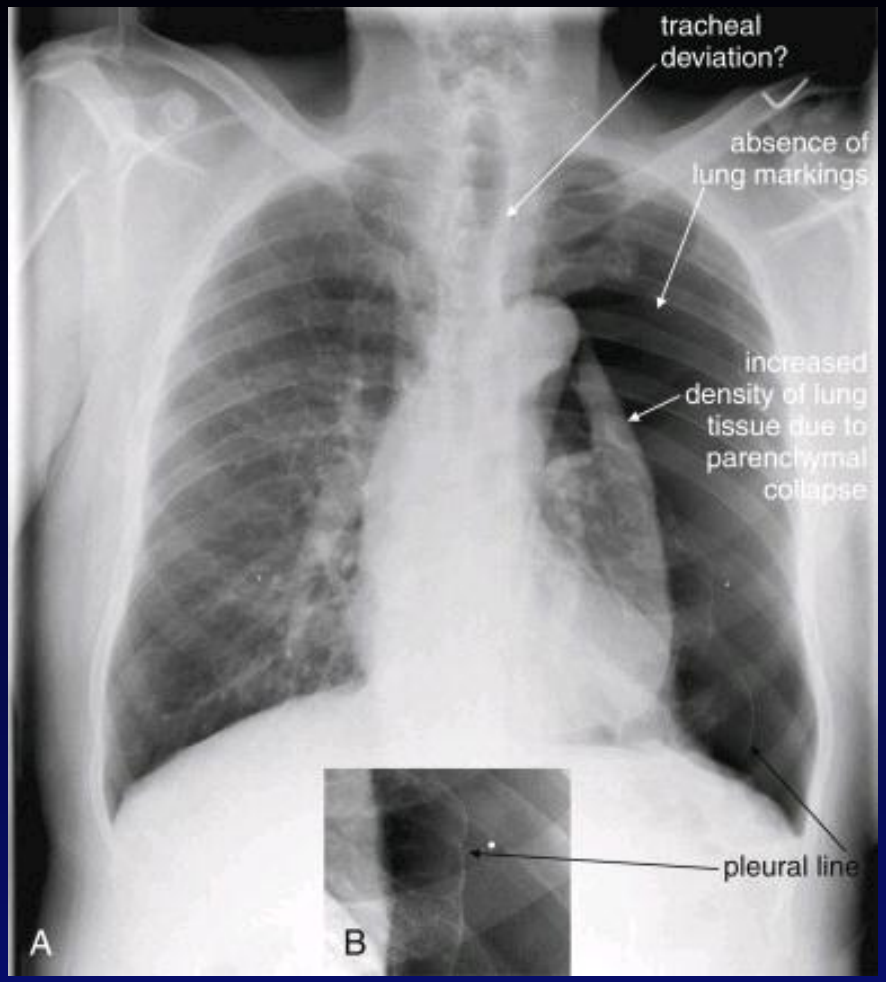


Anteroposterior chest radiograph shows endotracheal tube *(arrows)* extending into bronchus intermedius, with resulting collapse of left lung and right upper lobe from hypoventilation.

PVM

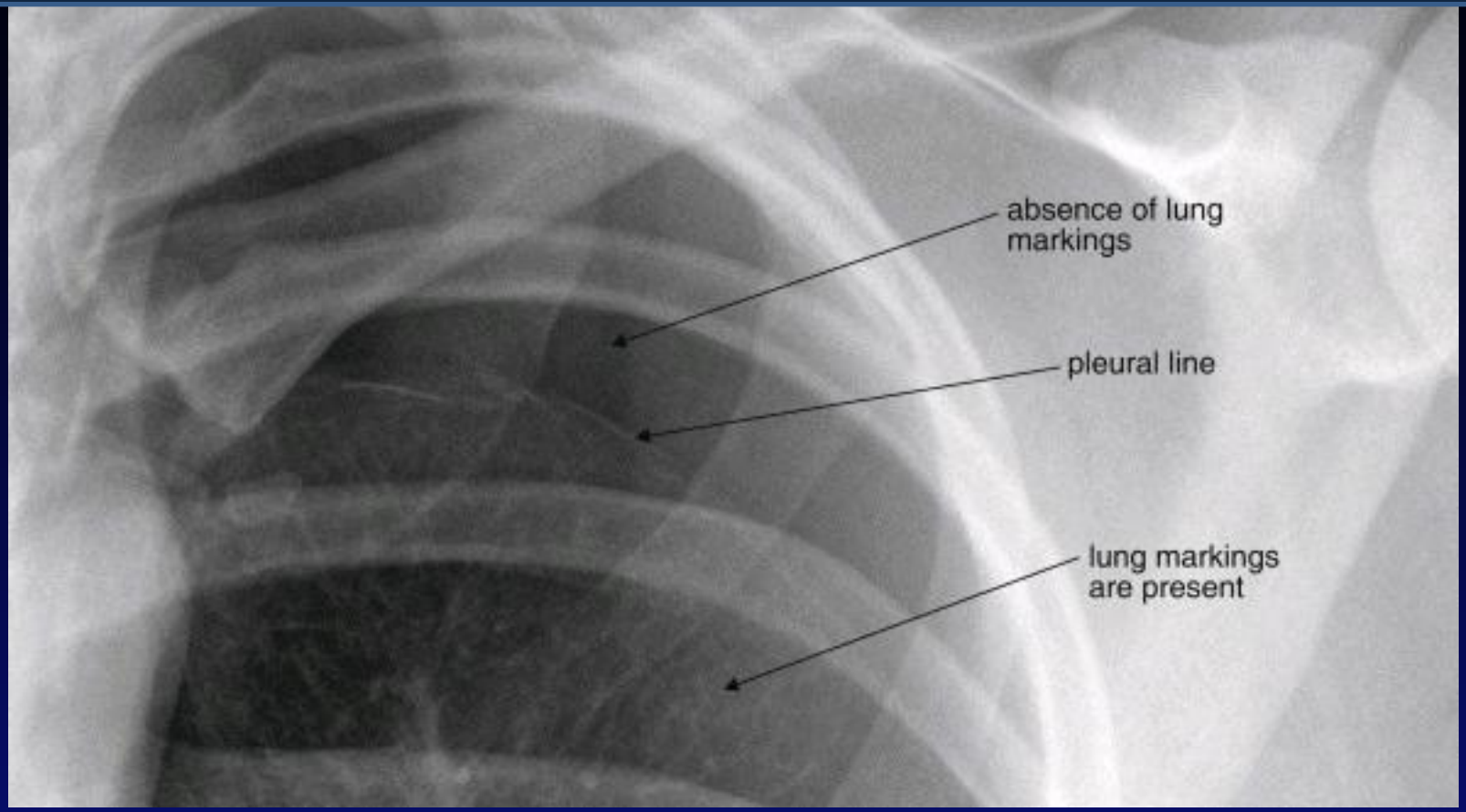


A 22-year-old man was involved in a high-speed motor vehicle crash. A, Anteroposterior chest radiograph shows right pneumothorax, pneumomediastinum, right lung collapse, and subcutaneous emphysema. B, Computed tomography shows tracheal laceration *(large arrow)*, right pneumothorax *(asterisk)*, and collapsed right lung *(small arrows)* in dependent portion of chest ("fallen lung sign").

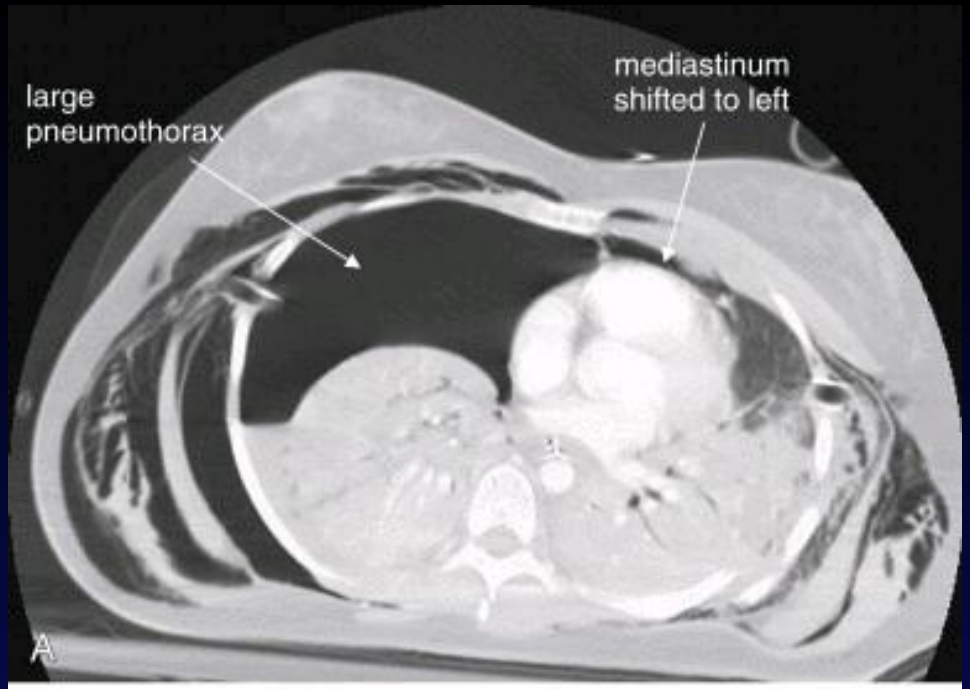


Curvas permitem diagnóstico: piora da complacência após pneumotórax.

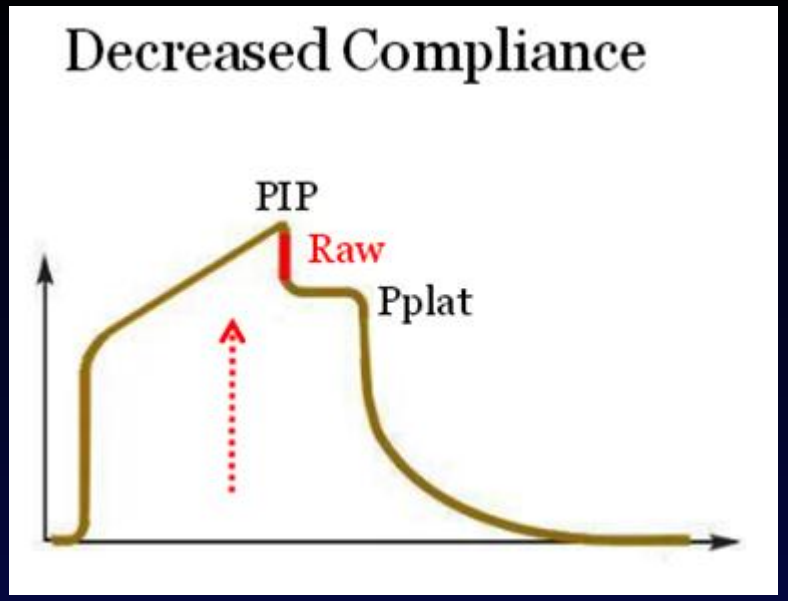
Necessário atenção, principalmente se penumotórax pequeno!!!!

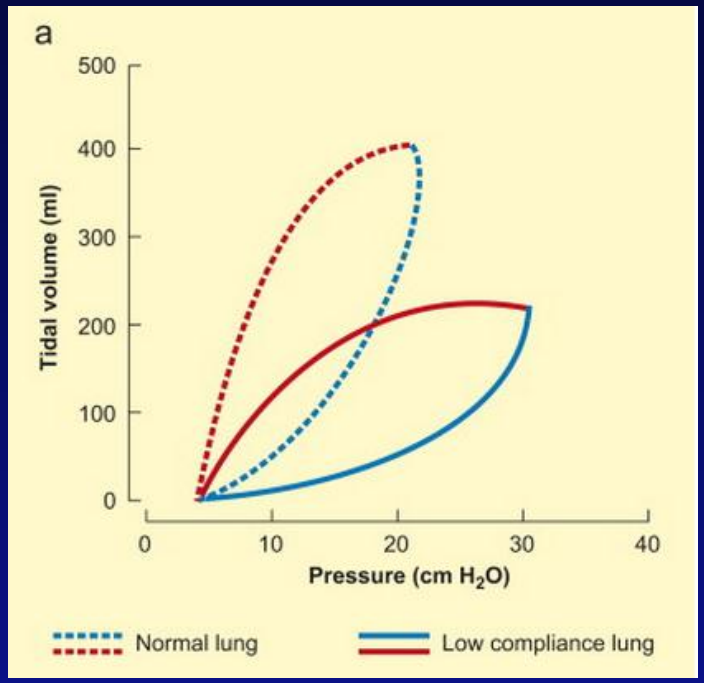


This young male suffered a spontaneous left pneumothorax. The x-ray demonstrates several features typical of pneumothorax and is subtle, though the pneumothorax is relatively large. This pneumothorax appears to be restricted to the left apical region on this upright chest x-ray

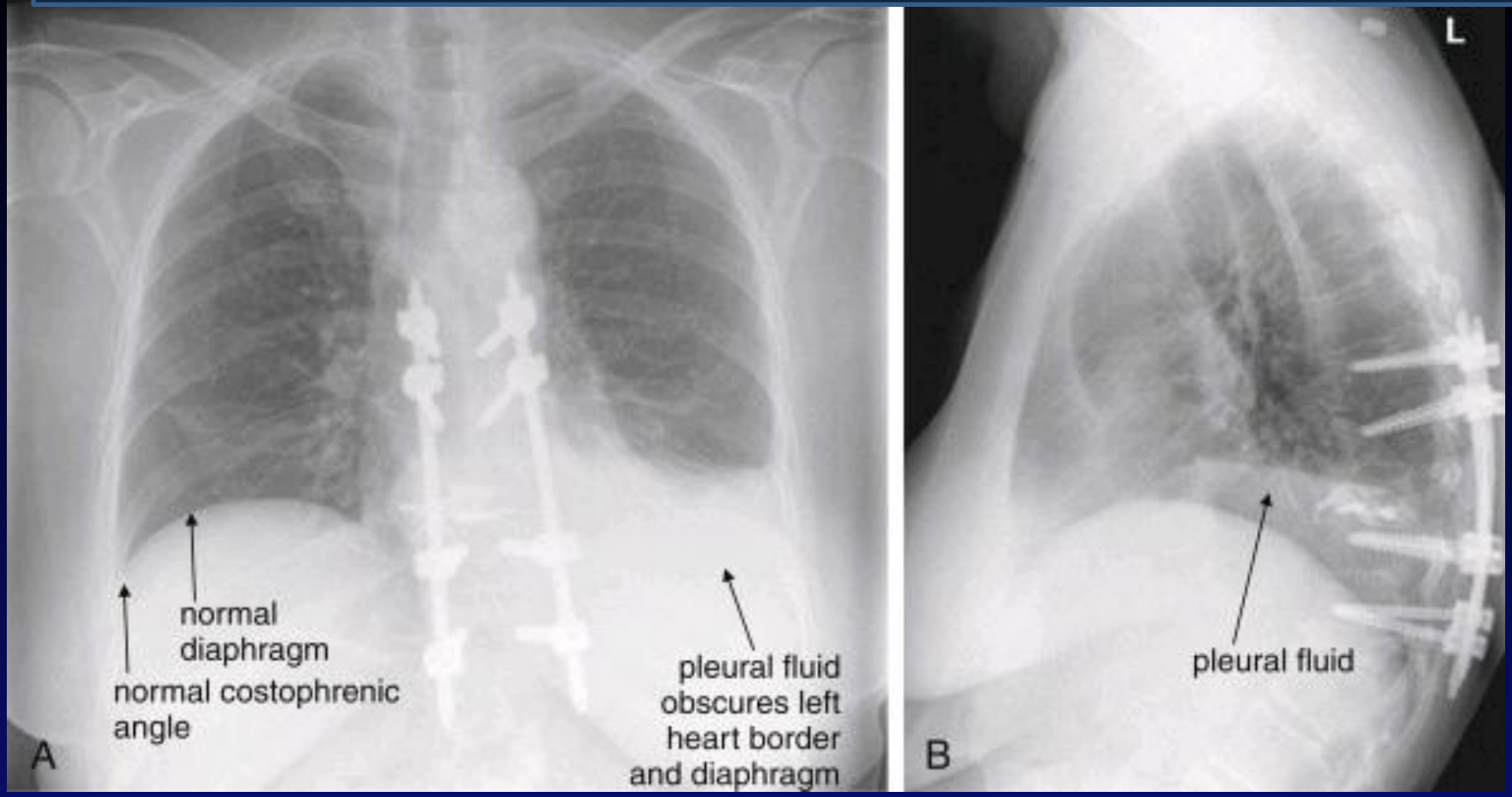

large
pneumothorax
mediastinum
shifted to left
A

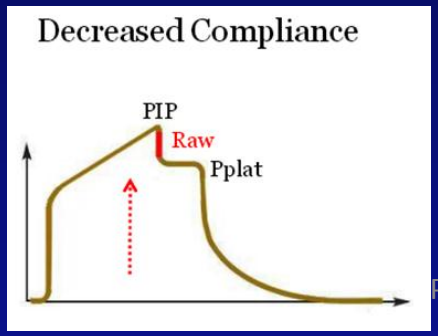

chest tube in
cross-section
subcutaneous
emphysema
B
PVM

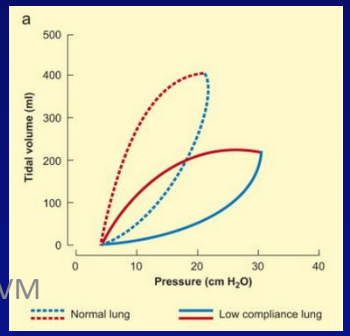

Decreased Compliance
PIP
Raw
Pplat


a
500
400
300
200
100
0
Tidal volume (ml)
0
10
20
30
40
Pressure (cm H2O)
Normal lung
Low compliance lung

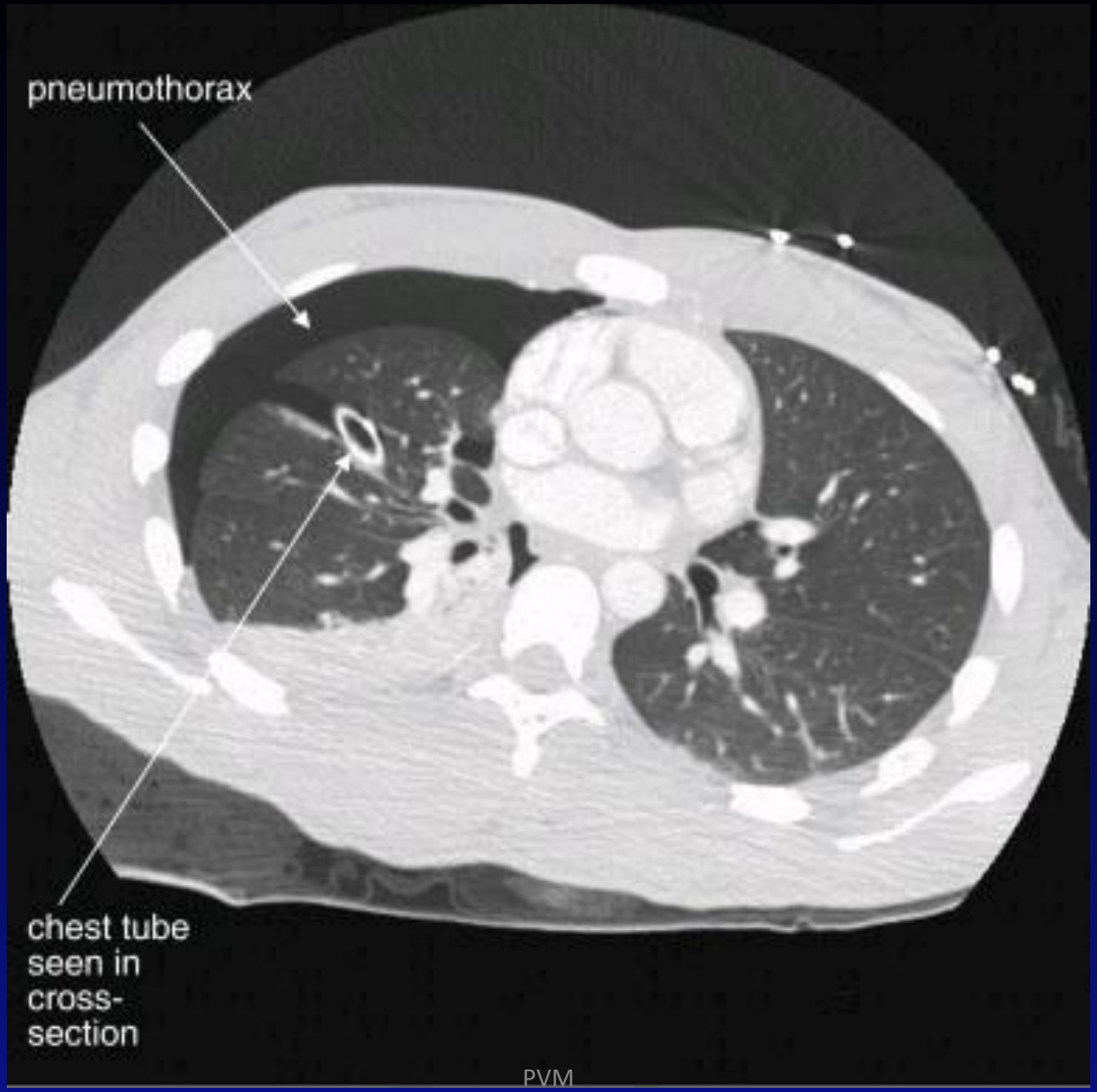
Curvas permitem diagnóstico: piora da complacência após derrame pleural



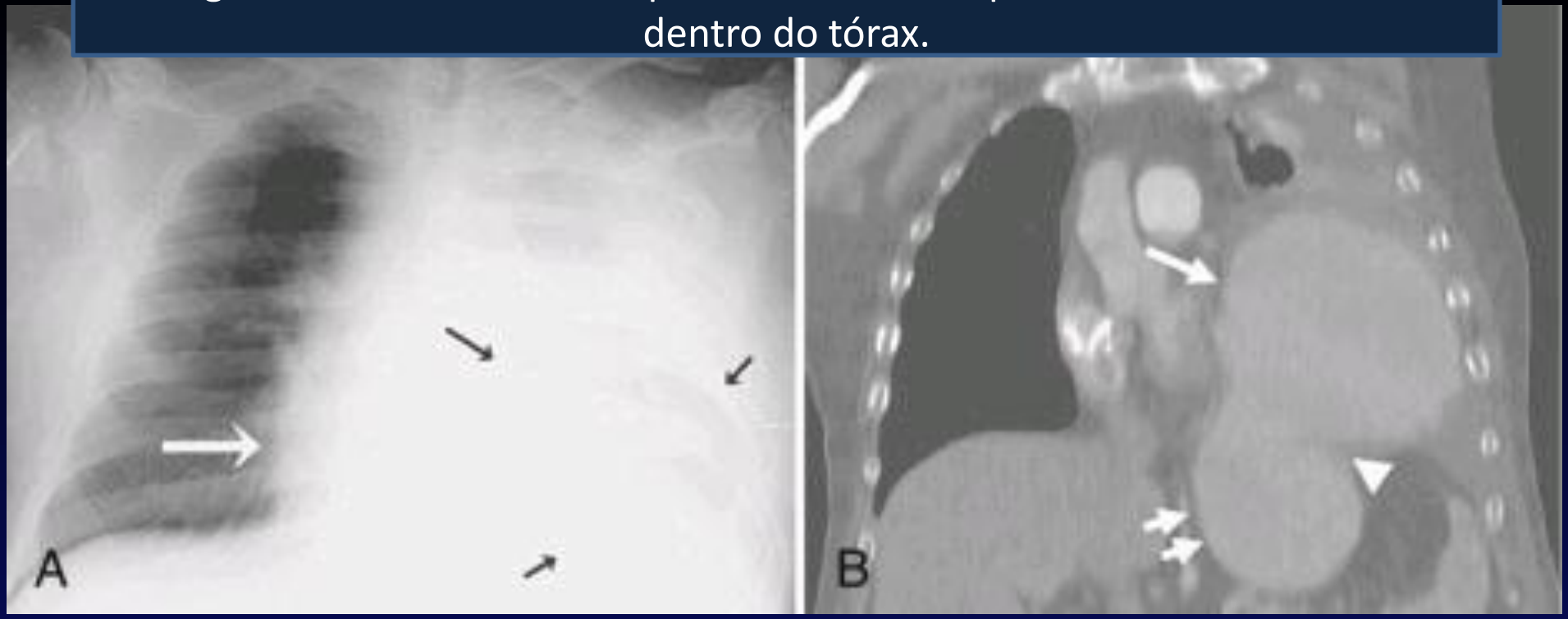




PVM

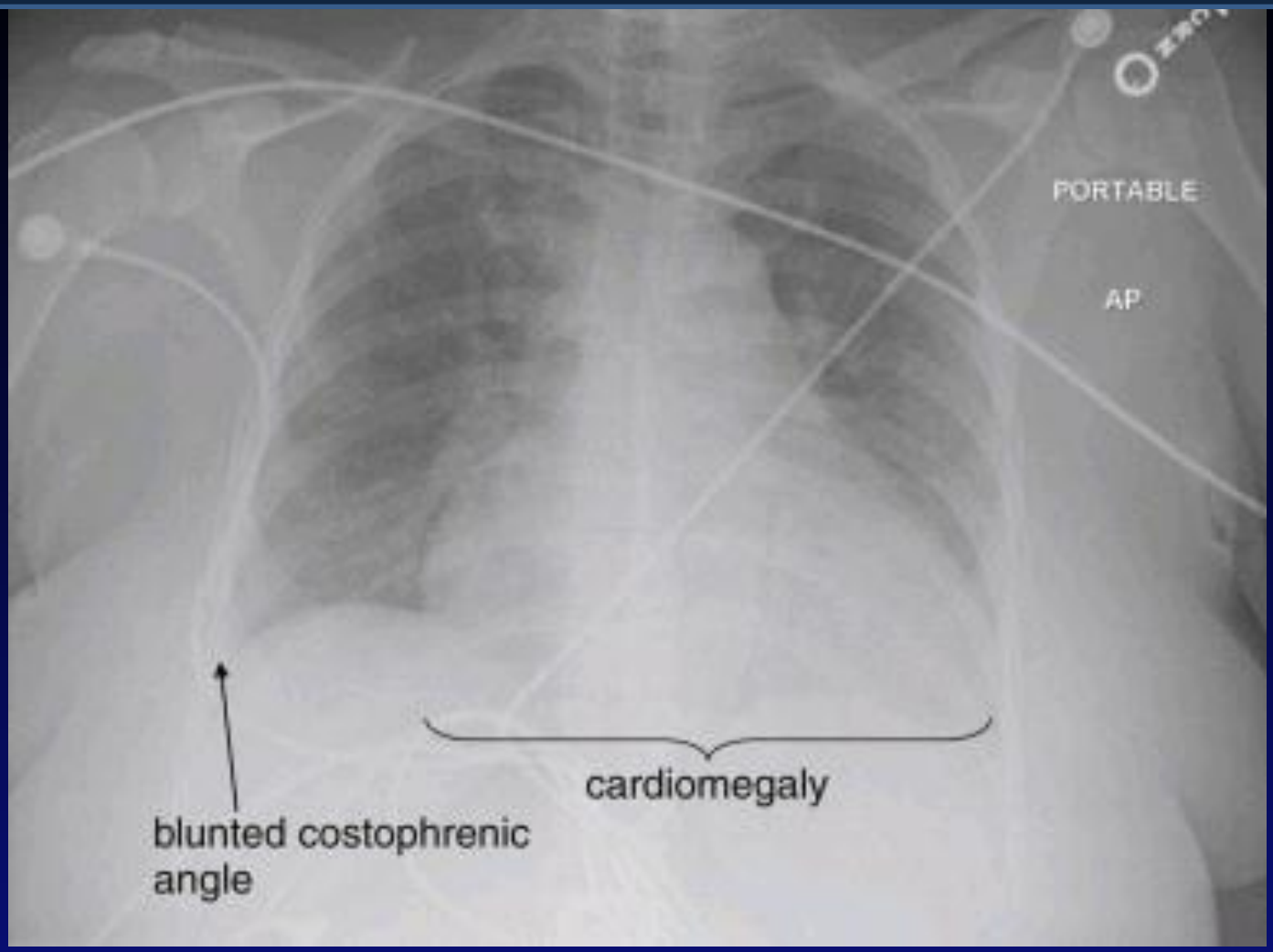

pneumothorax
chest tube
seen in
cross-
section

Diagnóstico diferencial: complacência reduzida por conteúdo abdominal dentro do tórax.



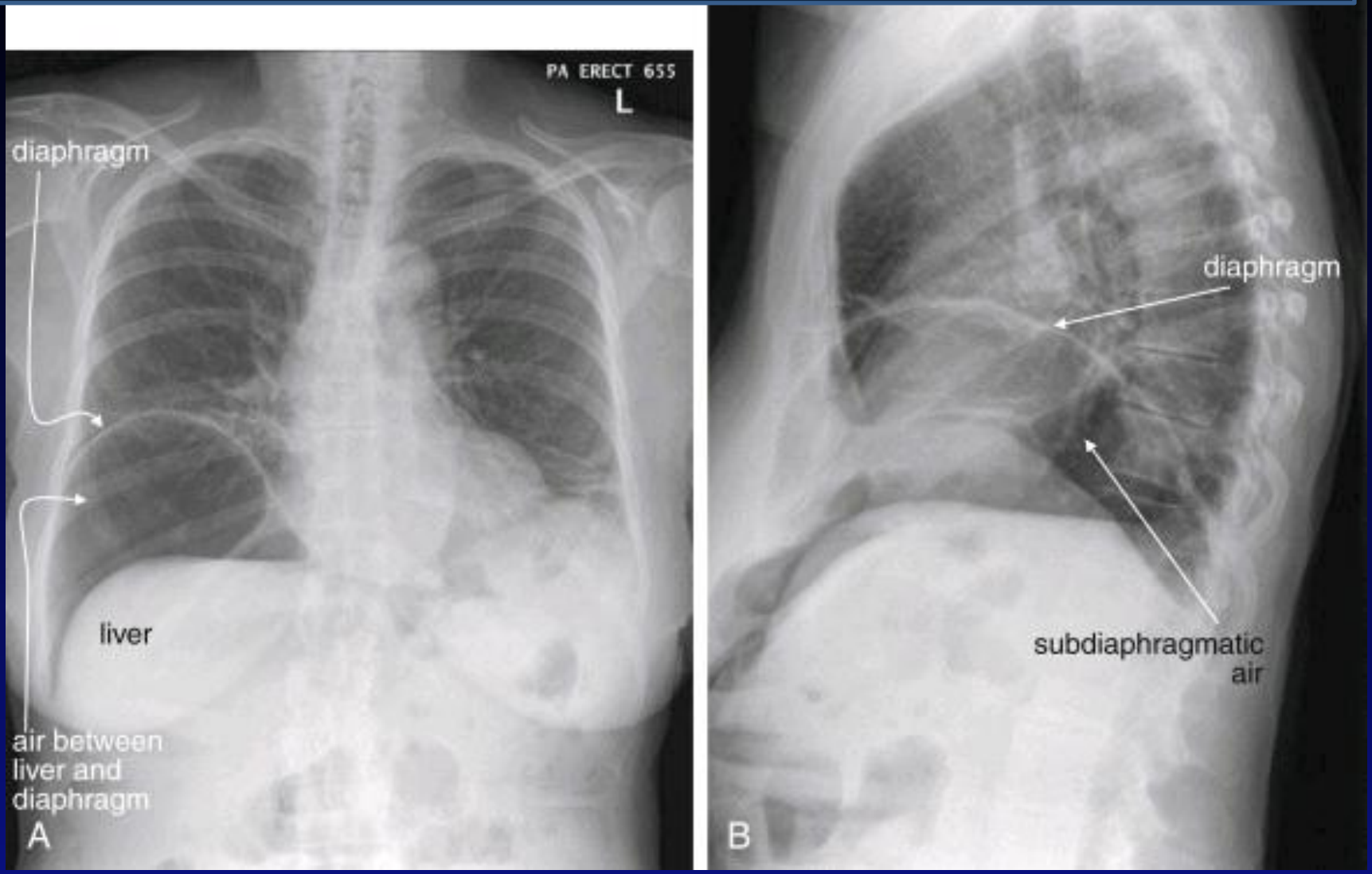
A 48-year-old man involved in a motor vehicle crash sustained a diaphragmatic injury. A, Bedside chest radiograph shows diffuse opacity in left hemithorax and rightward mediastinal displacement *(white arrow)*. A round lucency representing the gastric bubble is present within opacified left hemithorax *(black arrows)*. B, Coronal computed tomography re-formation shows partial herniation of stomach (gastric fundus *[single arrow]* and gastric body *[double arrows])* into chest through a large defect in diaphragm *(arrowhead)*.

Diagnóstico diferencial: complacência reduzida por congestão pulmonar



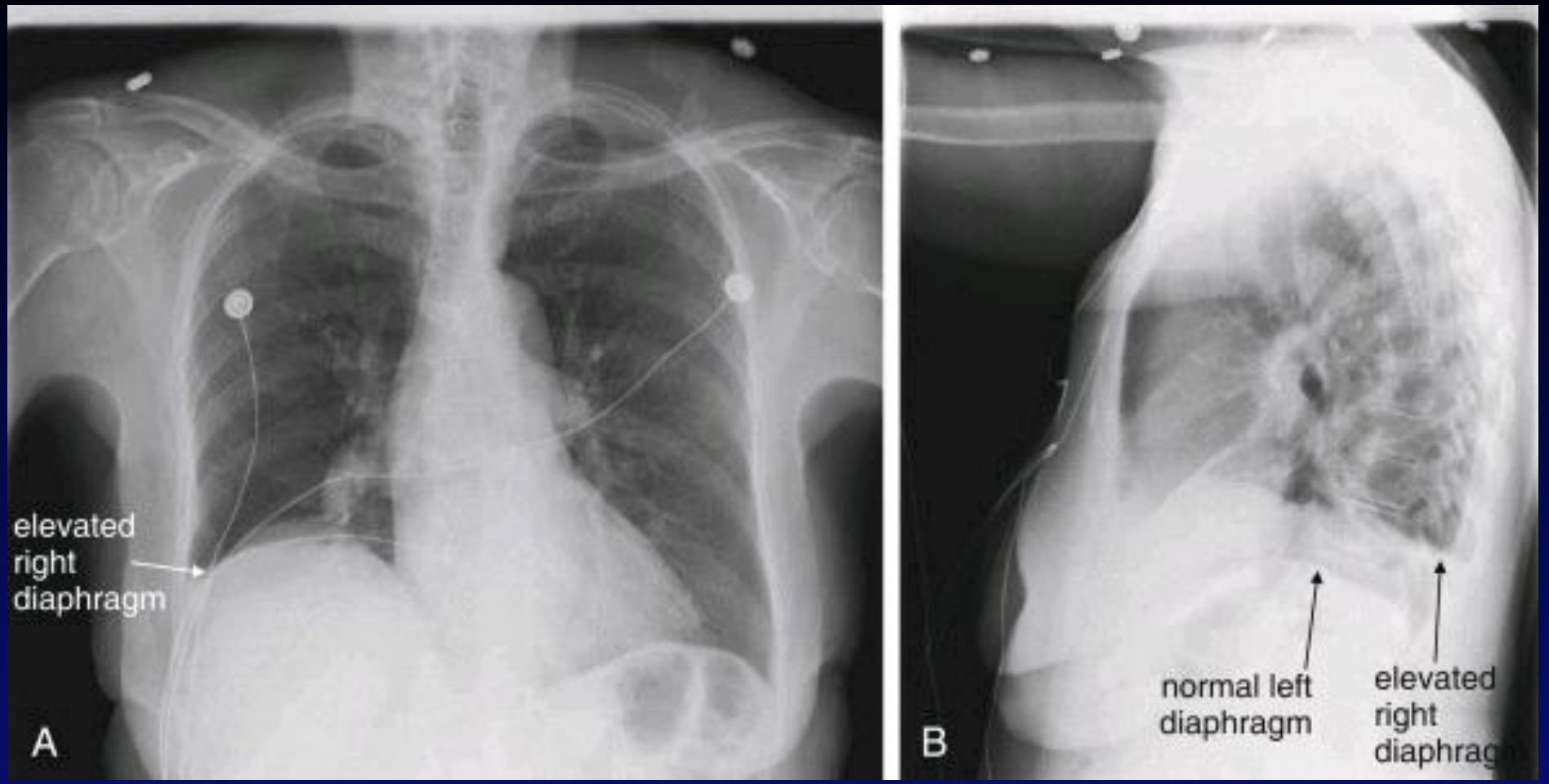
Congestive heart failure, postpartum: Ejection fraction of less than 15%, no pericardial effusion.

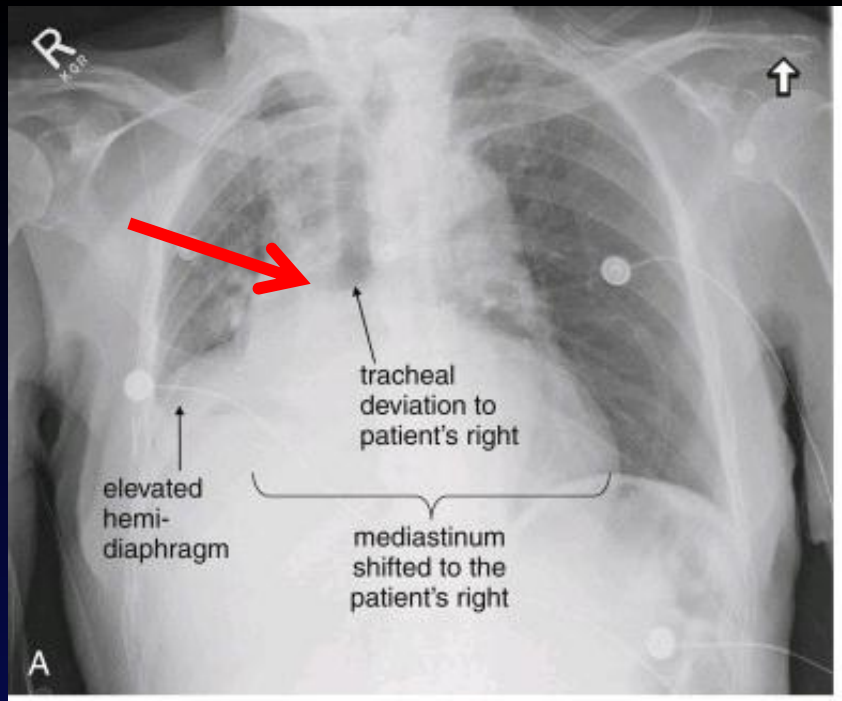
Diagnóstico diferencial: complacência reduzida por pneumoperitônio. Pode ser uma complicação do CPAP nasal, ou úlcera péptica, como no RX abaixo

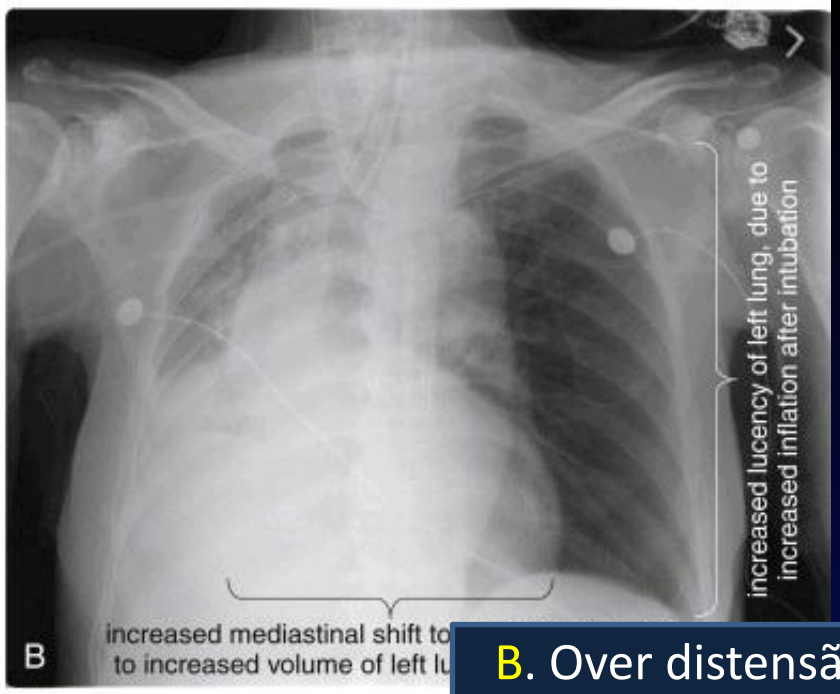


This patient was found to have a perforated gastric ulcer at laparotomy.

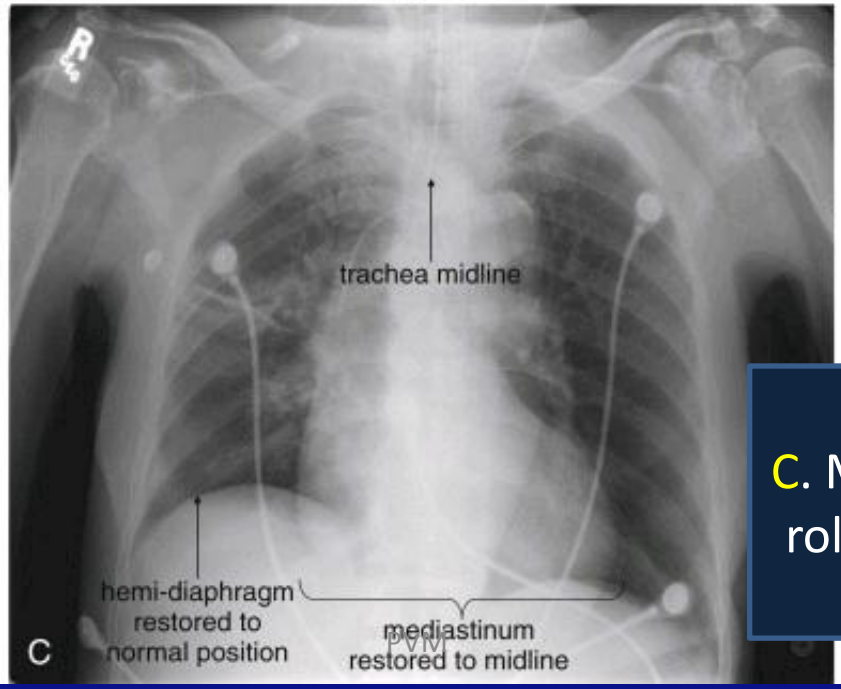
Diagnóstico diferencial: complacência reduzida por atelectaisa







A. Atelectasia por rolha em paciente asmático. Ver sinal de "stop bronquico" seta vermelha

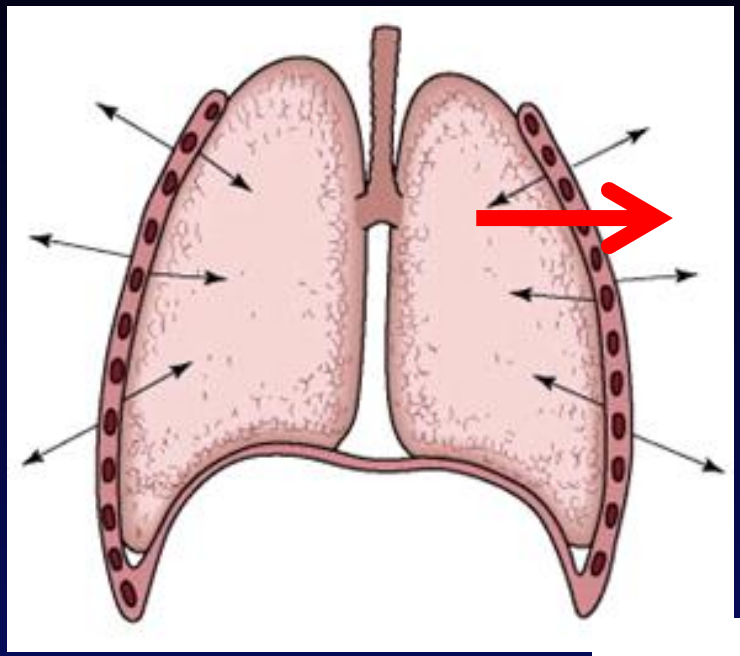


B. Over distensão a esquerda e piora da atelectasia a direita após intubação e instalação de VM, com piora da hipóxia

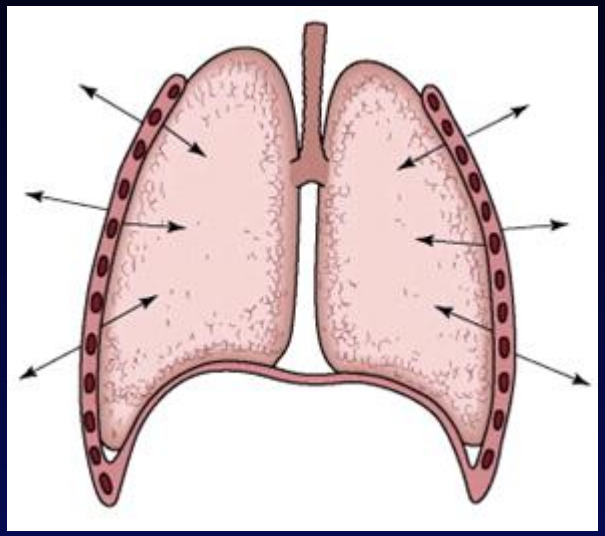
C. Melhora após remover rolha com broncoscopia

VM PROTERTORA

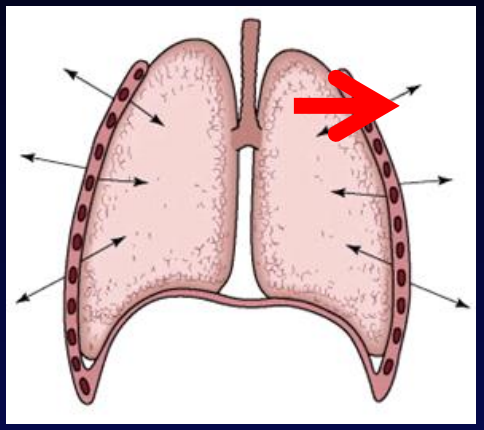
CRF

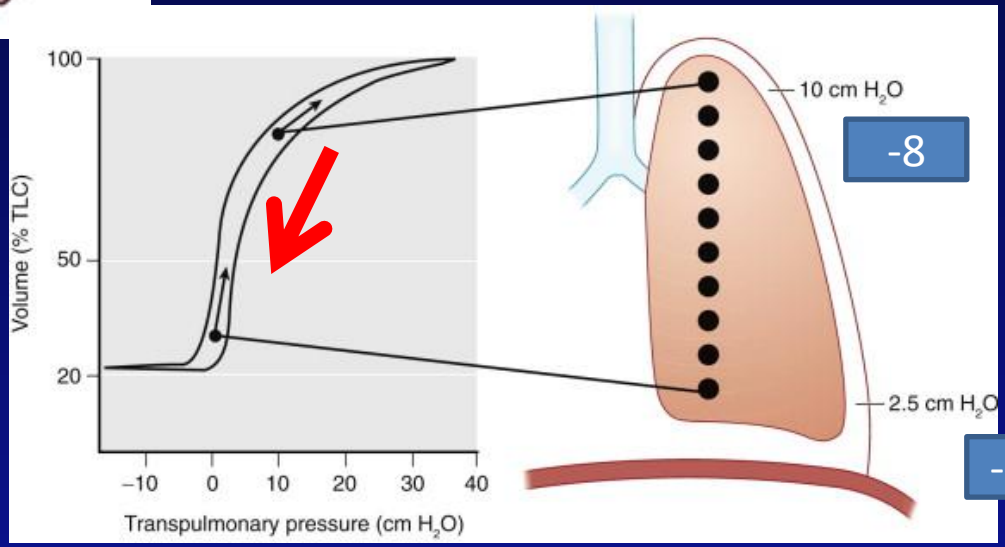


Volume de Fechamento



CRF

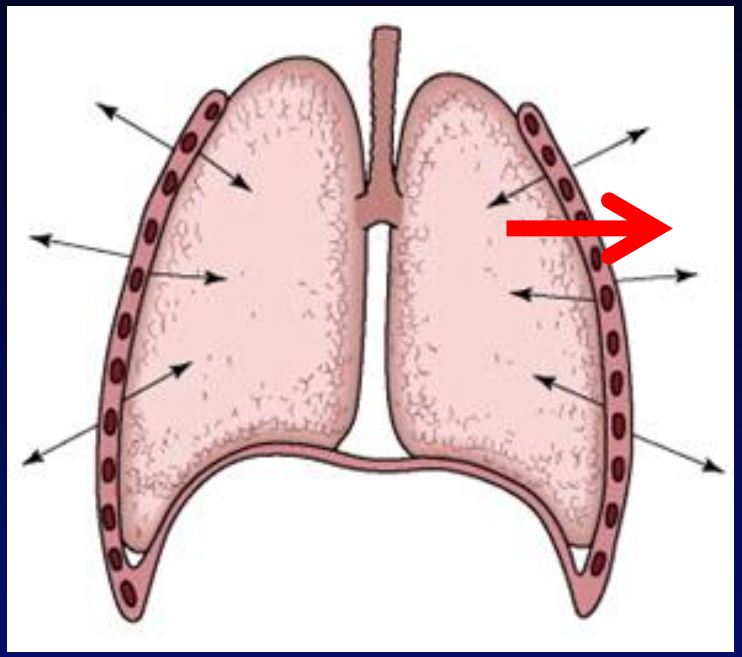




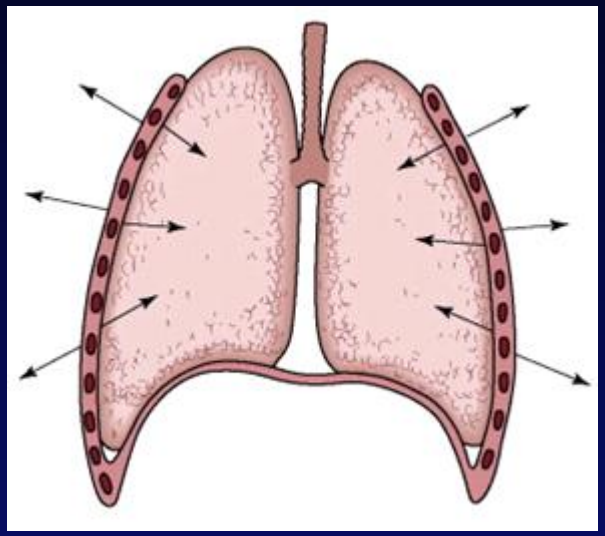
-8

-1,5

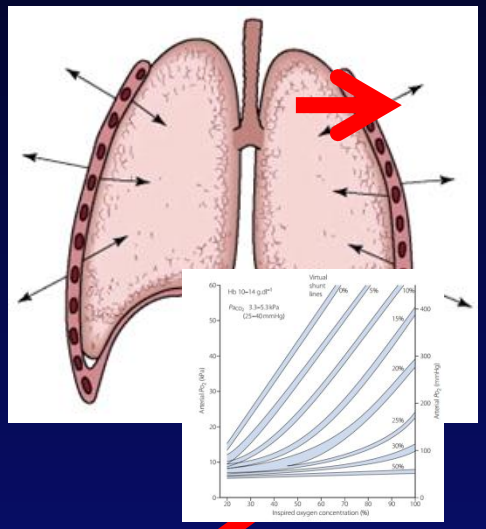
CRF



VF



CRF



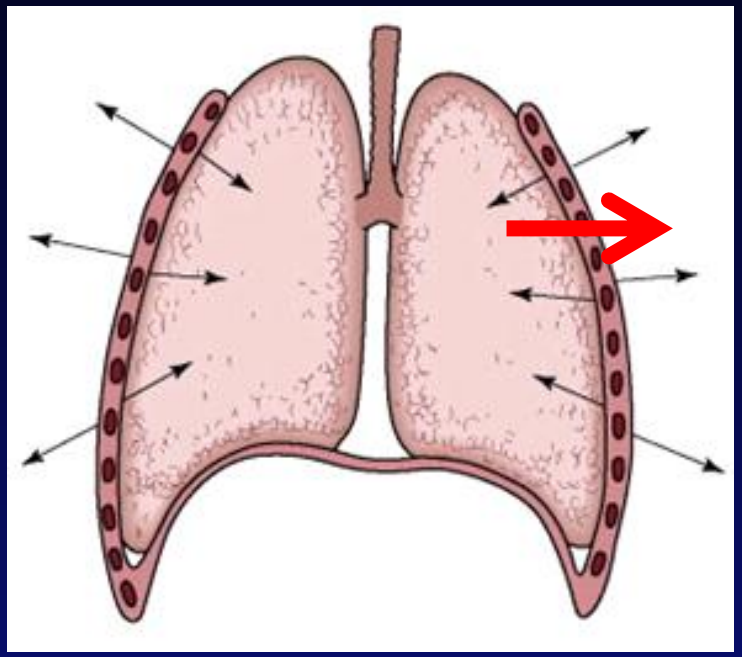
CRF > VF
Desejável

VF > CRF
Atelectasia

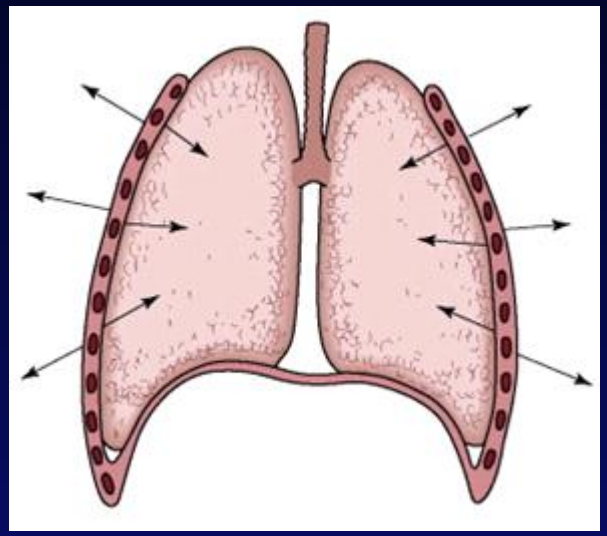
PVM

Anestesia, biotrauma, inflamação, atelectasia,
FIO2 alta, Ausência de PEEP, edema

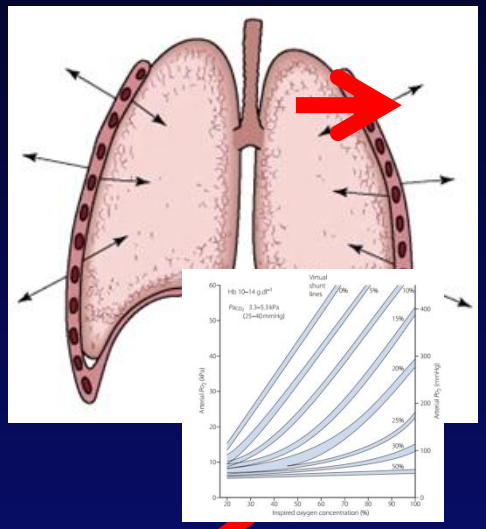
CRF



VF



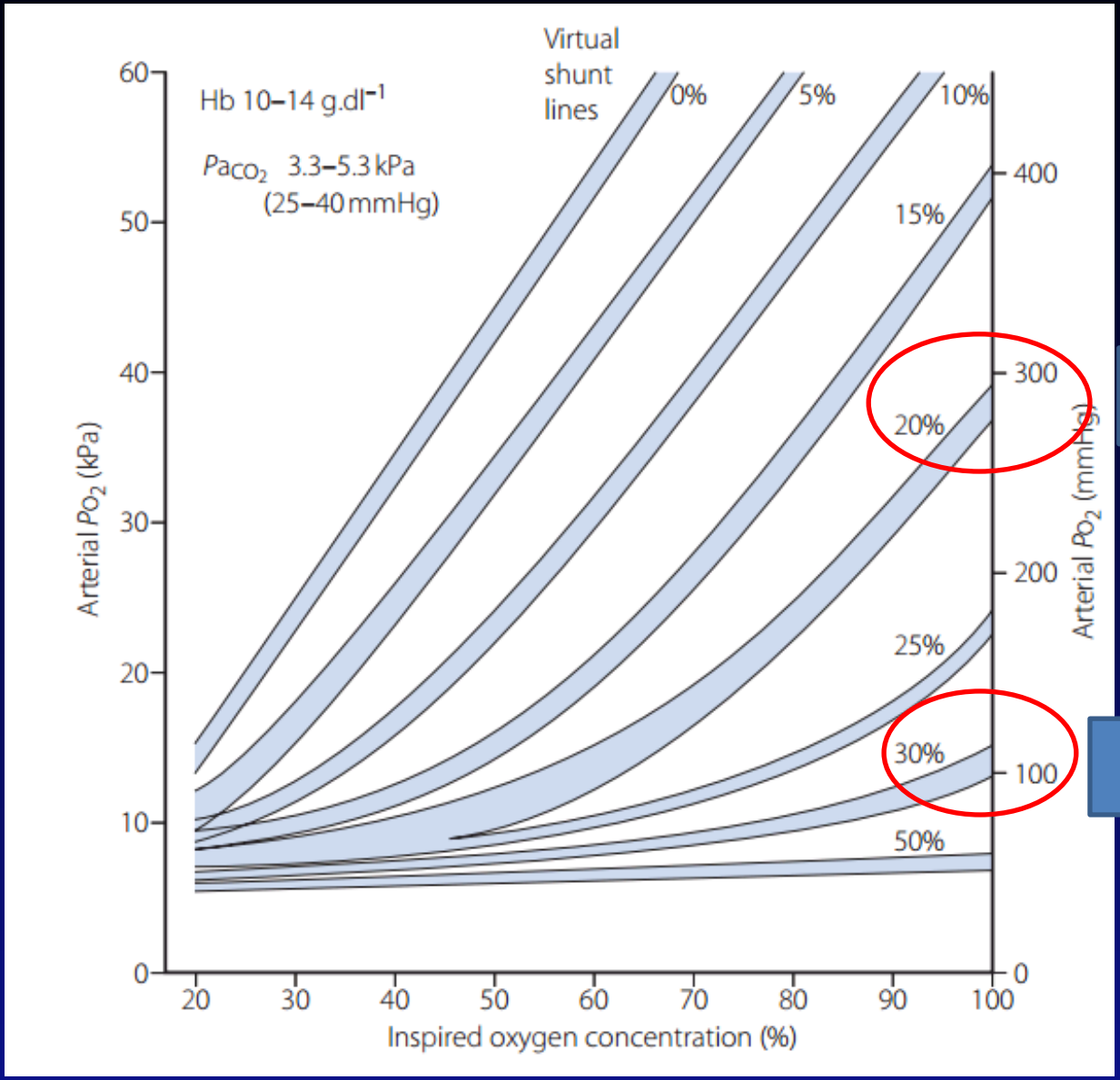
CRF



Desejável

Atelectasia

SHUNT

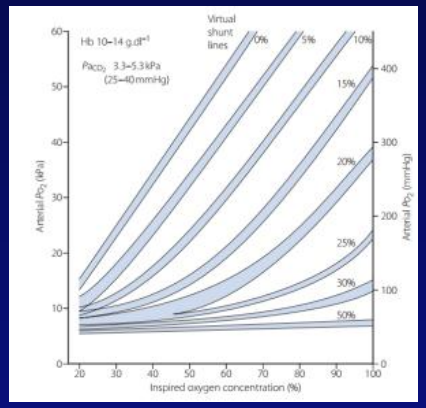


P/F = 285

P/F = 100

VM Protetora

- Evitar barotrauma
- Evitar volutrauma
- Evitar atelectrauma
- Usar PEEP para estabilizar o alvéolo
- Minimizar FiO2
- Vt < 6ml/Kg
- Pressão plateou <25-30cmH2O
- Diminuir espaço morto

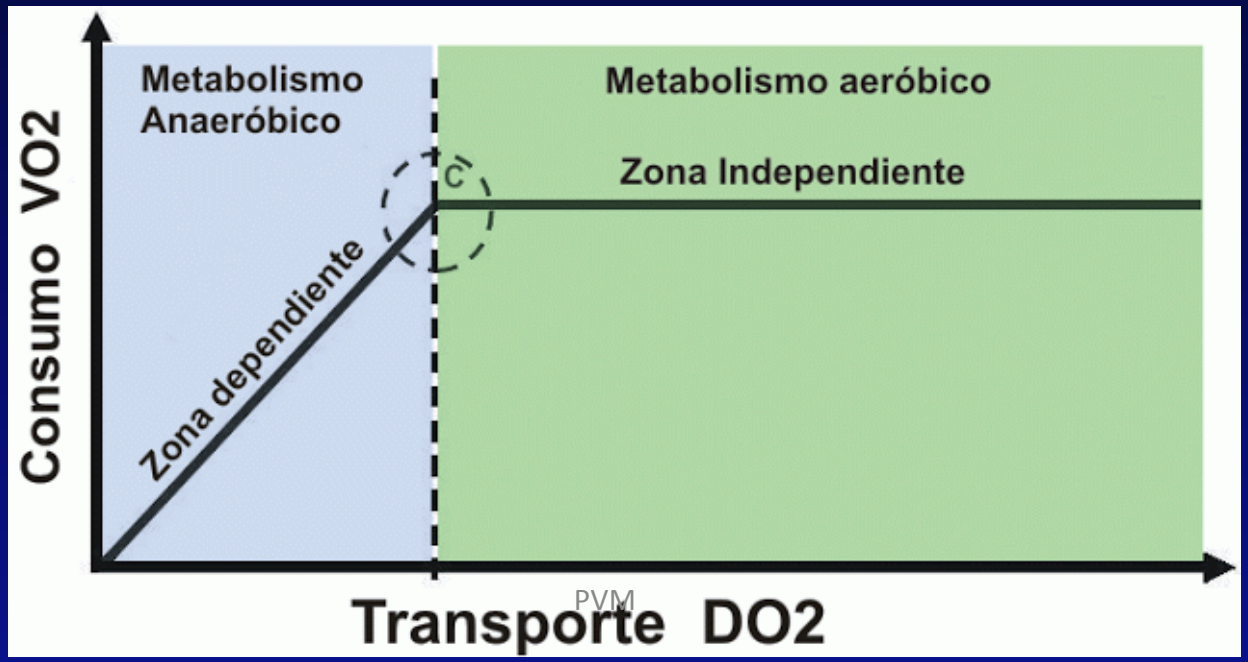


Biotrauma

- Efeitos deletérios da vasoconstricção pulmonar hipóxica.
  - Aumenta RVP
  - Confunde diagnóstico

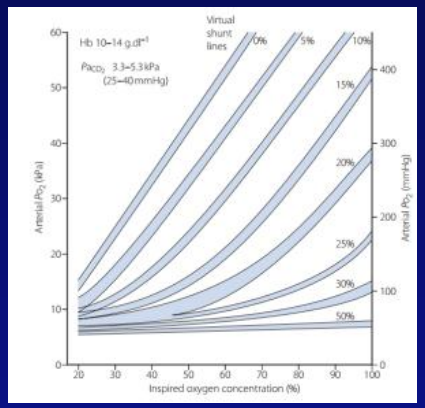
VM Protetora

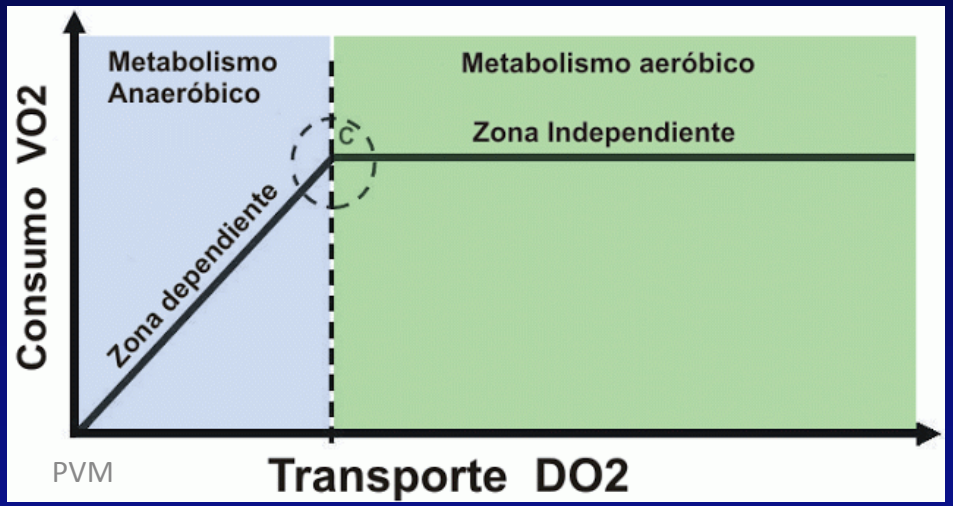
- Dosimetria: “VM é uma Arte”
  - Resolver o problema minimizando o dano
  - VM: parte da estratégia para manter paciente na ZONA VERDE

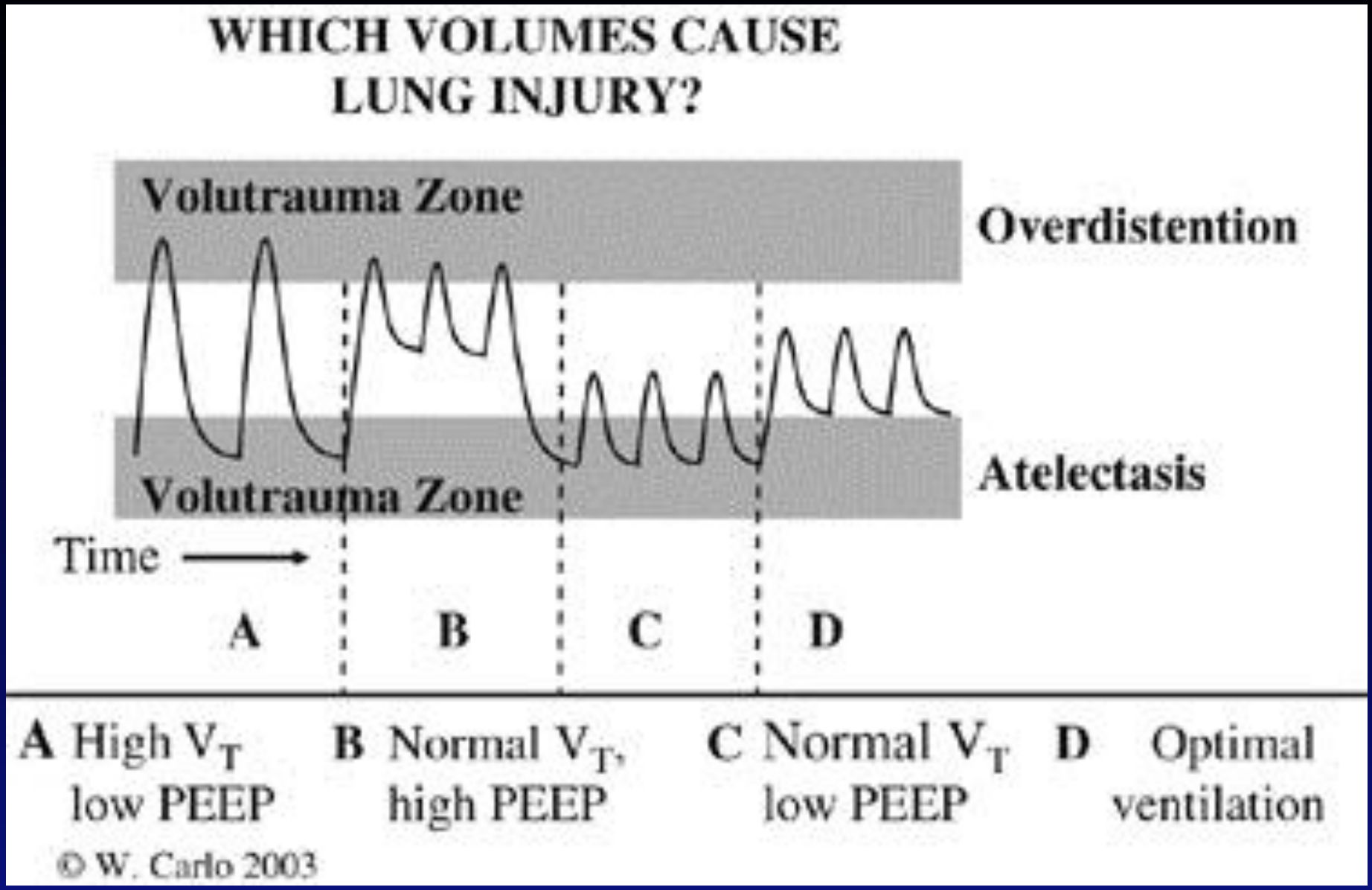


DOSIMETRIA

- DO2= DC x CaO2 (CaO2=Hb x 1,34 x StO2)
  - Biotrauma: aumento pós-carga VD, diminui DC
  - Biotrauma: SARA: diminui CaO2
  - Suporte insuficiente: aumenta trabalho respiratório; não melhora a hipoxemia.







Journal of Perinatology (2007) 27, S64 – S70r2007 Nature Publishing Group All rights reserved. 0743-8346/07 $30 PVM

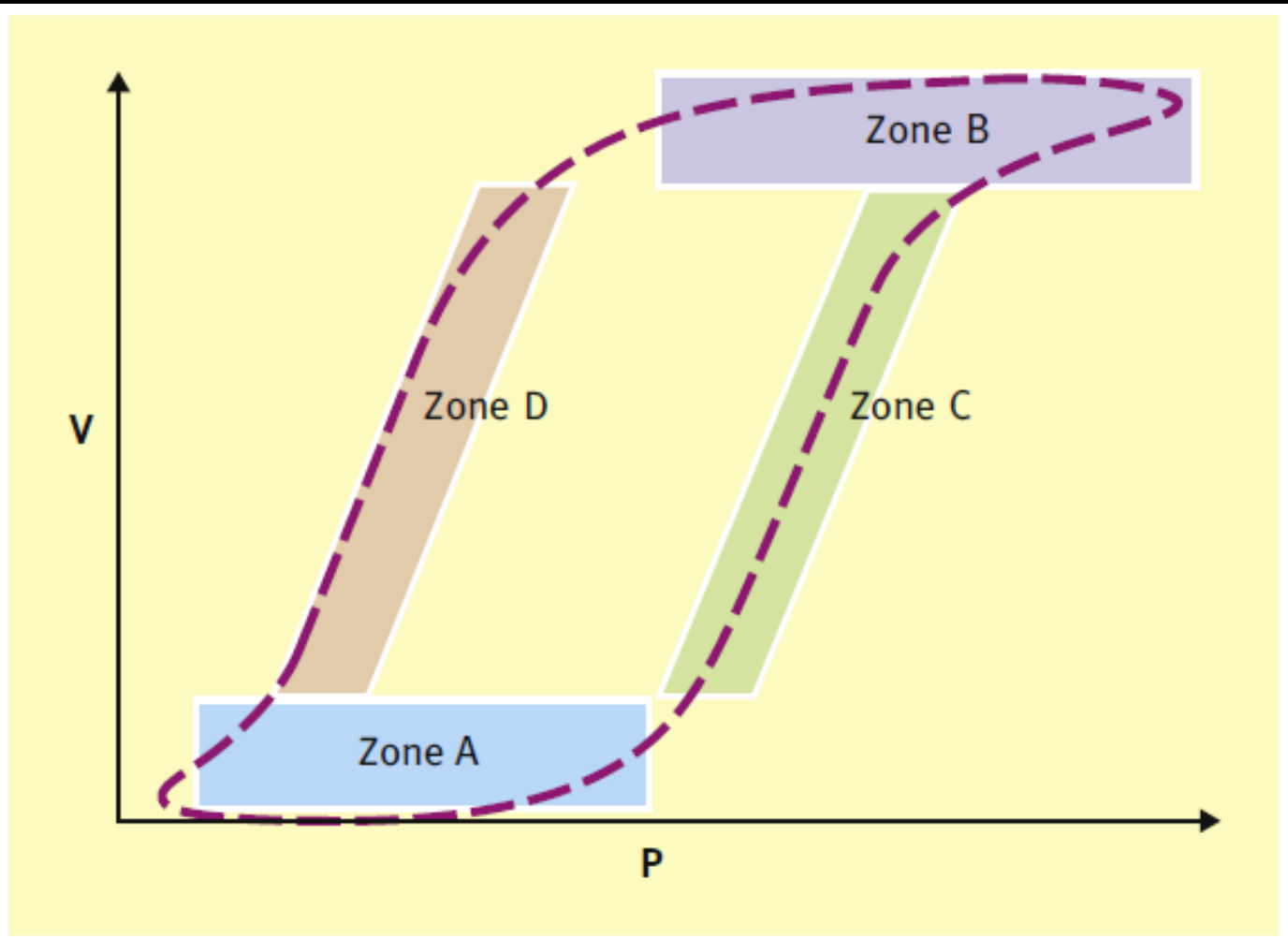


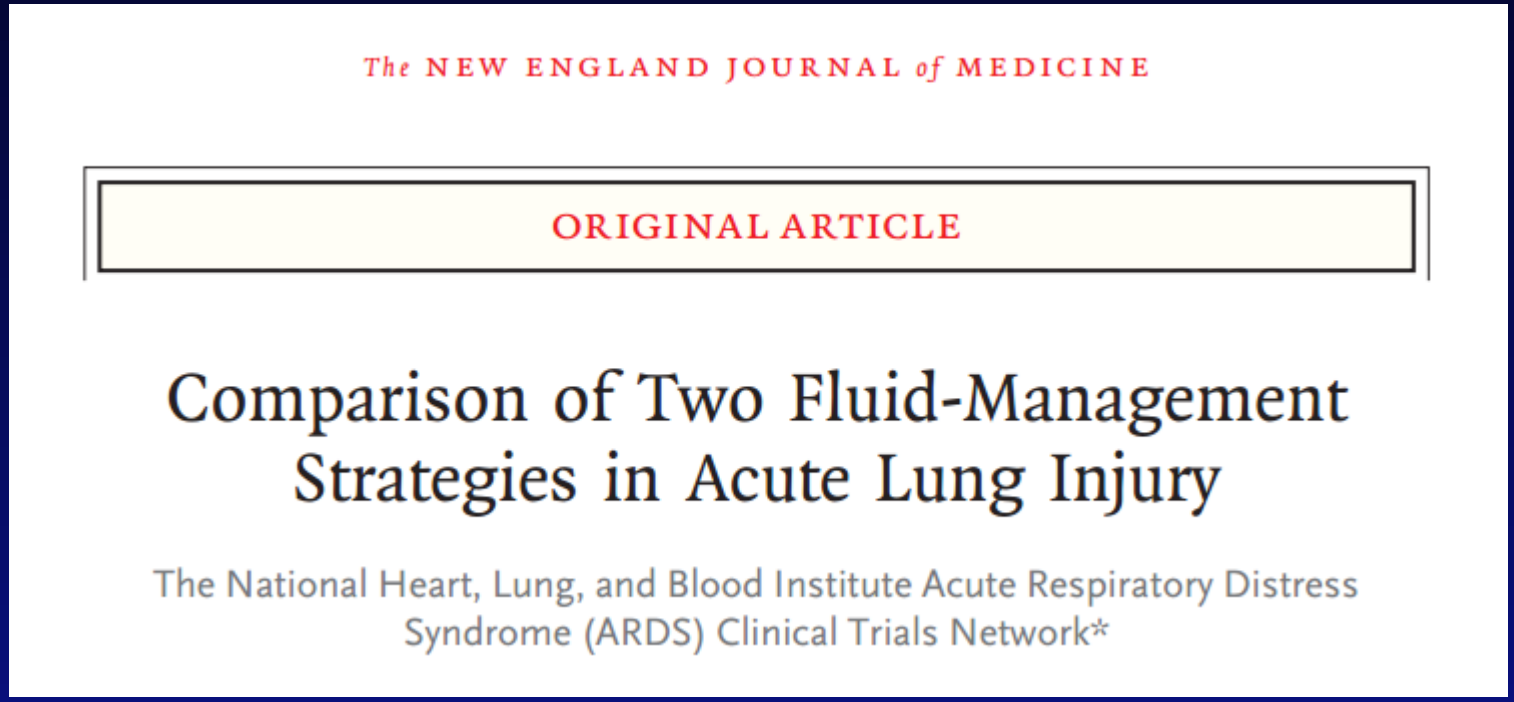
Figure 2 Strategy to avoid ventilator-induced lung injury — adopted from HFO ventilation model (P = Pressure, V = Volume). Zone A = Under-inflation causing atelectrauma. Zone B = over-inflation causing Volu-trauma. Zone C = optimal recruitment inflation. Zone D = optimal expi-ratory inflation: The goal should be to ventilate babies' lungs from Zone C to Zone D during each cycle therefore avoiding Zone A & B.

Abordagem da Disfunção Pulmonar

- Ventilação mecânica protetora
  - Evitar barotrauma/volutrauma/atelectrauma
  - Usar PEEP para estabilizar o alvéolo
  - Minimizar FiO2
  - Vt < 6ml/Kg
  - Pressão plateou < 25-30 cmH2O
  - Permitir hipercapnia
  - Minimizar espaço morto

Abordagem da Disfunção Pulmonar

- Não é só a VM que lesa o pulmão



The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Comparison of Two Fluid-Management Strategies in Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Comparison of Two Fluid-Management Strategies in Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*

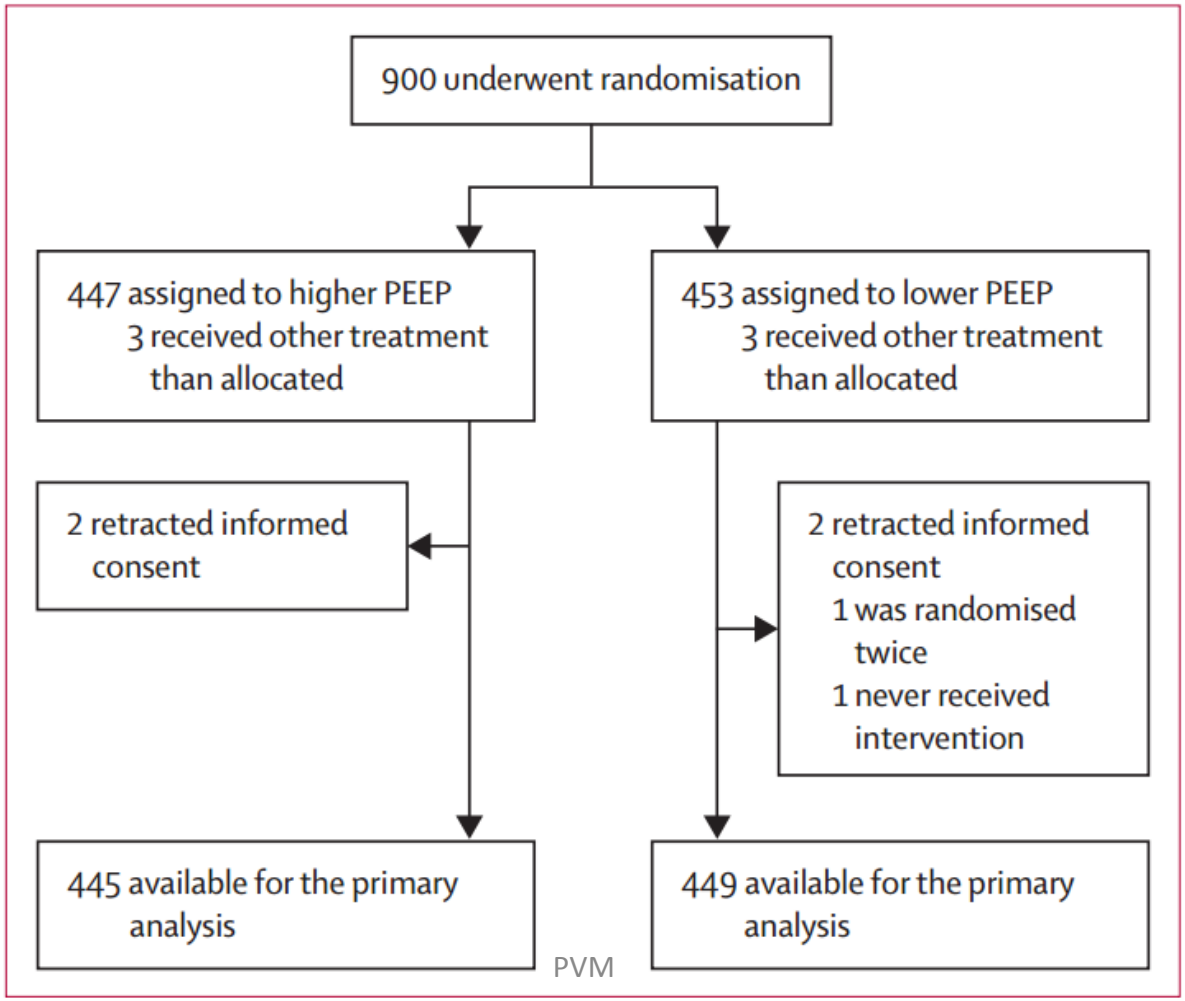
Table 3. Main Outcome Variables.*

Outcome	Conservative Strategy	Liberal Strategy	P Value
Death at 60 days (%)	25.5	28.4	0.30
Ventilator-free days from day 1 to day 28†	14.6±0.5	12.1±0.5	<0.001
ICU-free days†			
Days 1 to 7	0.9±0.1	0.6±0.1	<0.001
Days 1 to 28	13.4±0.4	11.2±0.4	<0.001

PVM

High versus low positive end-expiratory pressure during general anaesthesia for open abdominal surgery (PROVHILO trial): a multicentre randomised controlled trial

The PROVE Network Investigators for the Clinical Trial Network of the European Society of Anaesthesiology*



PVM

PROVHILO TRIAL

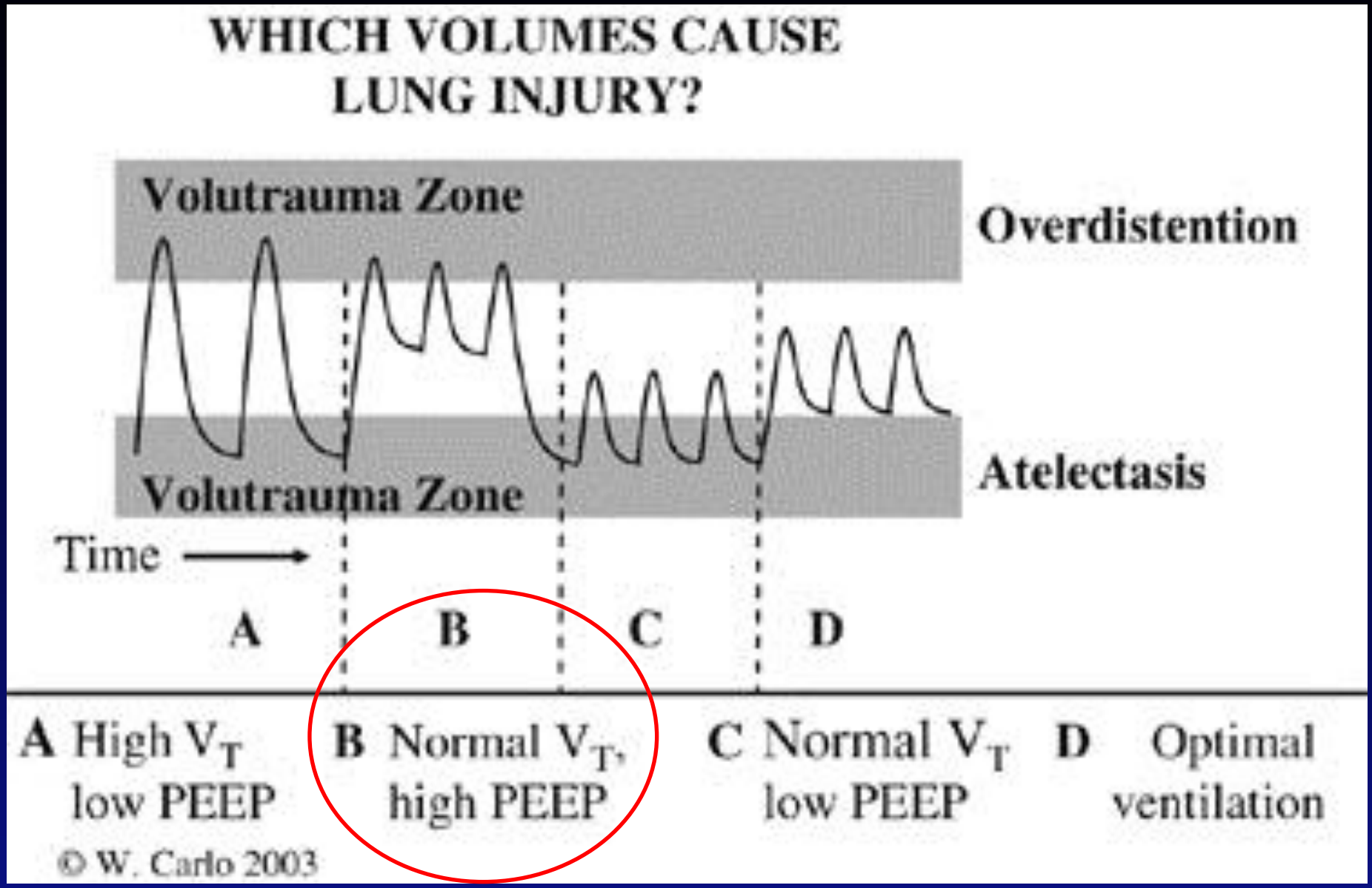
- N pequeno
- Atelectasia persistente no pós-operatório relacionada a FiO2 alta

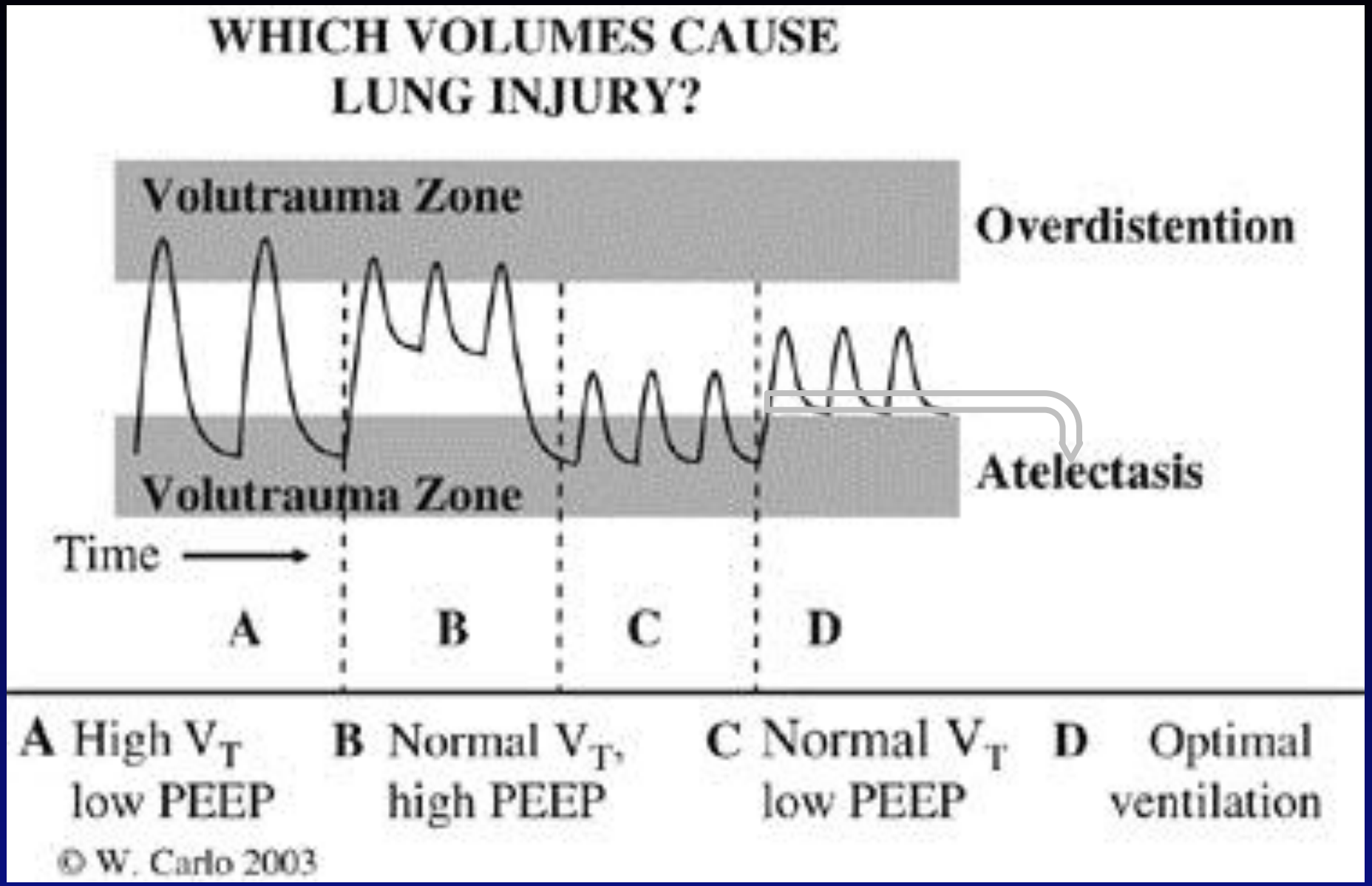
- Grupo PEEP alto: melhor complacência torácica mas não houve melhor desfecho:
  - Volutrauma nas regiões não dependentes
  - Hemodinâmica

PROVHILO TRIAL

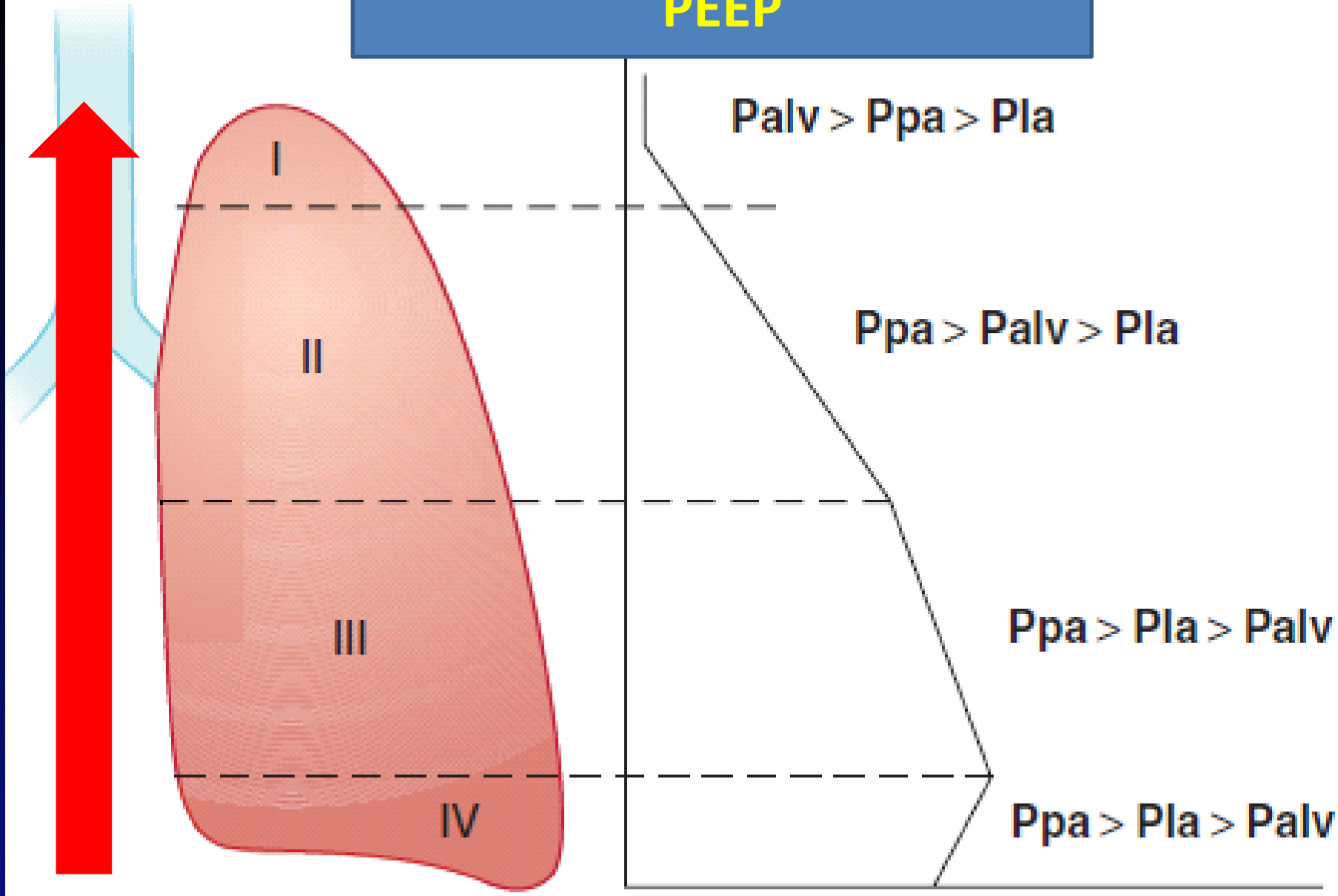
	Higher PEEP group (n=445)	Lower PEEP group (n=449)	Relative risk (95% CI)	p
Intraoperative complications				
Rescue strategy for desaturation	11/442 (2%)	34/445 (8%)	0·34 (0·18–0·67)	0·0008
Hypotension††	205/441 (46%)	162/449 (36%)	1·29 (1·10–1·51)	0·0016
Vasoactive drugs needed	274/444 (62%)	228/445 (51%)	1·20 (1·07–1·35)	0·0016
New arrhythmias needing intervention	12/442 (3%)	5/445 (1%)	2·38 (0·84–6·70)	0·09

(Table 3 continues on next page)


WHICH VOLUMES CAUSE LUNG INJURY?
Volutrauma Zone
Overdistention
Atelectasis
Volutrauma Zone
Time
A
B
C
D
A High V_T low PEEP
B Normal V_T, high PEEP
C Normal V_T low PEEP
D Optimal ventilation
© W. Carlo 2003


WHICH VOLUMES CAUSE LUNG INJURY?
Volutrauma Zone
Overdistention
Volutrauma Zone
Atelectasis
Time
A
B
C
D
A High V_T low PEEP
B Normal V_T, high PEEP
C Normal V_T low PEEP
D Optimal ventilation
© W. Carlo 2003

PEEP



Alveolar–capillary units in health and disease

a Normal alveolar–capill

PEEP

Capillary at pulmonary arterial side

Capillary at pulmonary venous side

Alveolus

Deoxygenated blood

Oxygenated blood

V/Q

PEEP

Deoxygenated blood

Oxygenated blood

V/Q

PEEP

c Reduced ventilation

eoxygenated blood

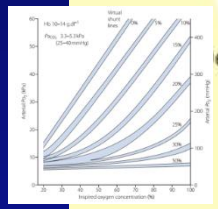
Oxygenated blood

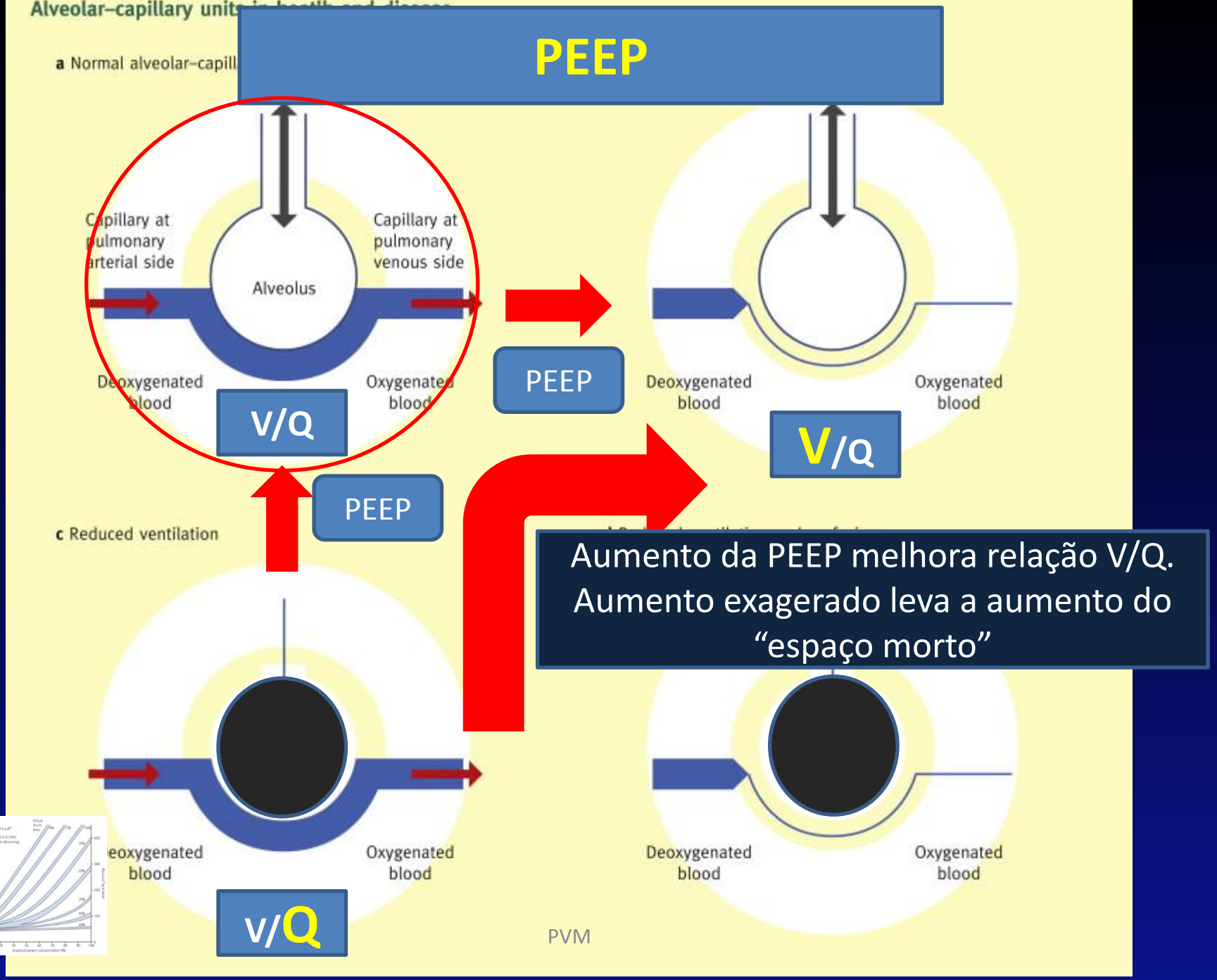
V/Q

d Reduced ventilation and perfusion

Deoxygenated blood

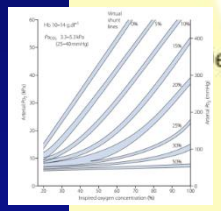
Oxygenated blood



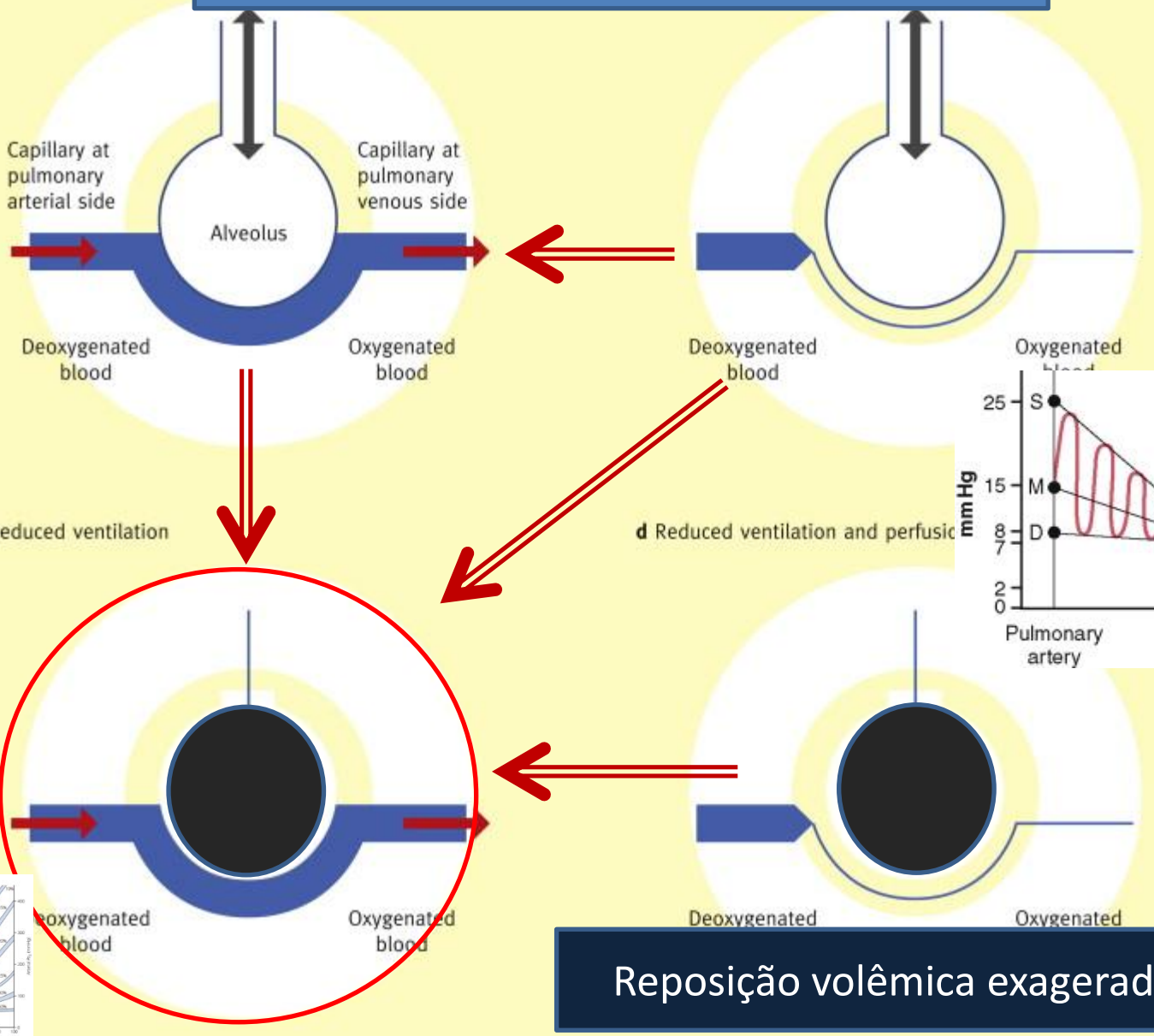

PEEP
a Normal alveolar–capill
Capillary at pulmonary arterial side
Alveolus
Capillary at pulmonary venous side
Deoxygenated blood
Oxygenated blood
V/Q
PEEP
Deoxygenated blood
Oxygenated blood
V/Q
PEEP
c Reduced ventilation
Aumento da PEEP melhora relação V/Q.
Aumento exagerado leva a aumento do "espaço morto"
eoxygenated blood
Oxygenated blood
V/Q
Deoxygenated blood
Oxygenated blood

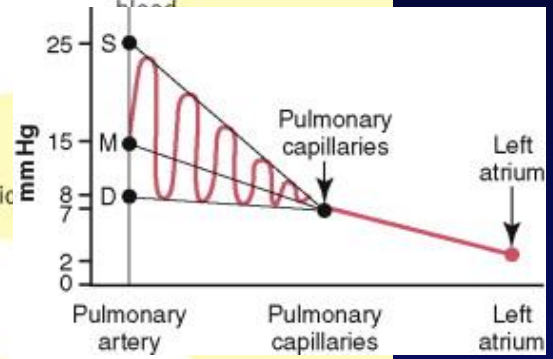
Inflamação

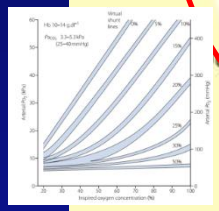
Biotrauma e inflamação: inundação do alvélolo e vasoconstrição pulmonar hipóxica



/\ Reposição Volêmica

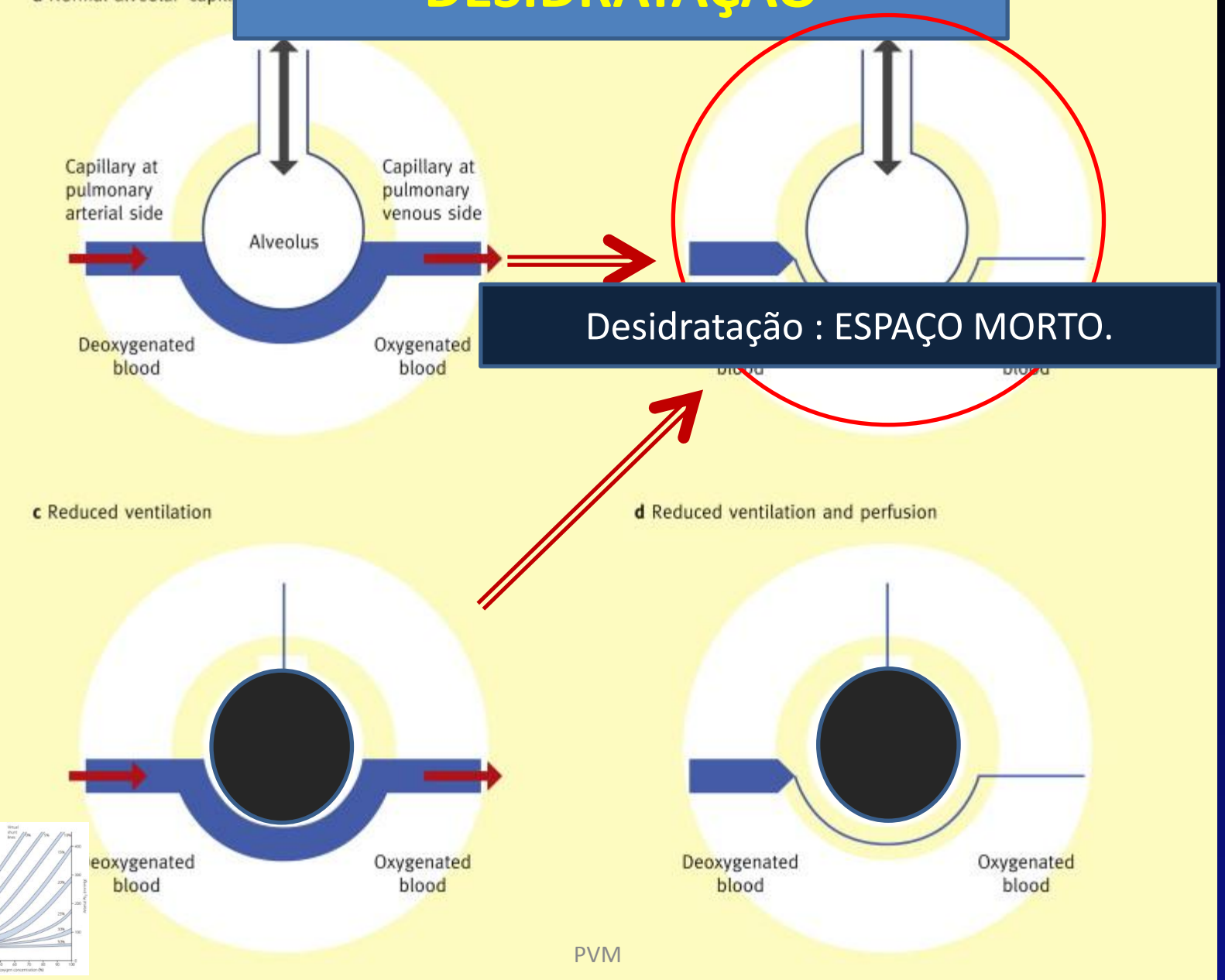






Reposição volêmica exagerada: shunt.

DESIDRATAÇÃO

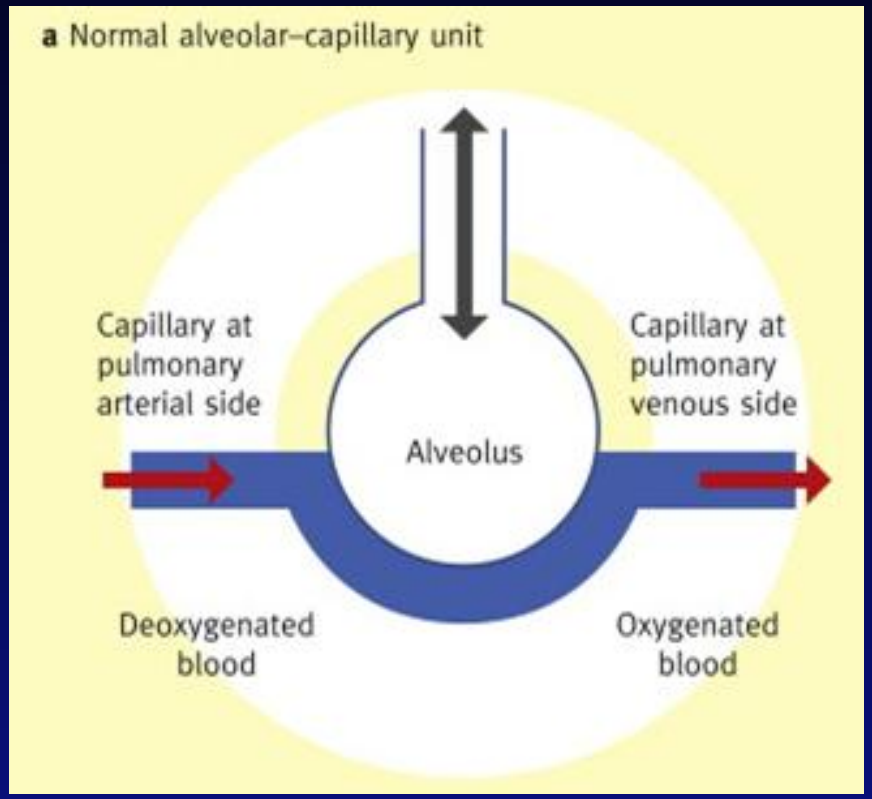


DOSIMETRIA

- Peep
- Reposição volêmica
- Vasopressores

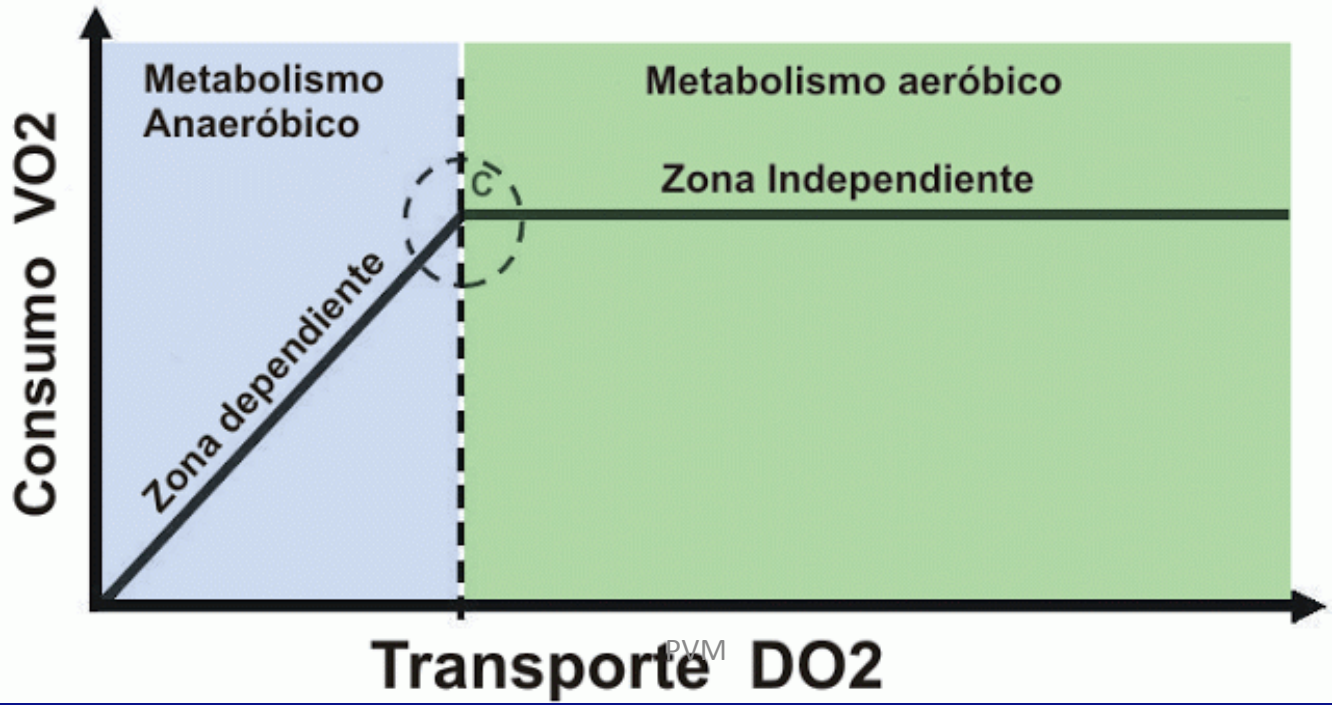
Monitorização adequada

- Hemodinâmica
- Respiratória
- Imagem



DOSIMETRIA

- DO2= DC x CaO2
  - Lactato
  - SvO2 e SvcO2



PVM

DOSIMETRIA

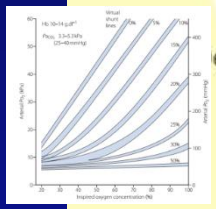
PaO2/FiO2

- Recrutamento
- PEEP
- Armadilhas:
  - PEEP muito alto: aumenta espaço morto fisiológico
  - Reposição volêmica excessiva: aumenta shunt

Capnografia

- Gradiente $PaCO_2$-$PETCO_2$
  - Correlação com Vd/Vt
  - PEEPideal: reduz o gradiente Pa-PET
  - PEEP excessiva: aumenta o gradiente Pa-PET
    - Diminuiu DC
    - Aumenta espaço morto

- Calculo do espaço morto
  - $VD/VT=(PaCO_2-PECO_2)/PaCO_2$



PEEP

a Normal alveolar–capill

Capillary at pulmonary arterial side

Alveolus

Capillary at pulmonary venous side

Deoxygenated blood

Oxygenated blood

V/Q

PEEP

Deoxygenated blood

Oxygenated blood

V/Q

PEEP

c Reduced ventilation

d Reduced ventilation and perfusion

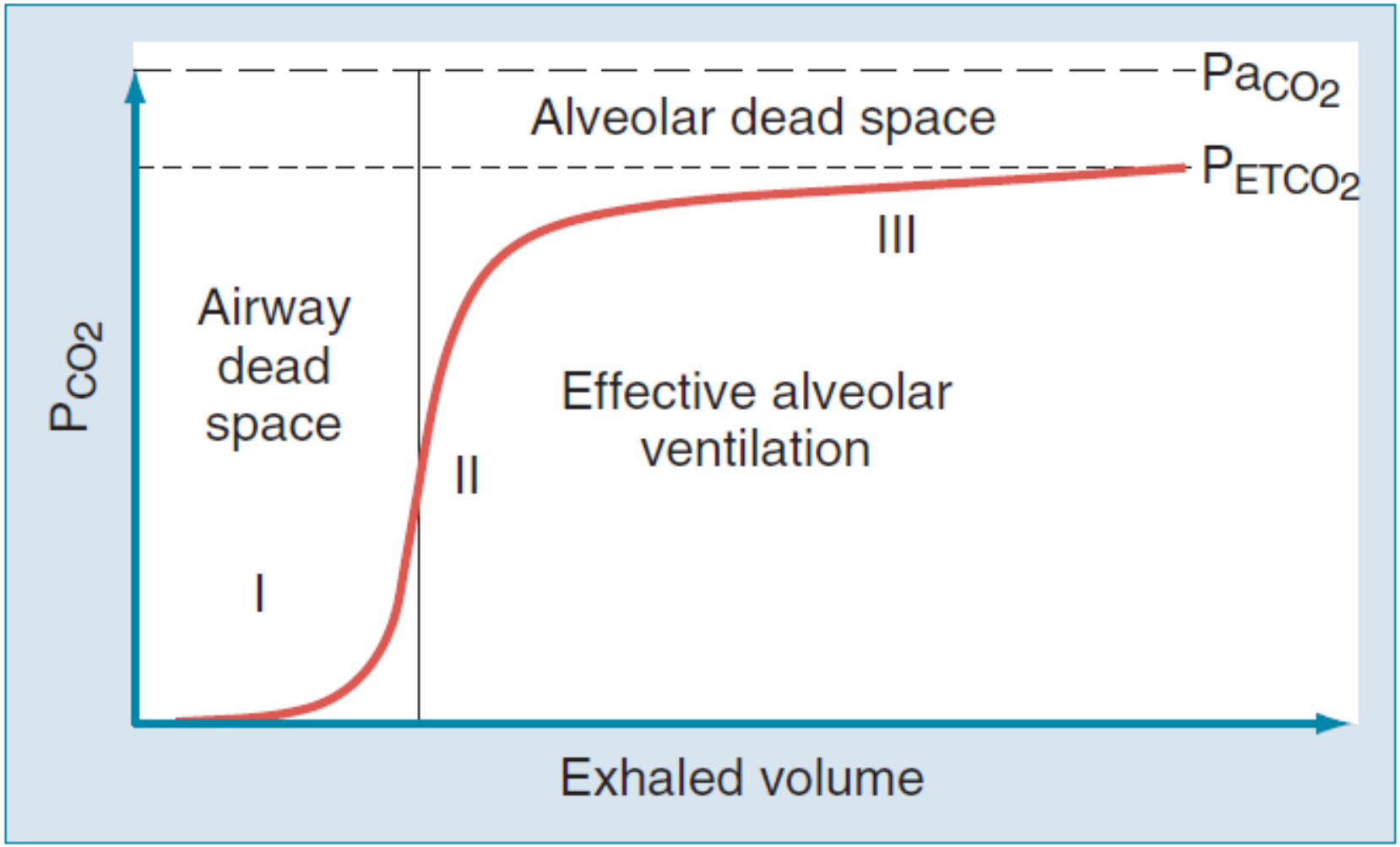
eoxygenated blood

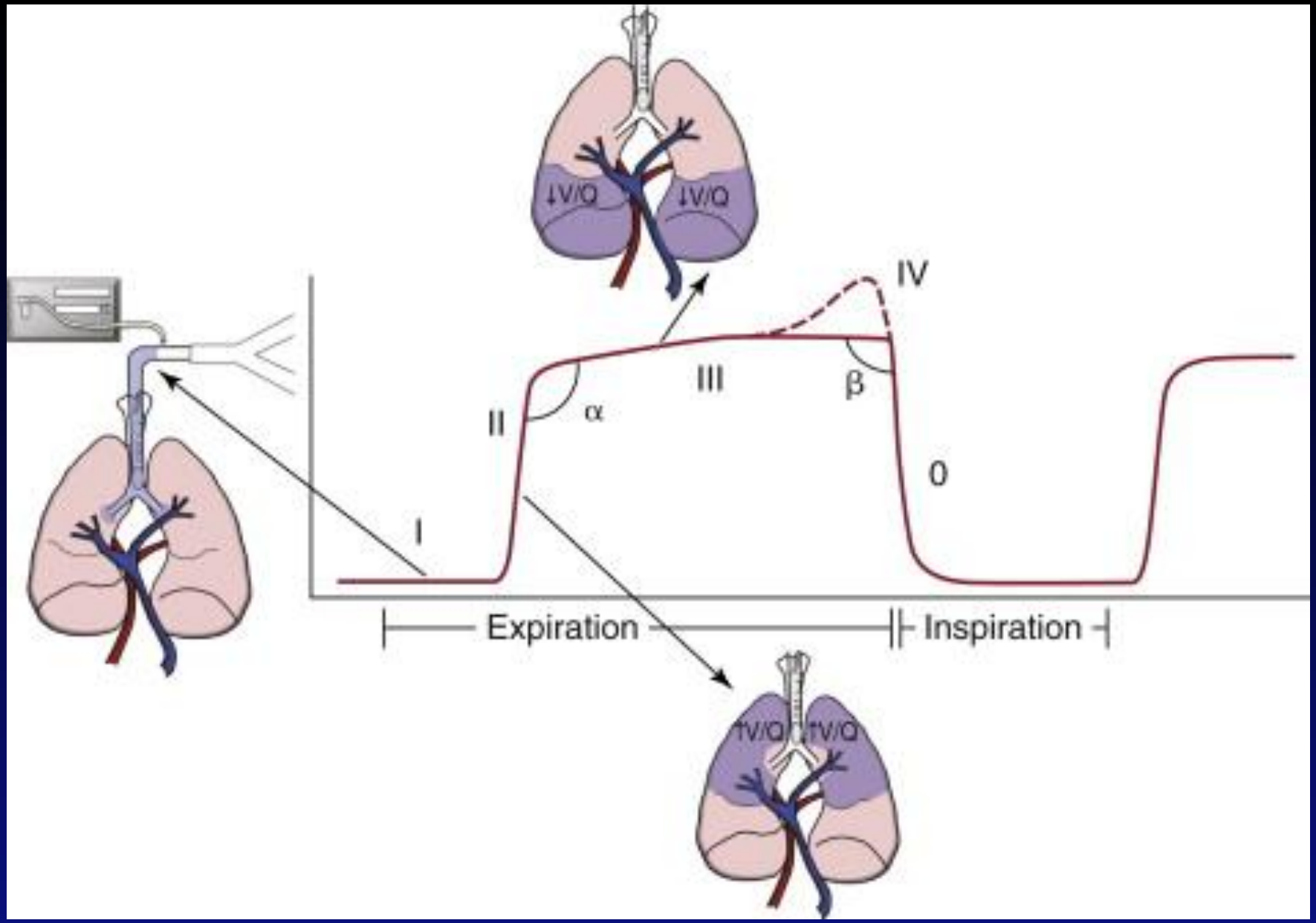
Oxygenated blood

V/Q

Deoxygenated blood

Oxygenated blood


Pa_{CO_2}
Alveolar dead space
P_{ETCO_2}
III
Airway dead space
P_{CO_2}
Effective alveolar ventilation
II
I
Exhaled volume



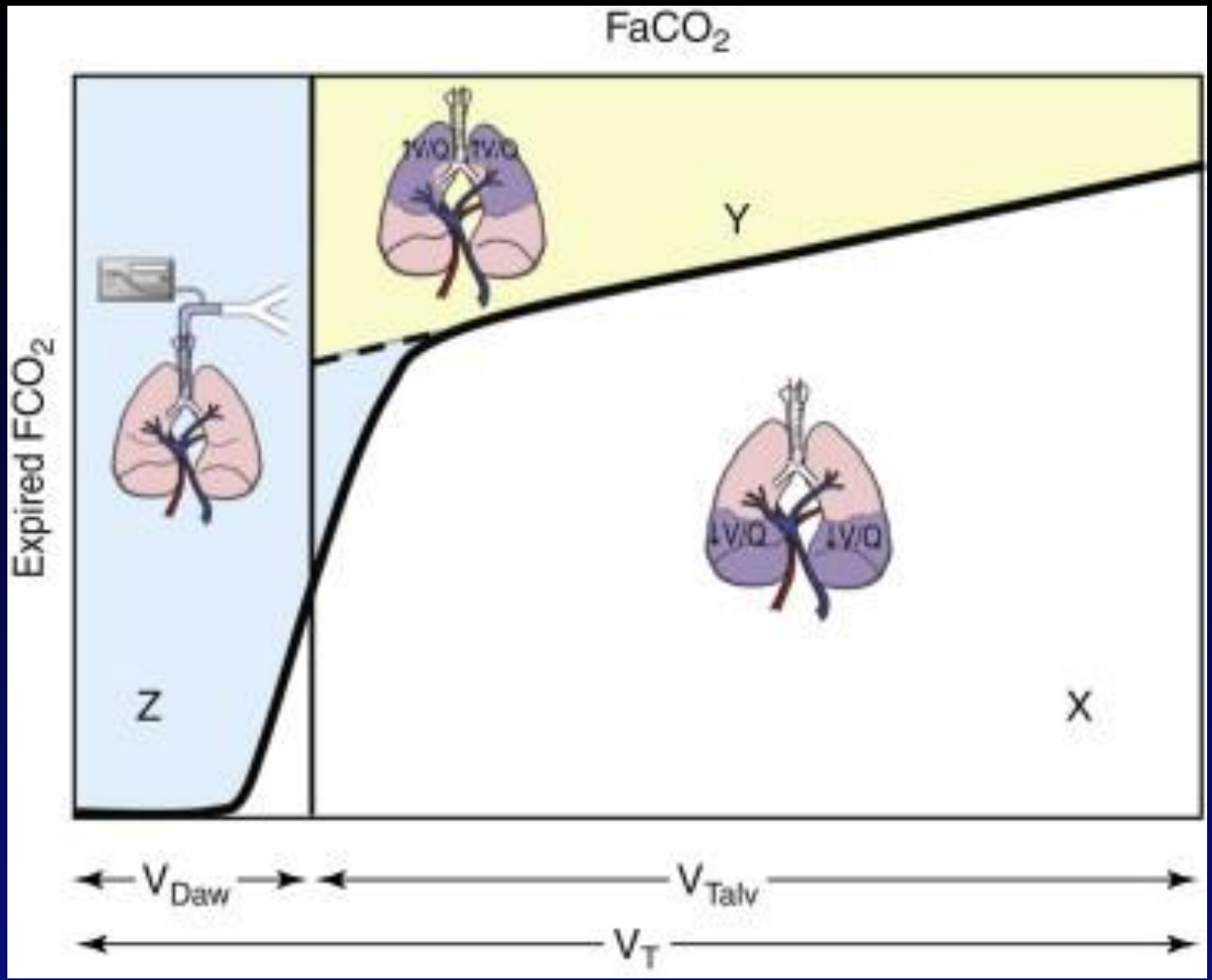
Anesthesia Equipment: Principles and Applications , Second Edition

Jan Ehrenwerth, James B. Eisenkraft, and James M. Berry

Chapter 10, 245-255

Copyright © 1993, 2013 by Saunders, an imprint of Elsevier Inc.

PVM



EM-alveolar: Y/(X + Y)

EM-fisiológico: (Y + Z)/(X + Y + Z)

Anesthesia Equipment: Principles and Applications , Second Edition

Jan Ehrenwerth, James B. Eisenkraft, and James M. Berry

Chapter 10, 245-255

Copyright © 1993, 2013 by Saunders, an imprint of Elsevier Inc.

PVM

A correction for this article has been published in *Critical Care* 2011, 15:410

Research

Highly accessed

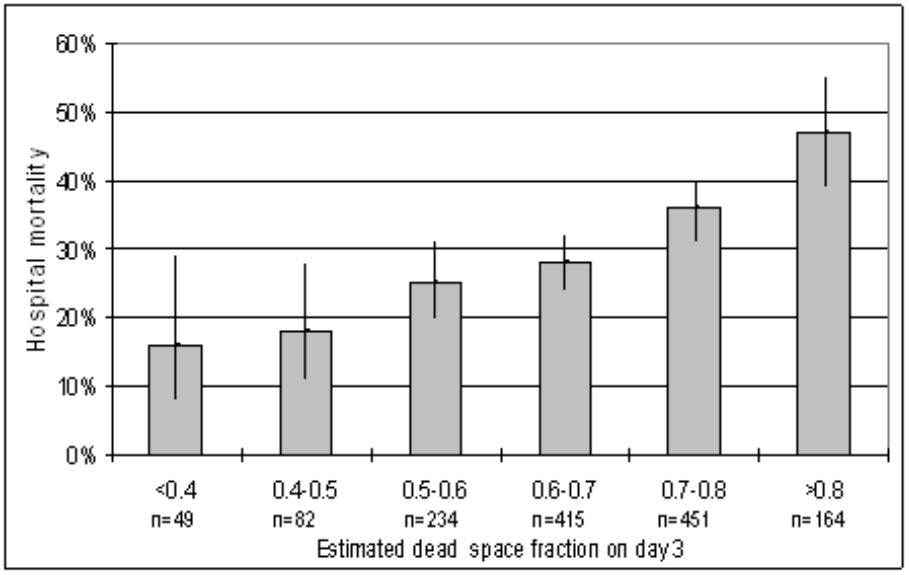
Open Access

Bedside quantification of dead-space fraction using routine clinical data in patients with acute lung injury: secondary analysis of two prospective trials

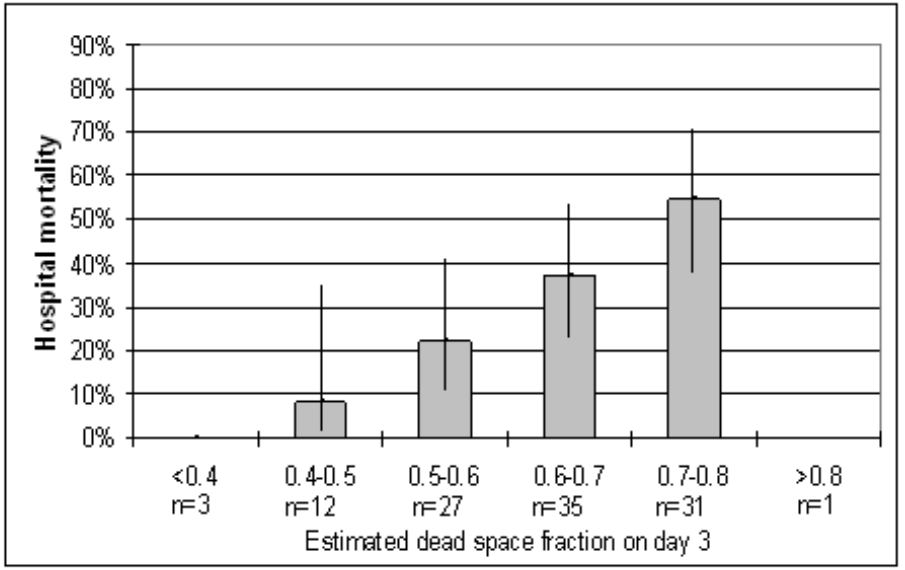
Hassan Siddiki[1], **Marija Kojicic**[2], **Guangxi Li**[2], **Murat Yilmaz**[3], **Taylor B Thompson**[4], **Rolf D Hubmayr**[2] and **Ognjen Gajic**[2]*

Key messages

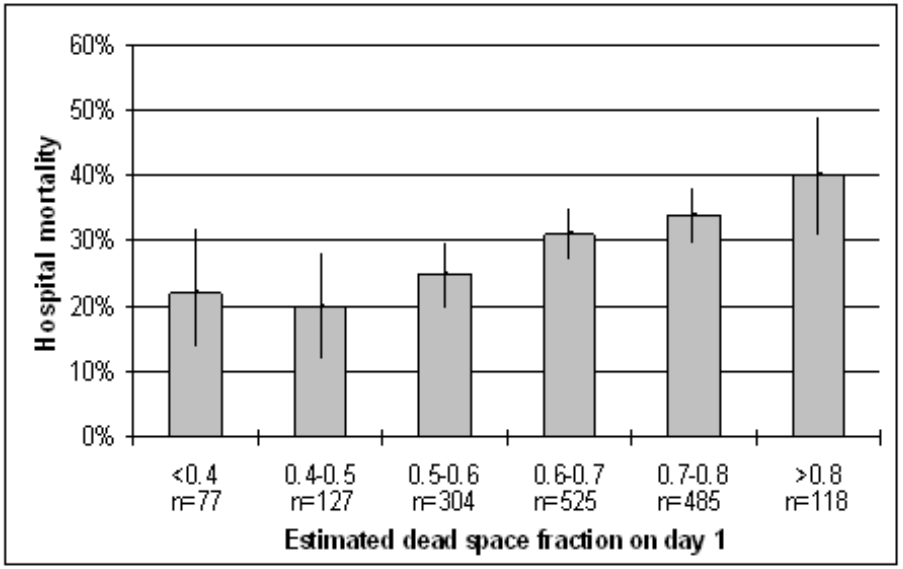
- Vd/Vt has important prognostic significance in patients with ALI and ARDS, but is not routinely measured in clinical practice.
- In mechanically ventilated patients with ALI and ARDS, Vd/Vt can be estimated from routinely available clinical data (arterial blood gas analysis and minute ventilation).
- Elevated estimated Vd/Vt portends a poor prognosis in patients with ALI and ARDS.


Hospital mortality
60%
50%
40%
30%
20%
10%
0%
<0.4 n=49
0.4-0.5 n=82
0.5-0.6 n=234
0.6-0.7 n=415
0.7-0.8 n=451
>0.8 n=164
Estimated dead space fraction on day 3

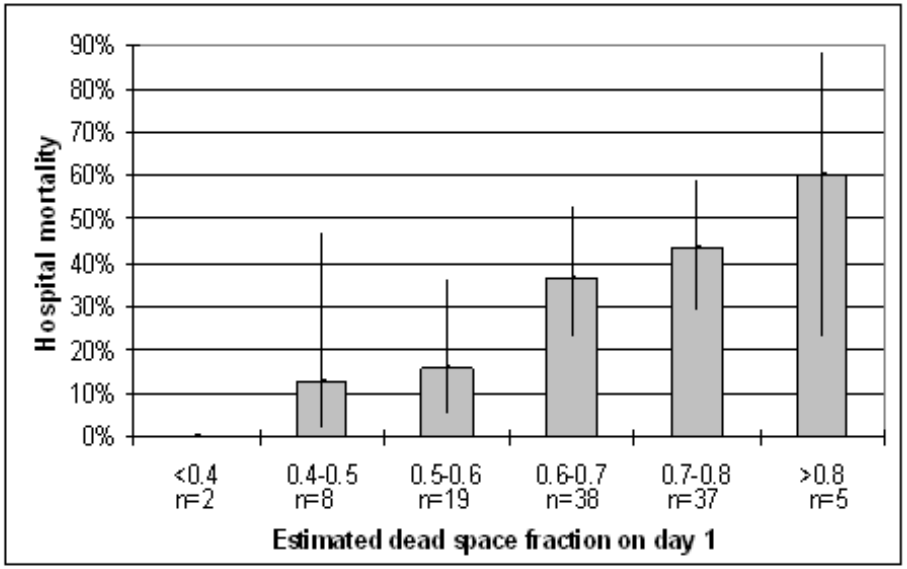
(a)


Hospital mortality
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
<0.4 n=3
0.4-0.5 n=12
0.5-0.6 n=27
0.6-0.7 n=35
0.7-0.8 n=31
>0.8 n=1
Estimated dead space fraction on day 3

(b)


Hospital mortality
60%
50%
40%
30%
20%
10%
0%
<0.4 n=77
0.4-0.5 n=127
0.5-0.6 n=304
0.6-0.7 n=525
0.7-0.8 n=485
>0.8 n=118
Estimated dead space fraction on day 1

(c)


Hospital mortality
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
<0.4 n=2
0.4-0.5 n=8
0.5-0.6 n=19
0.6-0.7 n=38
0.7-0.8 n=37
>0.8 n=5
Estimated dead space fraction on day 1

(d)

Original Research

Prognostic Value of the Pulmonary Dead-Space Fraction During the Early and Intermediate Phases of Acute Respiratory Distress Syndrome

Joan M Raurich MD PhD, Margalida Vilar MD, Asunción Colomar MD, Jordi Ibáñez MD PhD, Ignacio Ayestarán MD, Jon Pérez-Bárcena MD, and Juan A Llompart-Pou MD

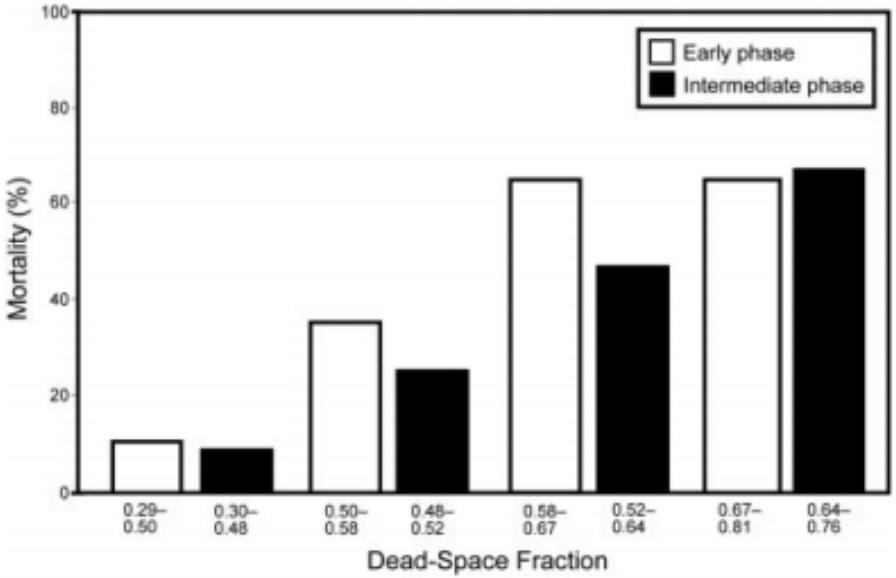


Fig. 1. Mortality according to the quartiles of dead-space fraction in 80 patients with early-phase acute respiratory distress syndrome and 49 patients with intermediate-phase acute respiratory distress syndrome.

Conclusions

Our findings are consistent with results from previous studies and confirm that a higher alveolar dead-space fraction in early and intermediate phases of ARDS is associated with a greater risk of death.

PVM

Table 2. Variables Associated With a Greater Risk of Death in the Early Phase of Acute Respiratory Distress Syndrome

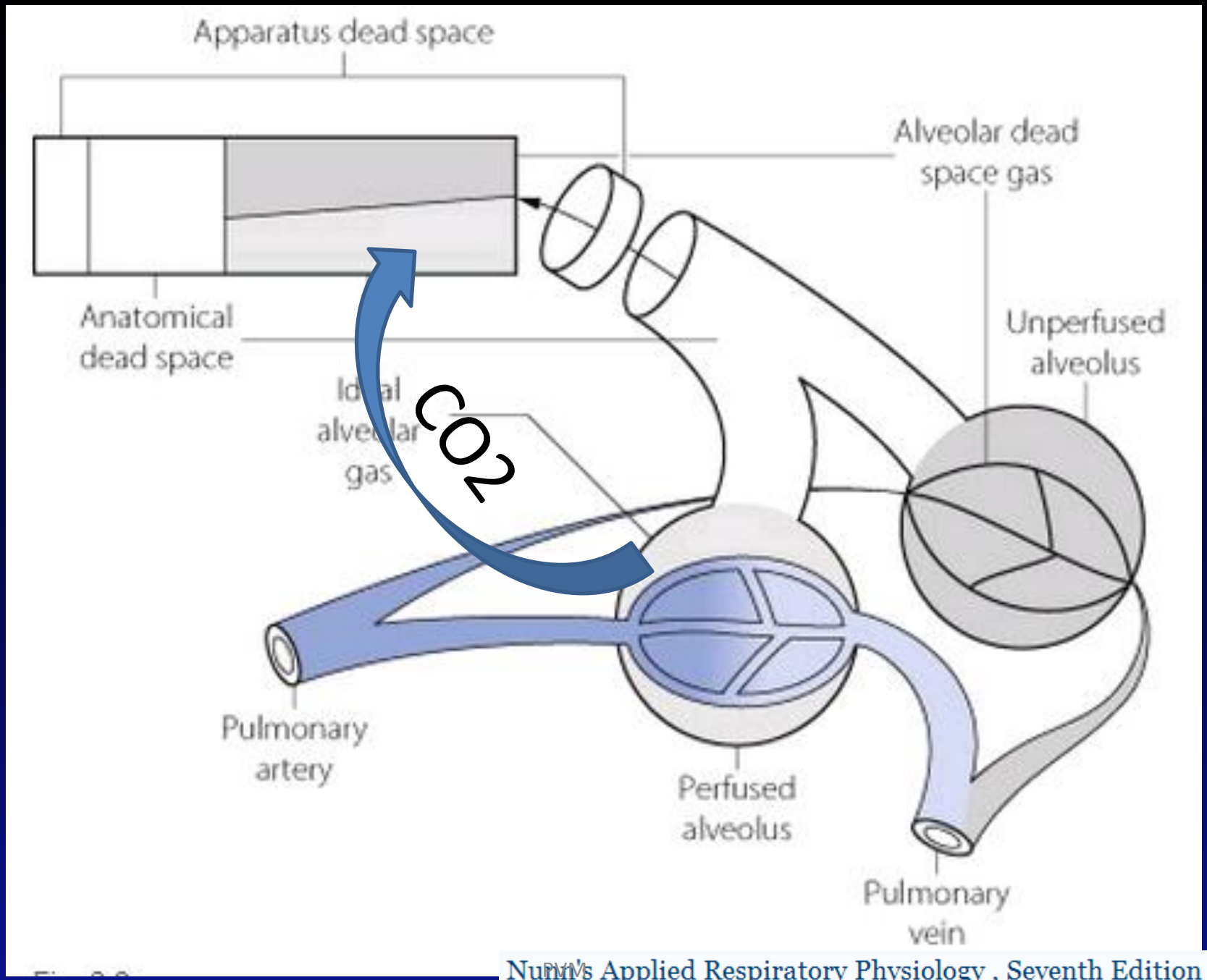
	Survivors (n = 45)	Non-survivors (n = 35)	P
Age (mean ± SD y)	44 ± 16	59 ± 17	< .001
SAPS II (mean ± SD)	39 ± 15	52 ± 16	< .001
SOFA score (mean ± SD)	8.4 ± 3.1	11.3 ± 3.2	< .001
Use of vasopressors (n, %)	30 (67)	29 (83)	.10
Use of activated protein C (n, %)	8 (18)	2 (6)	.17
Lung injury score (mean ± SD)	2.7 ± 0.5	2.9 ± 0.5	.22
PEEP (mean ± SD cm H_2O)	9.4 ± 3.7	10.0 ± 3.6	.50
Tidal volume (mean ± SD mL/kg IBW)	7.9 ± 2.6	7.7 ± 1.7	.76
Minute volume (mean ± SD L/min)	10.8 ± 2.8	11.5 ± 3.2	.28
Plateau pressure (mean ± SD cm H_2O)	26.3 ± 4.5	28.2 ± 6.4	.15
Quasistatic respiratory compliance (mean ± SD mL/cm H_2O)	30.5 ± 10.2	29.8 ± 12.1	.79
pH (mean ± SD)	7.39 ± 0.09	7.34 ± 0.10	.03
P_{aCO_2} (mean ± SD mm Hg)	42 ± 15	45 ± 8	.20
P_{aO_2}/F_{IO_2} (mean ± SD mm Hg)	162 ± 61	141 ± 44	.09
Dead-space fraction (mean ± SD)	0.53 ± 0.11	0.64 ± 0.09	< .001
CO_2 production (mean ± SD mL/min/kg of body weight)	3.4 ± 0.9	3.0 ± 0.8	.08

PVM

Table 4. Variables Associated With a Greater Risk of Death in the Intermediate Phase of Acute Respiratory Distress Syndrome

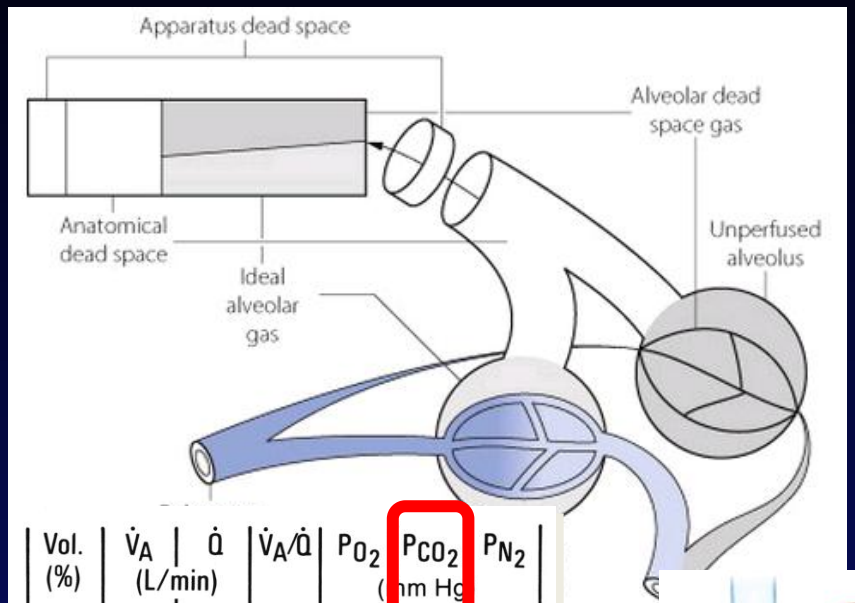
	Survivors (n = 31)	Non-survivors (n = 18)	P
Age (mean ± SD y)	46 ± 17	59 ± 19	.02
SAPS II (mean ± SD)	39 ± 15	50 ± 12	.02
SOFA score (mean ± SD)	6.7 ± 3.2	10.5 ± 2.6	< .001
Use of vasopressors (n, %)	11 (36)	12 (67)	.04
Use of activated protein C (n, %)	4 (13)	0 (0)	.28
Lung injury score (mean ± SD)	2.5 ± 0.6	2.8 ± 0.7	.14
PEEP (mean ± SD cm H_2O)	8.5 ± 3.8	9.7 ± 4.0	.33
Tidal volume (mean ± SD mL/kg IBW)	7.6 ± 1.5	7.3 ± 1.5	.32
Minute volume (mean ± SD L/min)	11.7 ± 2.8	11.4 ± 3.1	.69
Plateau pressure (mean ± SD cm H_2O)	25.4 ± 4.4	27.7 ± 6.2	.24
Quasistatic respiratory compliance (mean ± SD mL/cm H_2O)	31.8 ± 9.7	27.6 ± 14.2	.24
pH (mean ± SD)	7.45 ± 0.06	7.38 ± 0.09	.003
P_{aCO_2} (mean ± SD mm Hg)	39 ± 10	47 ± 10	.008
P_{aO_2}/F_{IO_2} (mean ± SD mm Hg)	205 ± 76	169 ± 77	.13
Dead-space fraction (mean ± SD)	0.50 ± 0.10	0.62 ± 0.09	< .001
CO_2 production (mean ± SD mL/min/kg of body weight)	3.6 ± 0.8	3.2 ± 1.0	.14

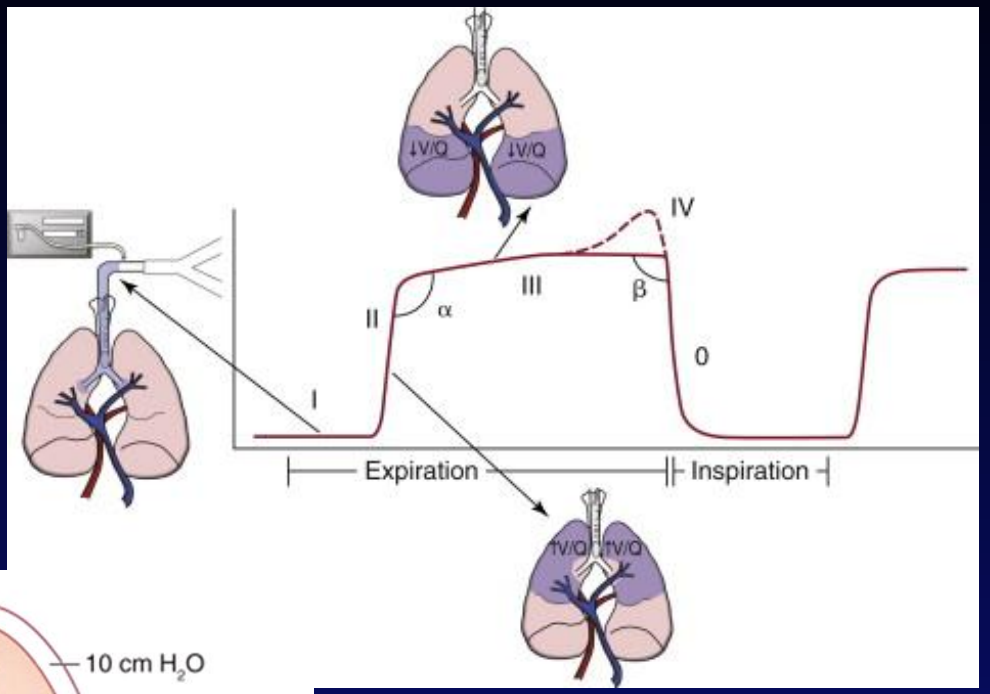
PVM



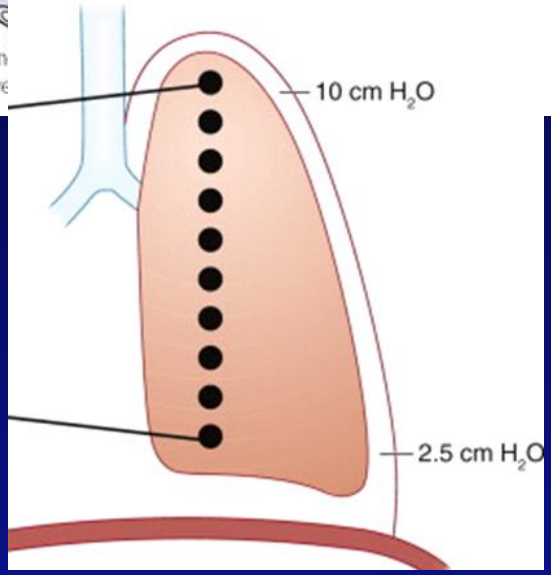
Nunn's Applied Respiratory Physiology , Seventh Edition

Vt pequeno: Aumento do Pa-Pet CO2





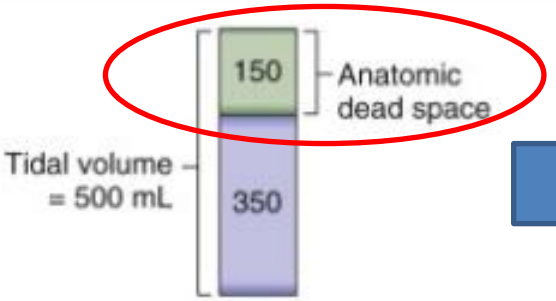
Vol. (%)	$\dot{V}_A$ (L/min)	$\dot{Q}$	$\dot{V}_A/\dot{Q}$	P_{O_2}	P_{CO_2} (mm Hg)	P_{N_2}
7	.24	.07	3.3	132	28	553
11	.52	.50	1.0	108	39	566
13	.82	1.29	0.63	89	42	582



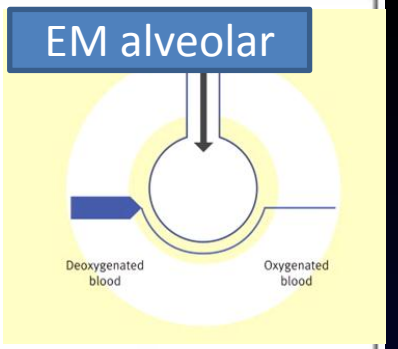
Lei de Poiseuille.

$$\Phi = \frac{\Delta P \,.\pi\,.r^4}{\eta\,.L\,.8}$$

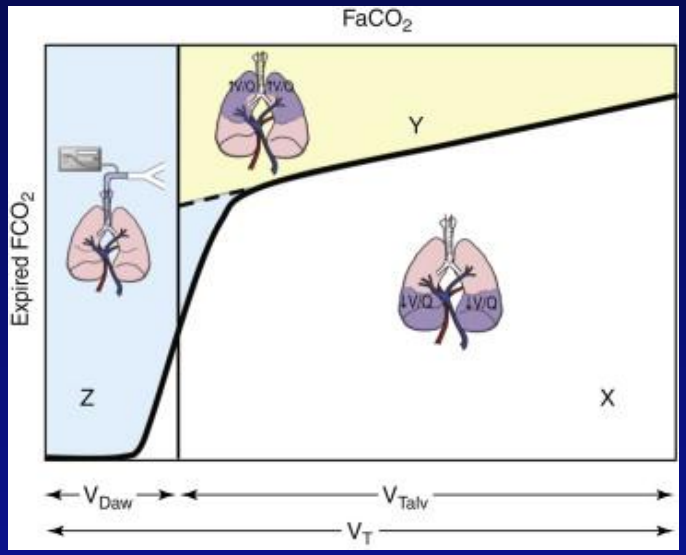
EM fisiológico=



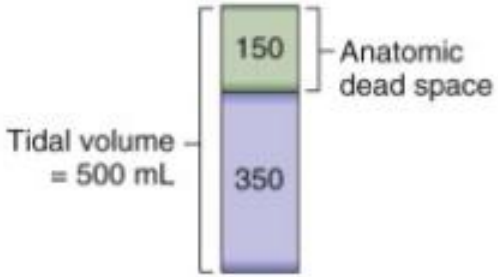
+



Vd/Vt= (PaCO2-PeCO2)/PaCO2
Vd/vT=0,6> Vd=0,6xVt> Vd=360ml*0,6= 216
Vt alveolar= 360-216= 144ml.

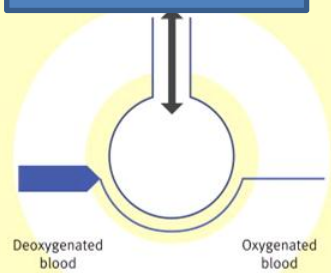


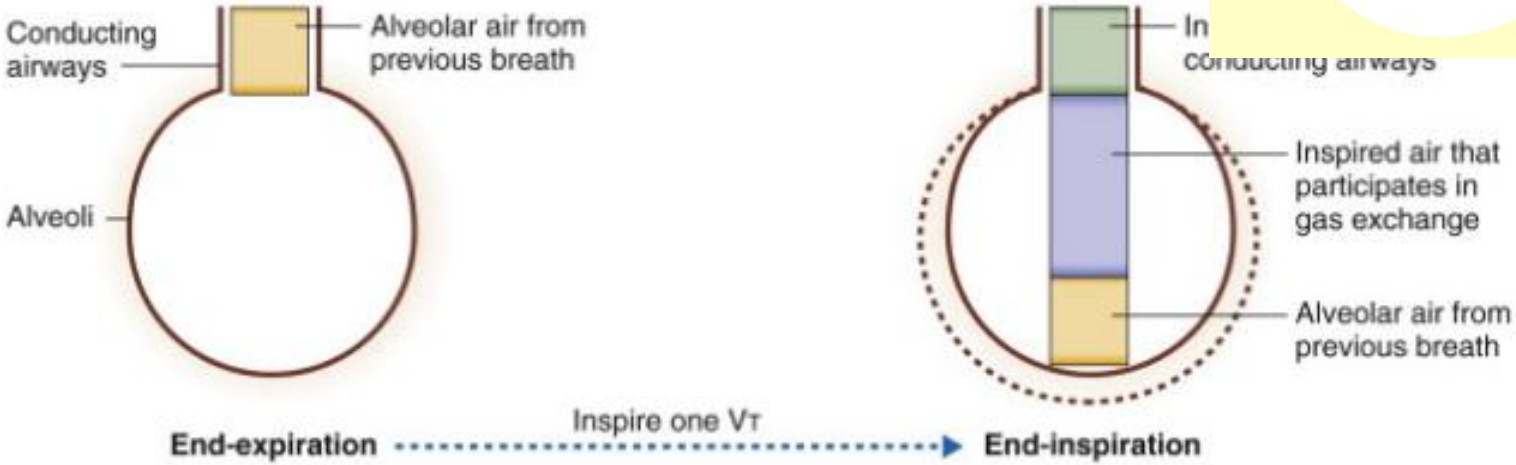
EM fisiológico=



+

EM alveolar

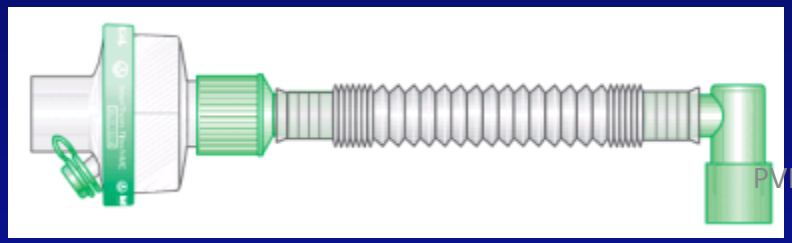




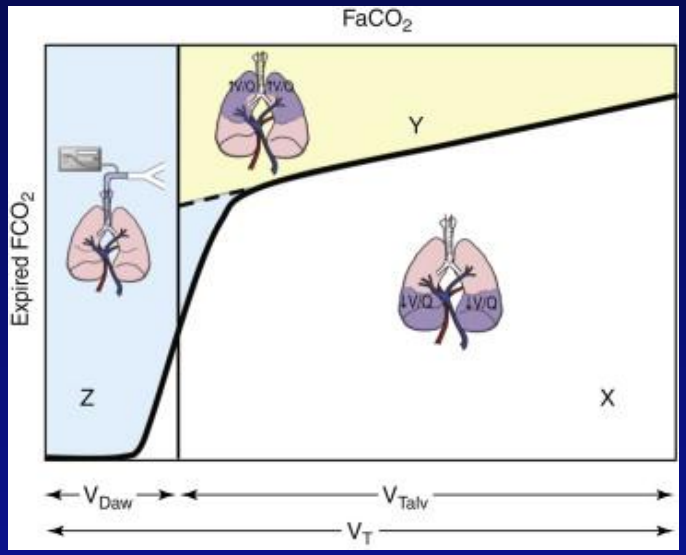
Vd/Vt= (PaCO2-PeCO2)/PaCO2

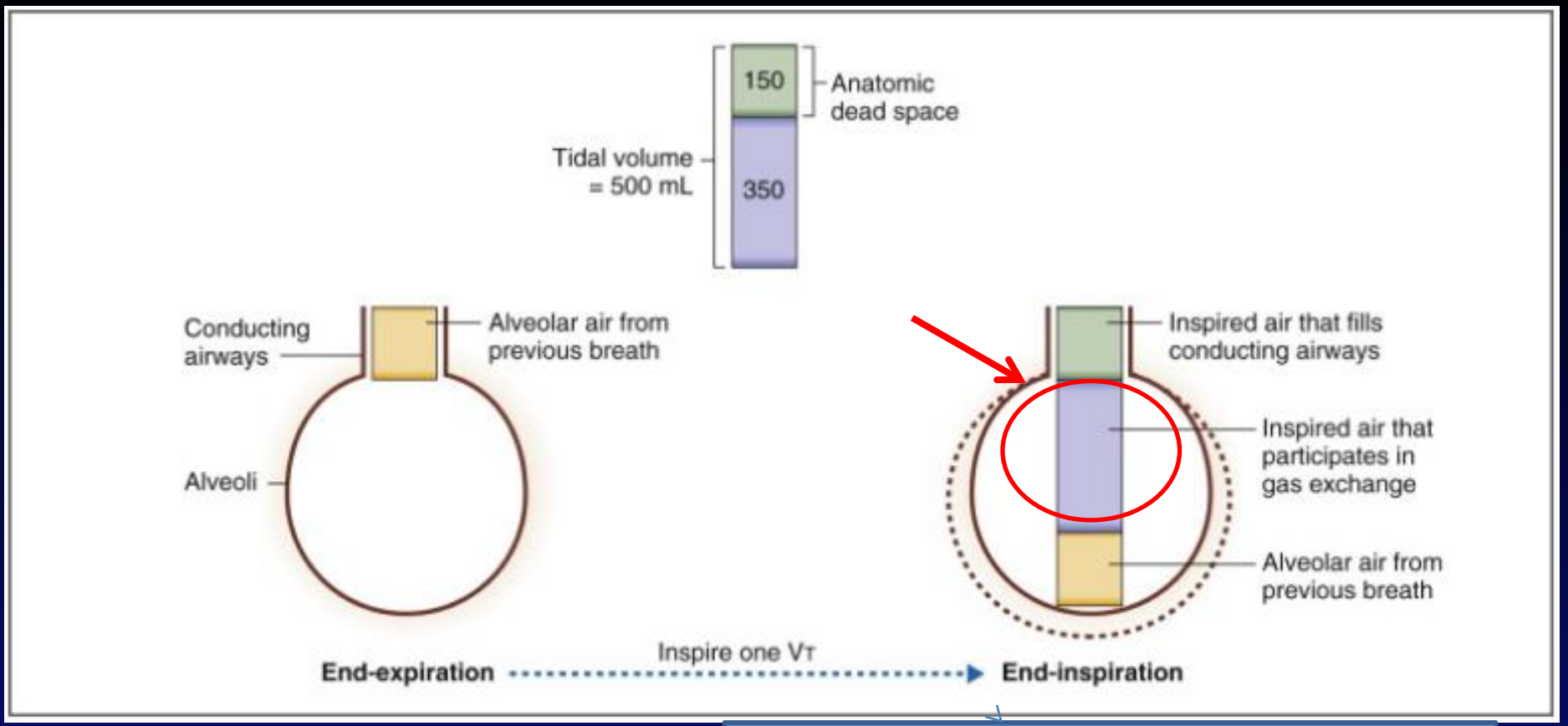
Vd/vT=0,6> Vd=0,6xVt> Vd=360ml*0,6= 216

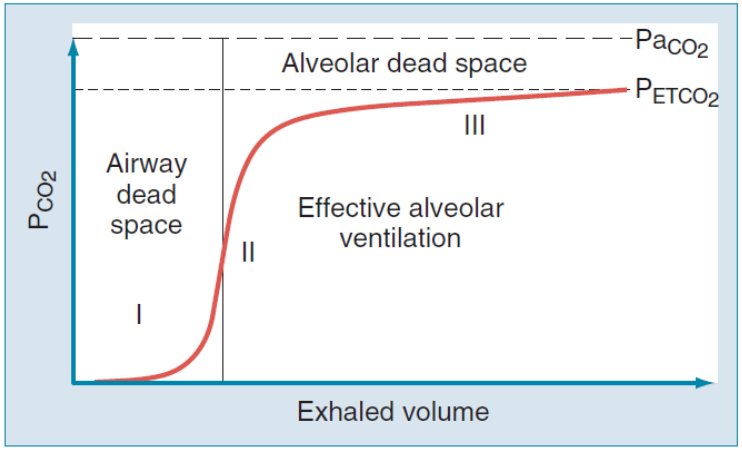
-26ml (traqueia extensora) = 190/360= **0,52**



PVM







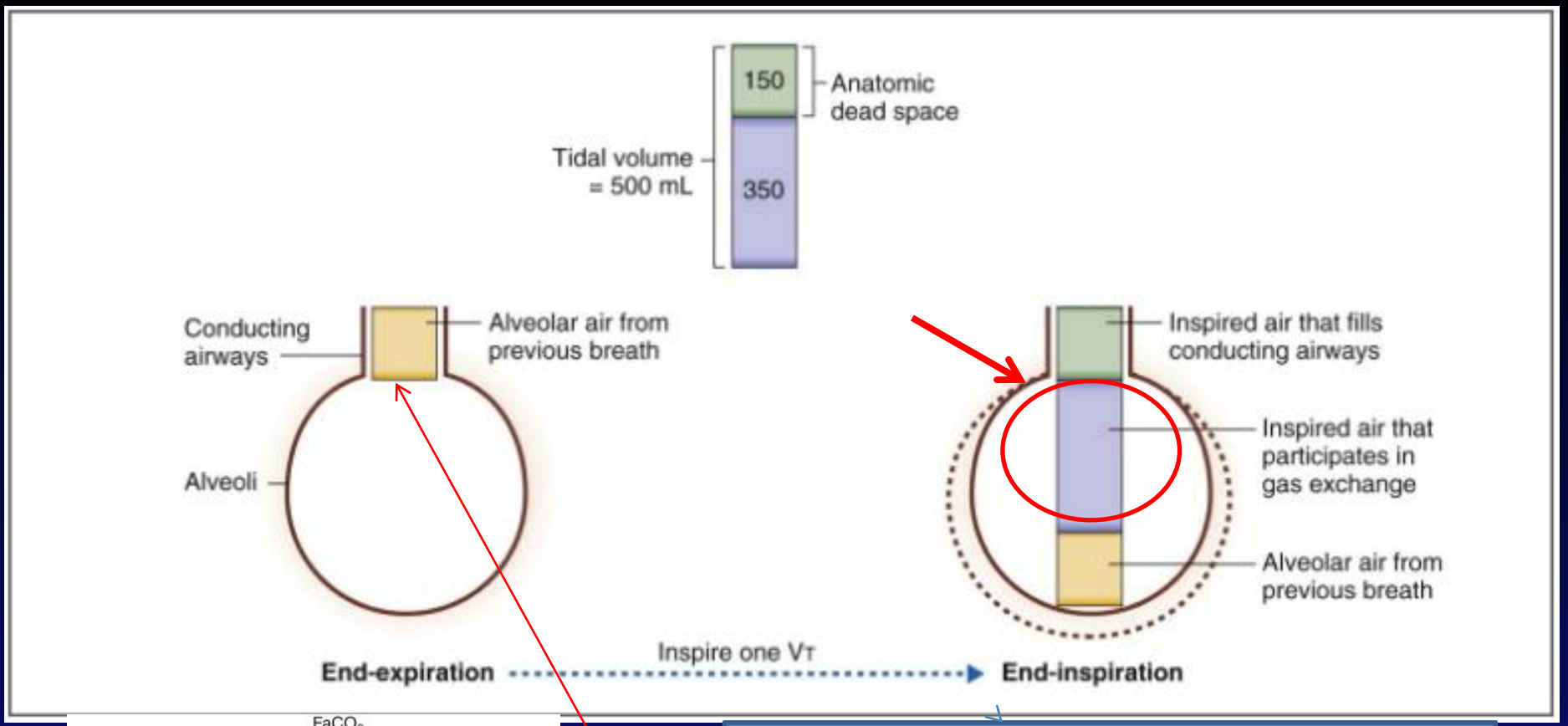
DIMINUEM "volume de troca"

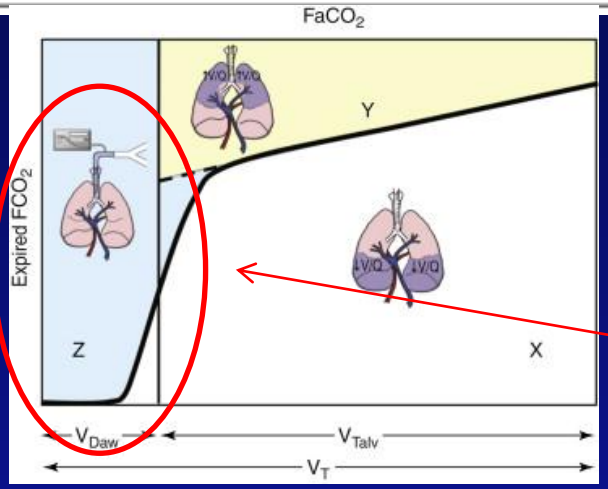
- Peep acima da ideal.
- Ti curto.
- Te curto.
- FR alta.
- EM anatômico.
- Aumento de resistência

Lei de Poiseuille.

$$\Phi = \frac{\Delta P \,.\pi\,.r^4}{\eta\,.L\,.8}$$

PVM

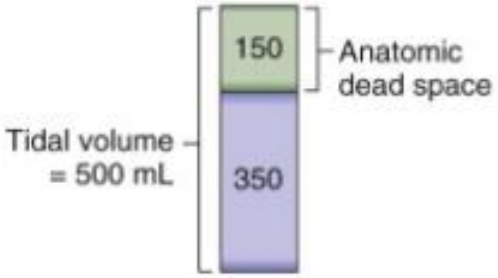


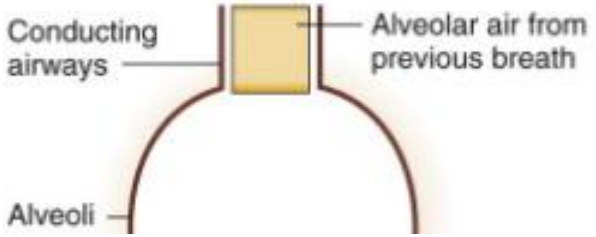


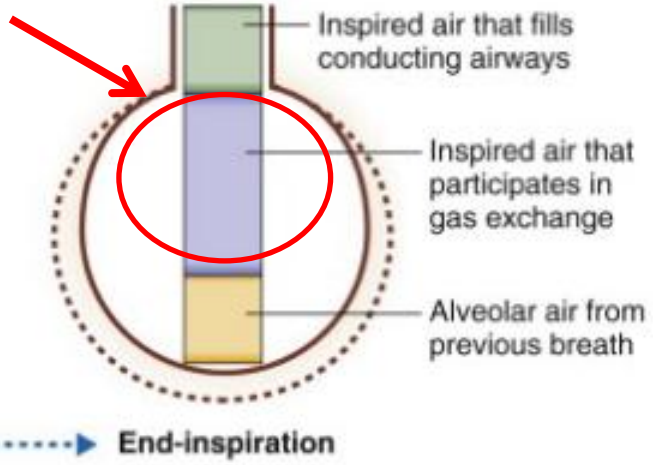
DIMINUEM "volume de troca"

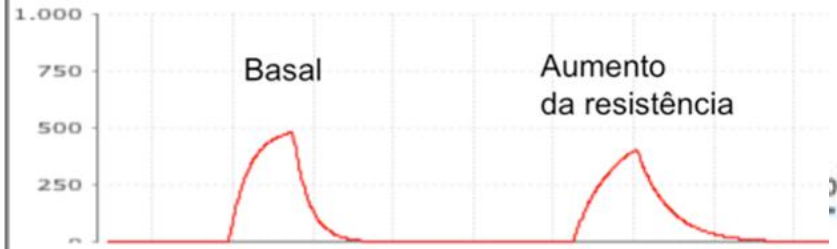
- Peep acima da ideal.
- Ti curto.
- Te curto.
- FR alta.
- EM anatômico.
- Aumento de resistência

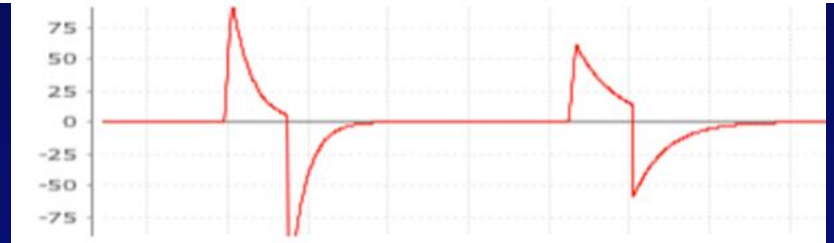
PVM

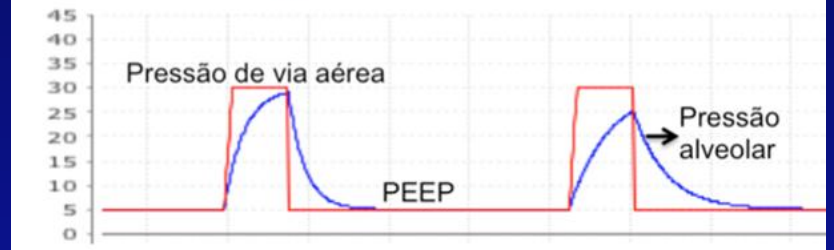












DIMINUEM “volume de troca”

- Peep acima da ideal.
- Ti curto.
- Te curto.
- FR alta.
- EM anatômico.
- Aumento de resistência

PVM

Manter Vt Efetivo

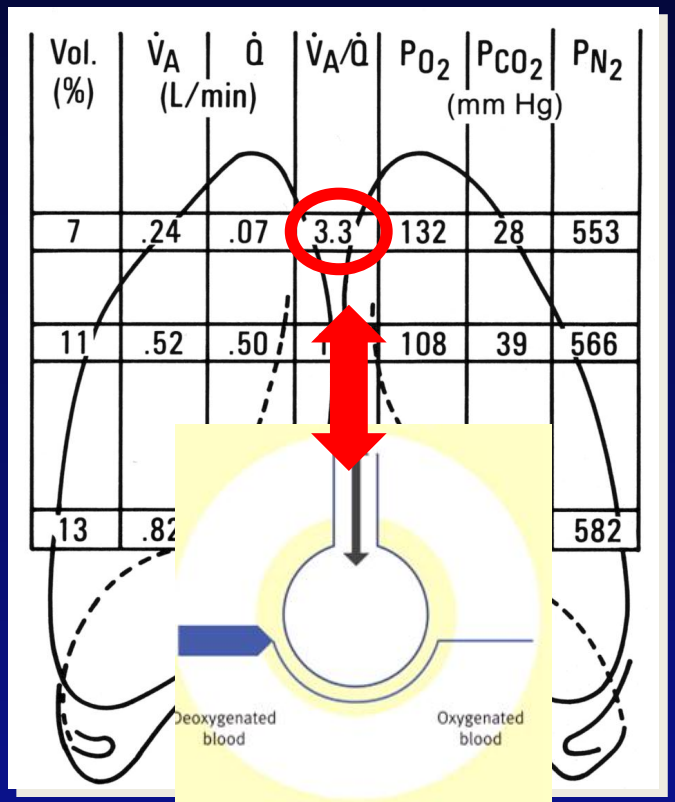
- Peep ideal.
- Ti adequado
- Te adequado
- Relação I/E adequada
- FR adequada
- Reduzir EM anatômico.
- Evitar aumento de resistência

Espaço Morto

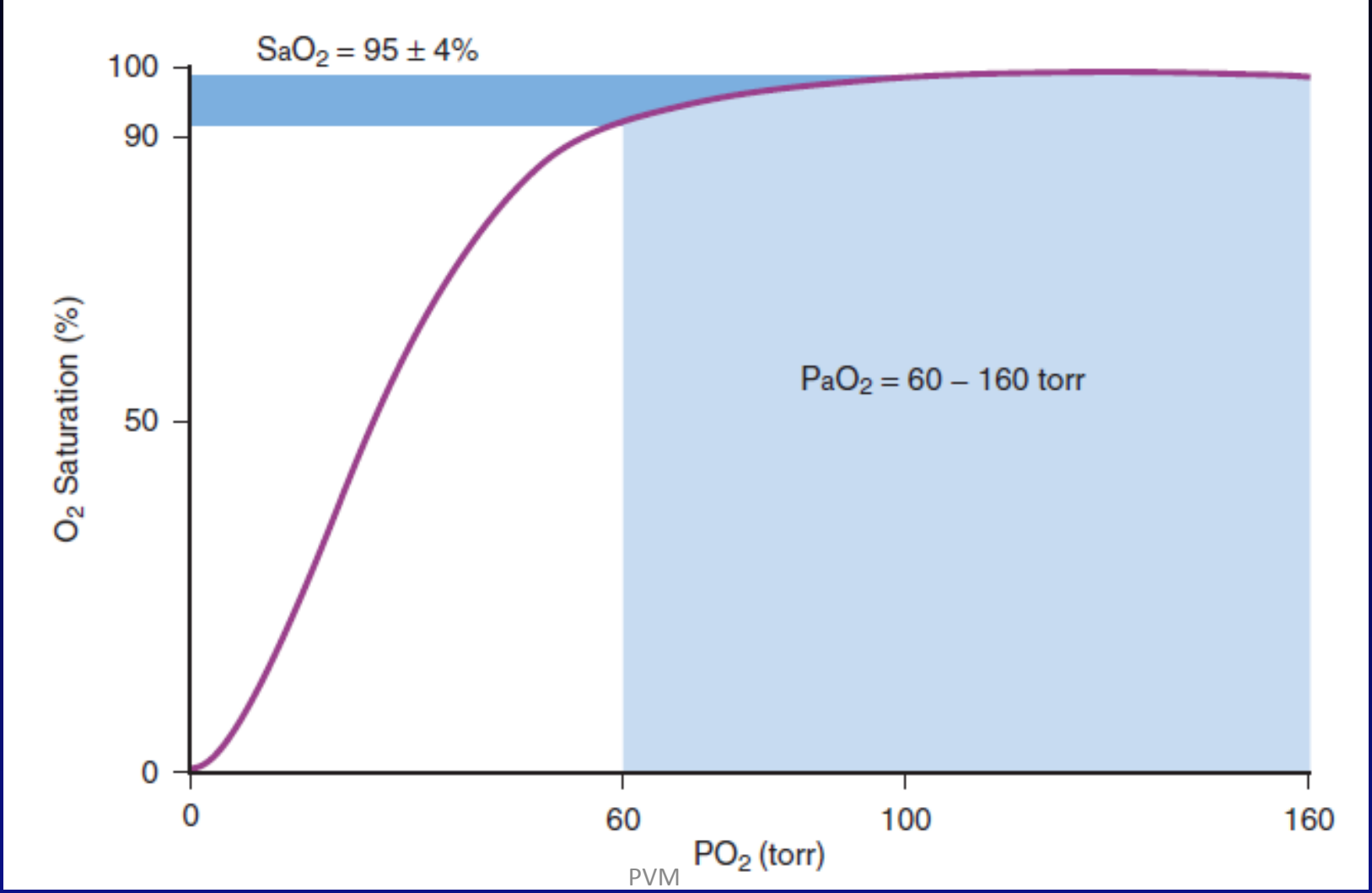
- Espaço morto anatômico
- Espaço morto alveolar

} Espaço morto fisiológico

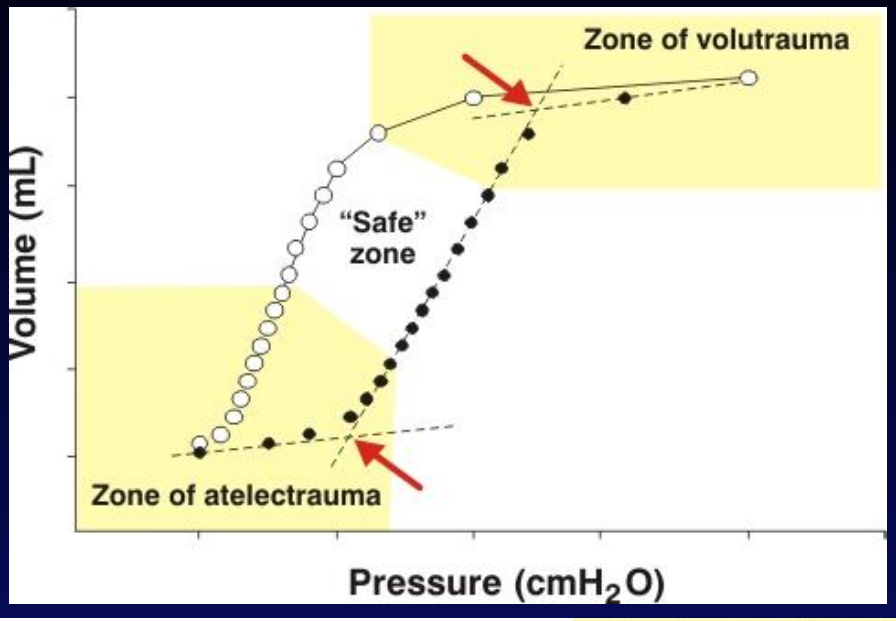
- Peep adequado
- Zona 1 de West
- Gradiente PaCO2-PETCO2
- VD/VT=(PaCO2−PECO2)/PaCO2

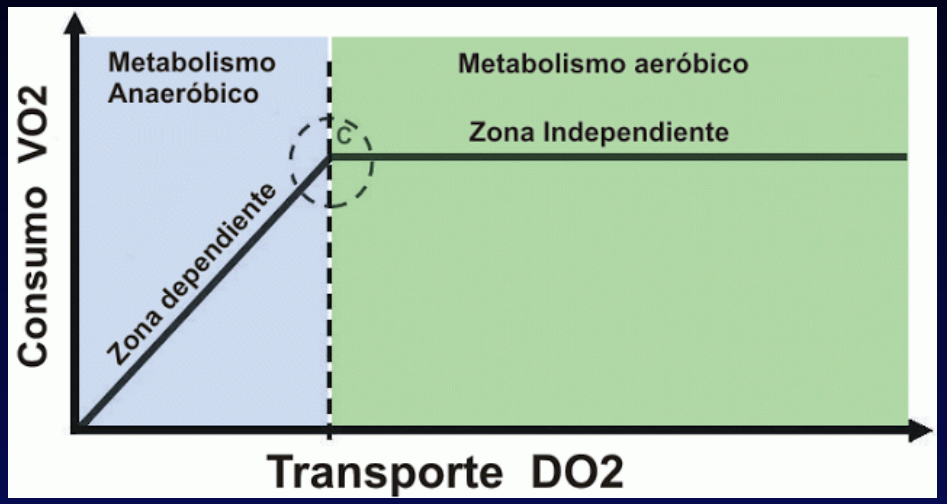


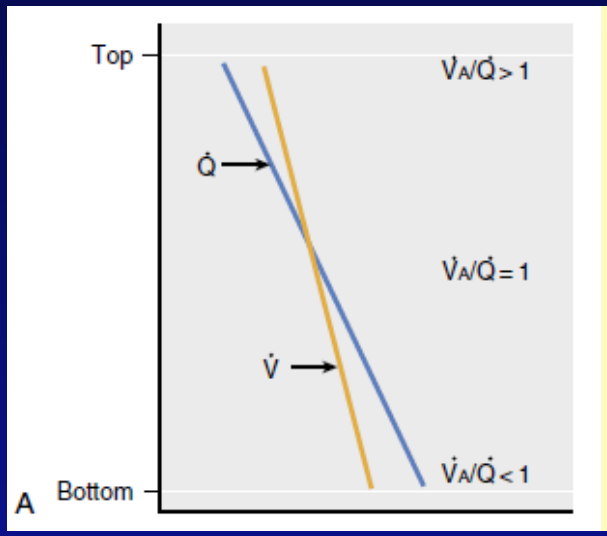
Oximetria

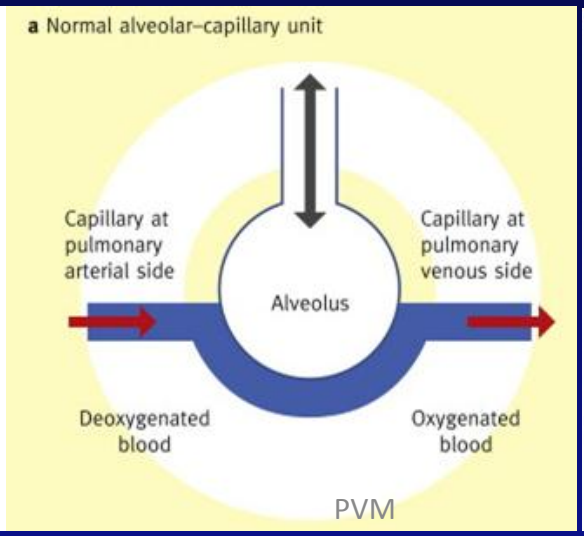

$SaO_2 = 95 \pm 4\%$
100
90
50
0
O_2 Saturation (%)
$PaO_2 = 60 – 160$ torr
0
60
100
160
PO_2 (torr)

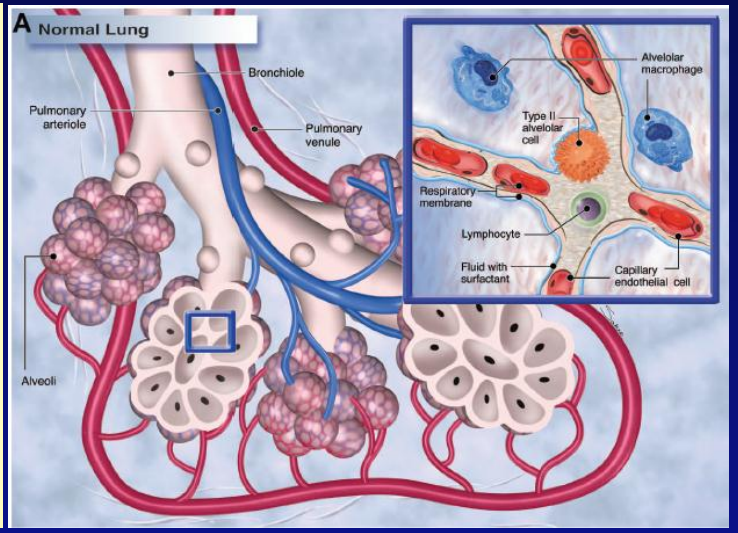
DOSIMETRIA



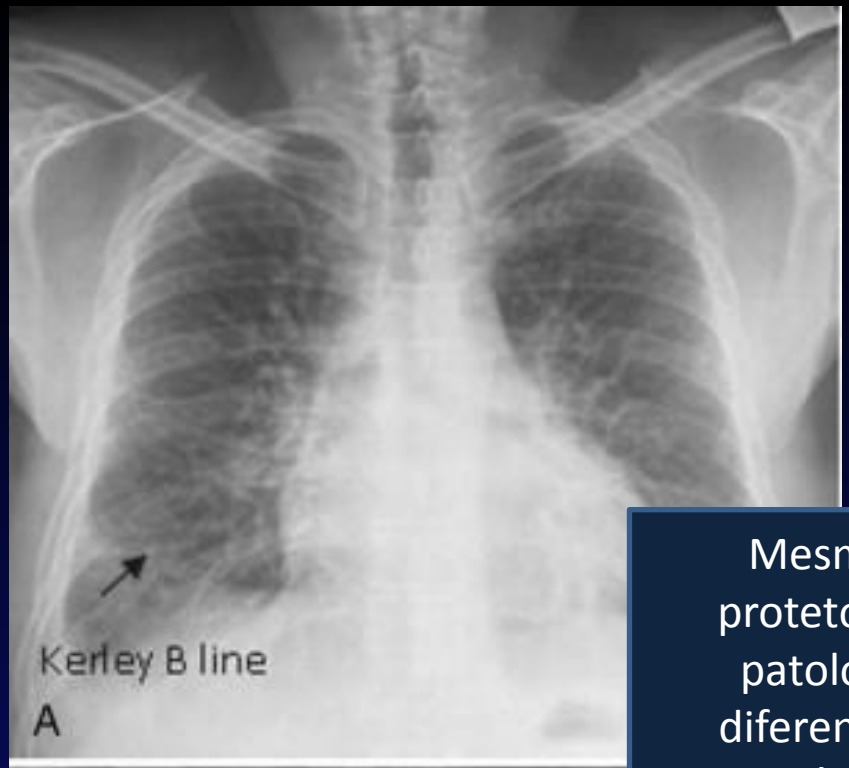


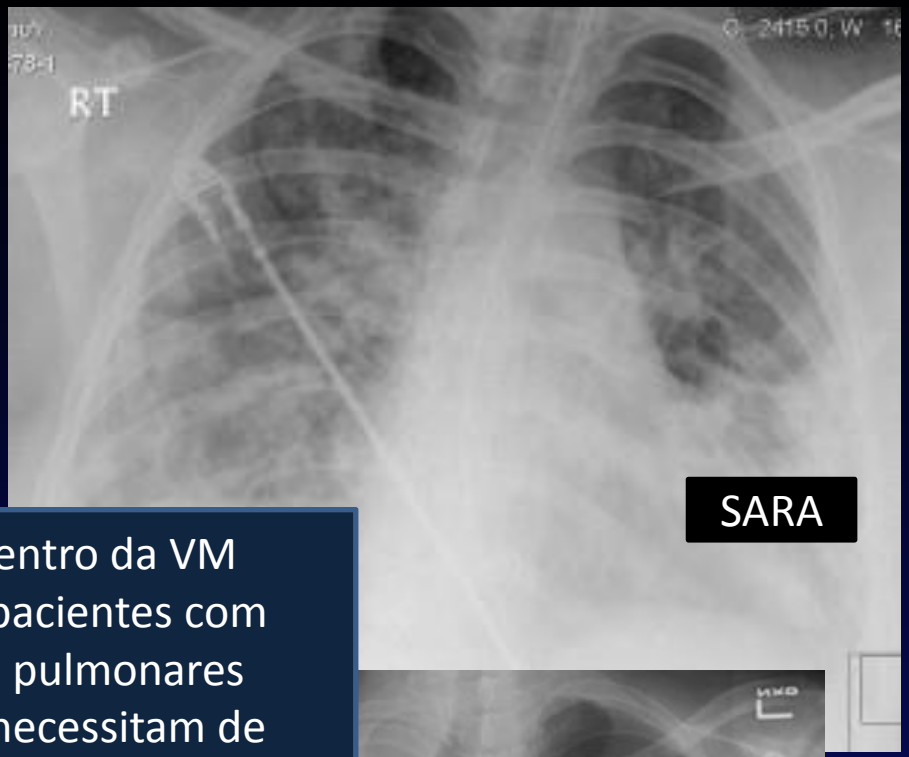






PVM

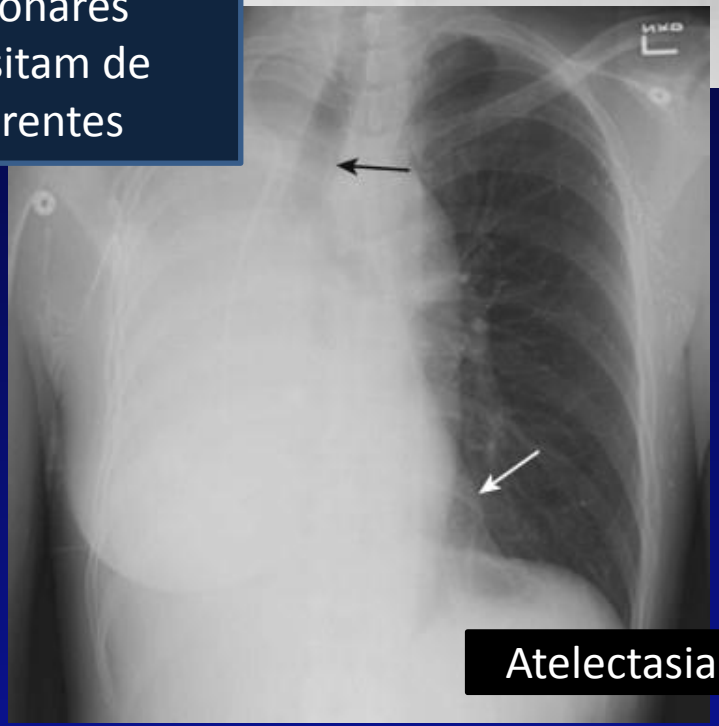




SARA

Mesmo dentro da VM protetora, pacientes com patologias pulmonares diferentes necessitam de parâmetros diferentes

Congestão



Atelectasia

VM e Proteção Pulmonar

Parâmetros da VM

Peep ideal e Parâmetros mínimos

Resposta mecânica e
Resposta fisiológica

Monitorização Clínica

Pa-PetCO2, Gráficos, ausculta, radiologia, pressões de enchimento...

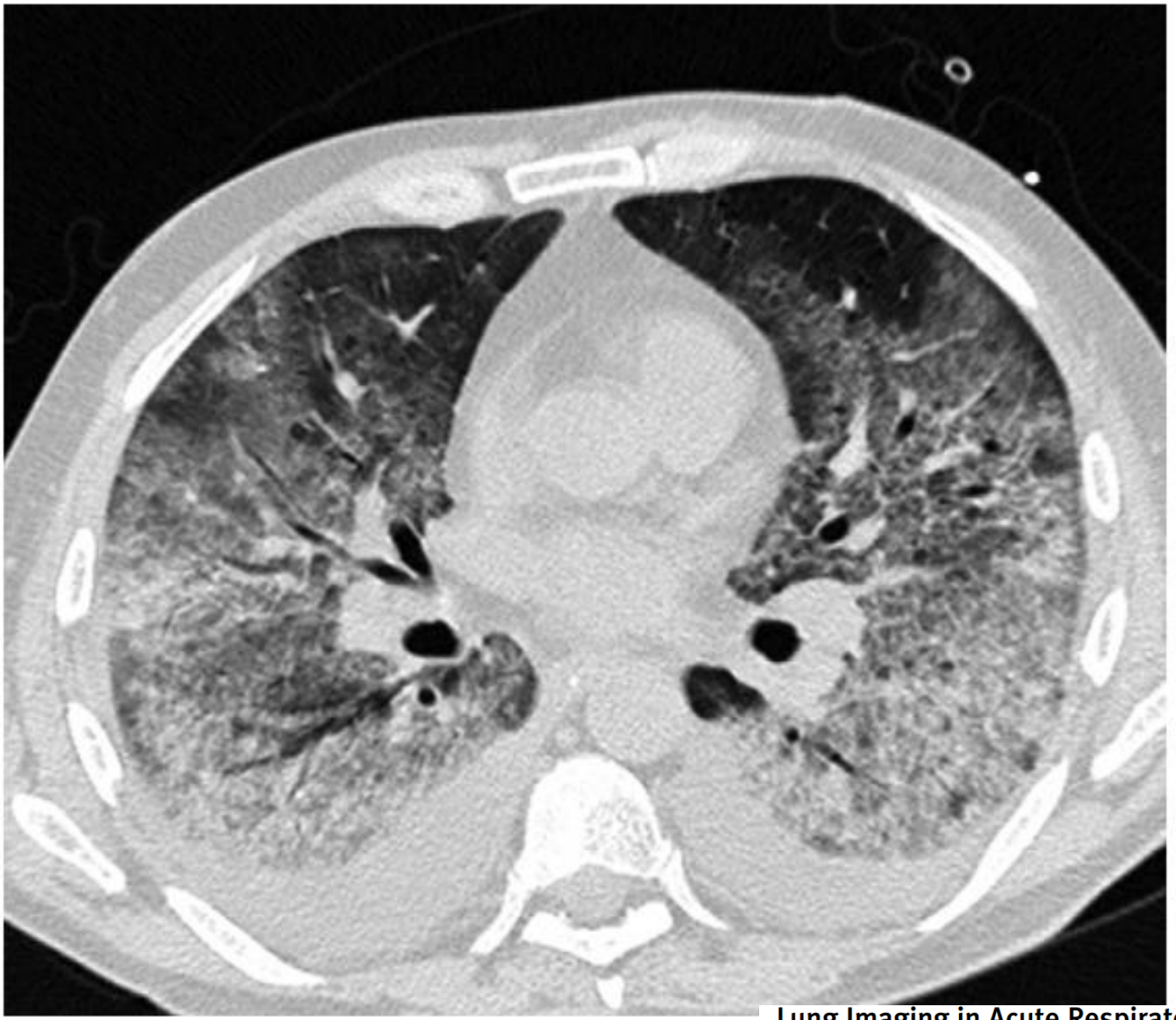
Monitorização Laboratorial

P/F – Lactato - SvcO2

Figure 20.5 Pulmonary acute respiratory distress syndrome with infiltrates in nondependent lung areas, little atelectasis in dependent lung areas, and small pleural effusions.

Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

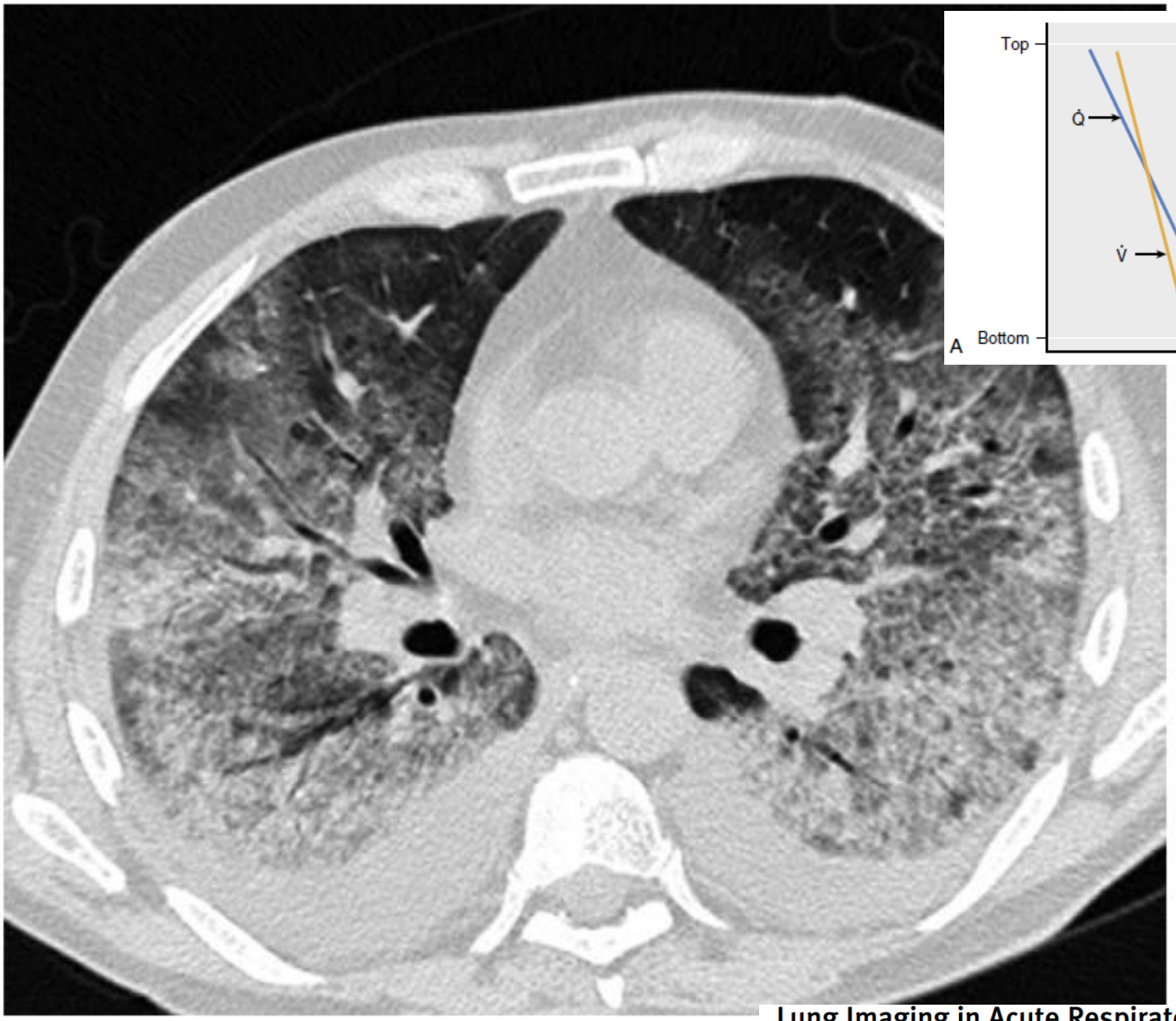
Klaus Markstaller and Hans-Ulrich Kauczor



PVM

Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

Klaus Markstaller and Hans-Ulrich Kauczor

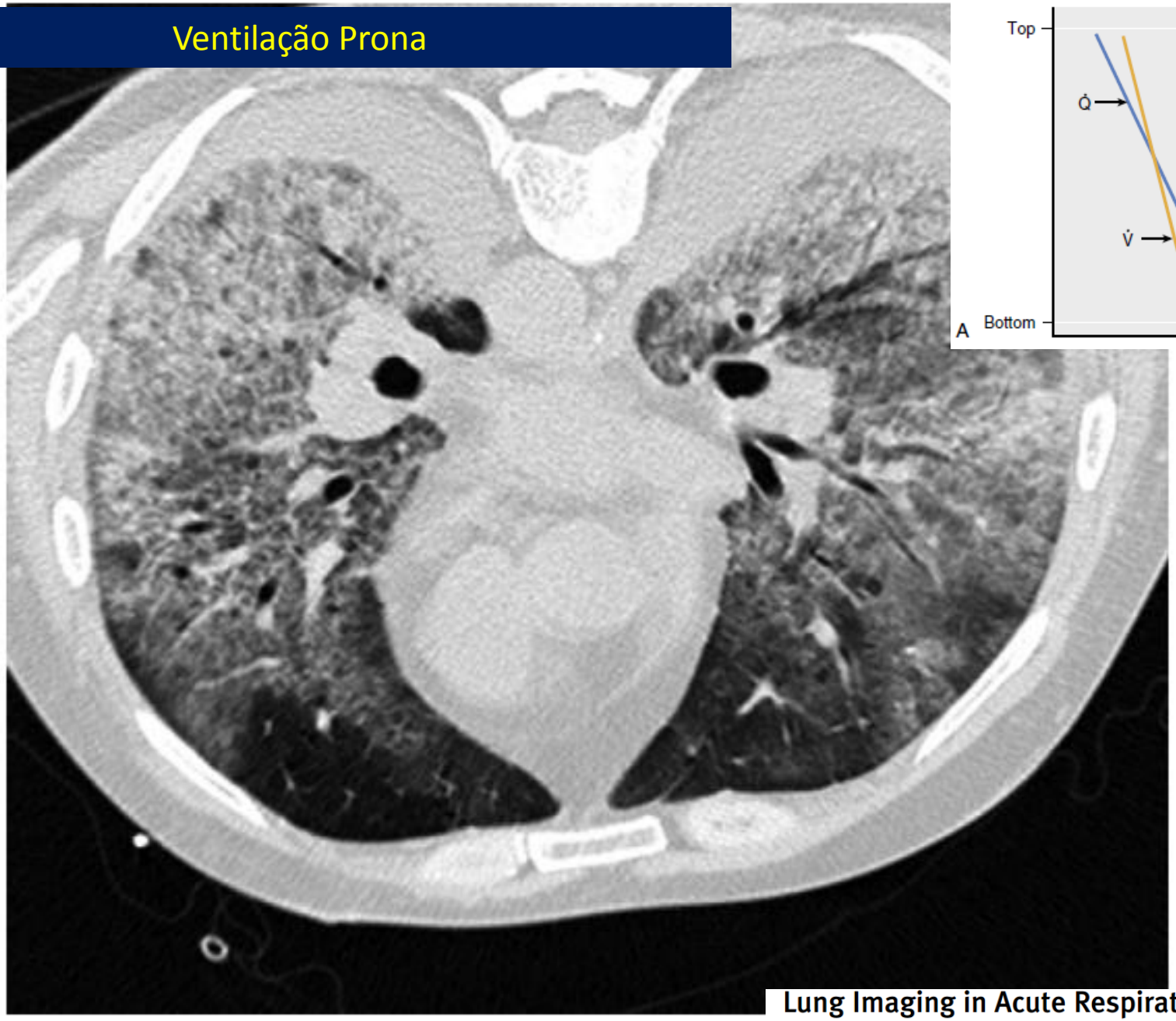


PVM

Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

Klaus Markstaller and Hans-Ulrich Kauczor

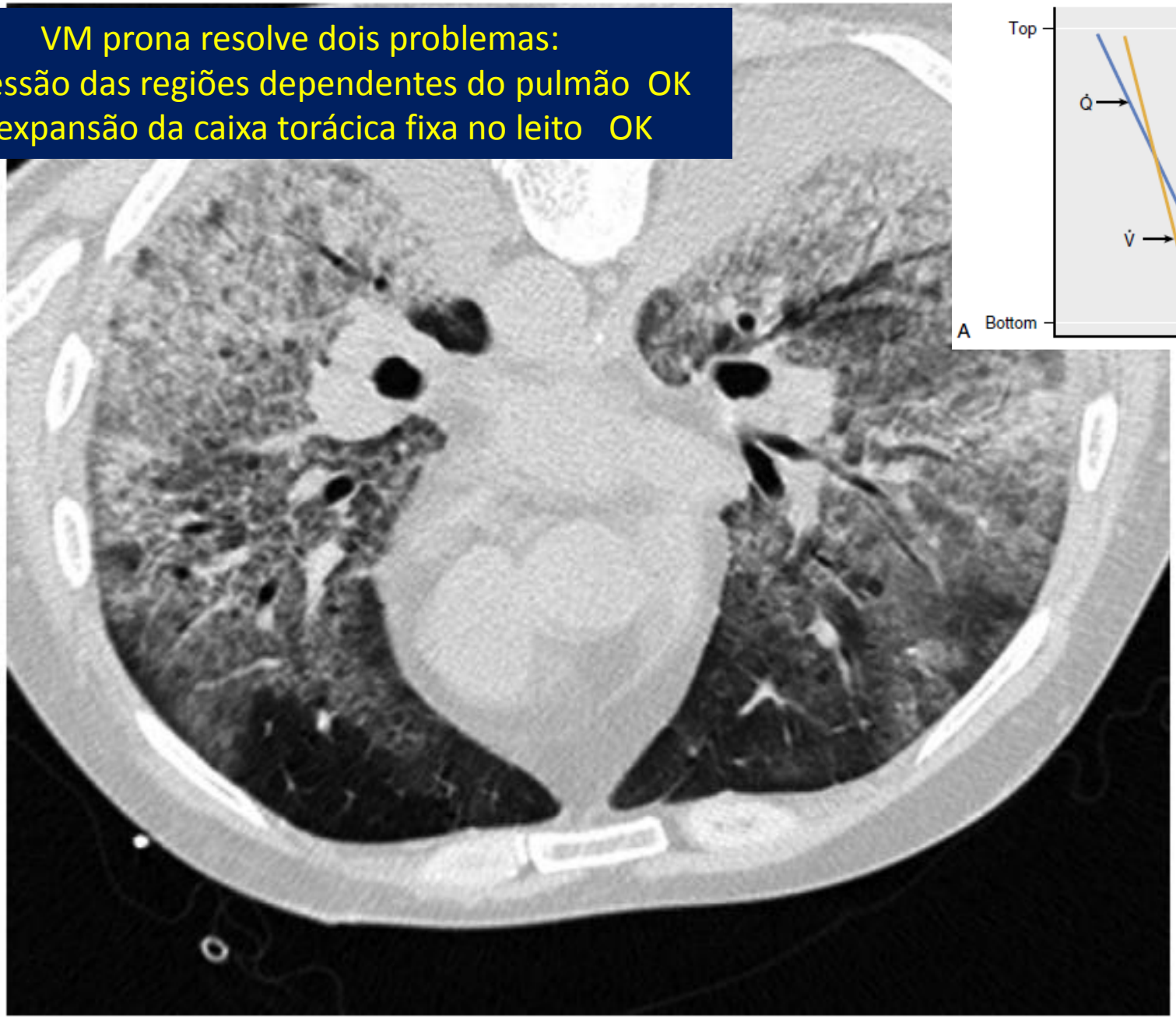
Ventilação Prona



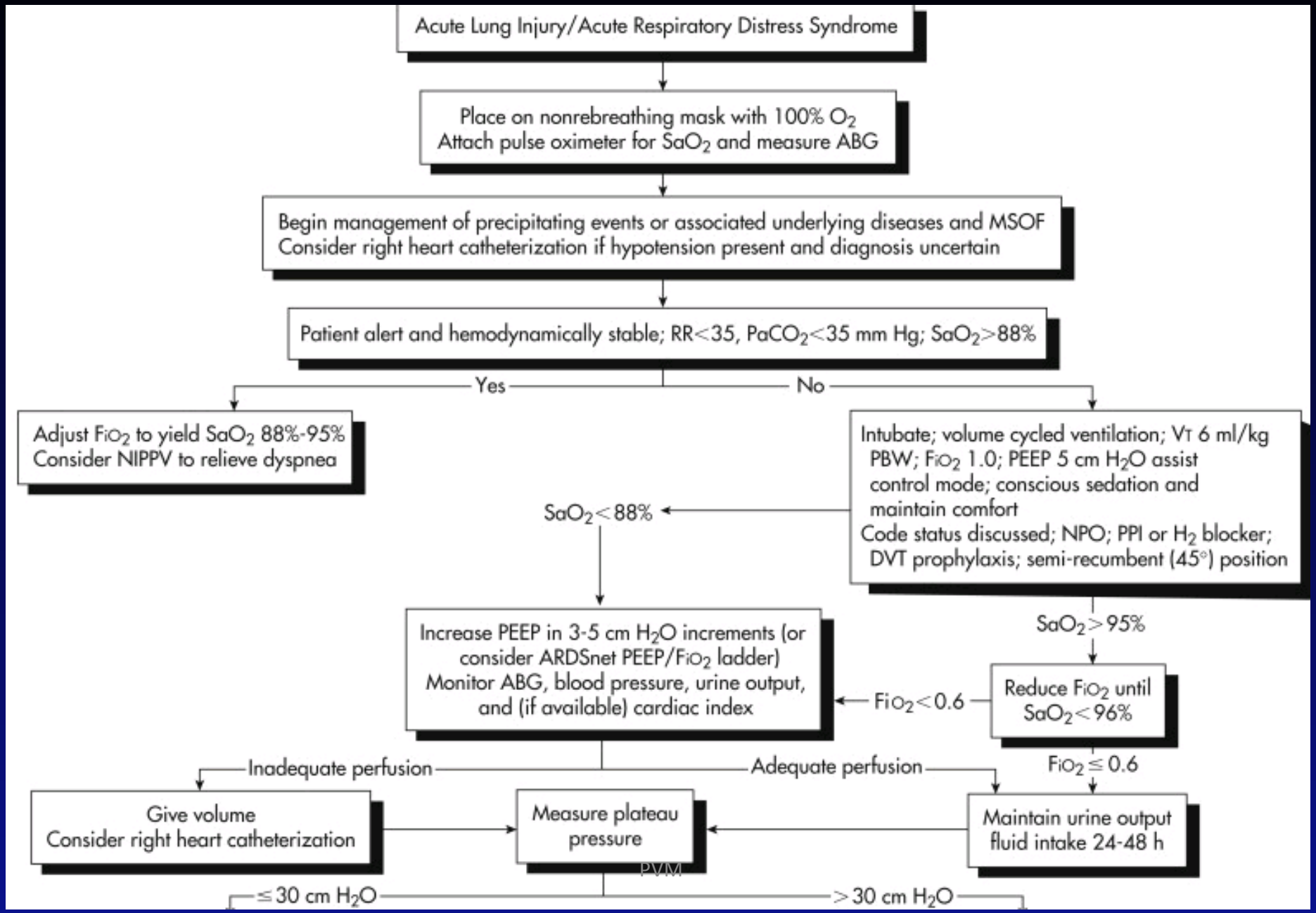
Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

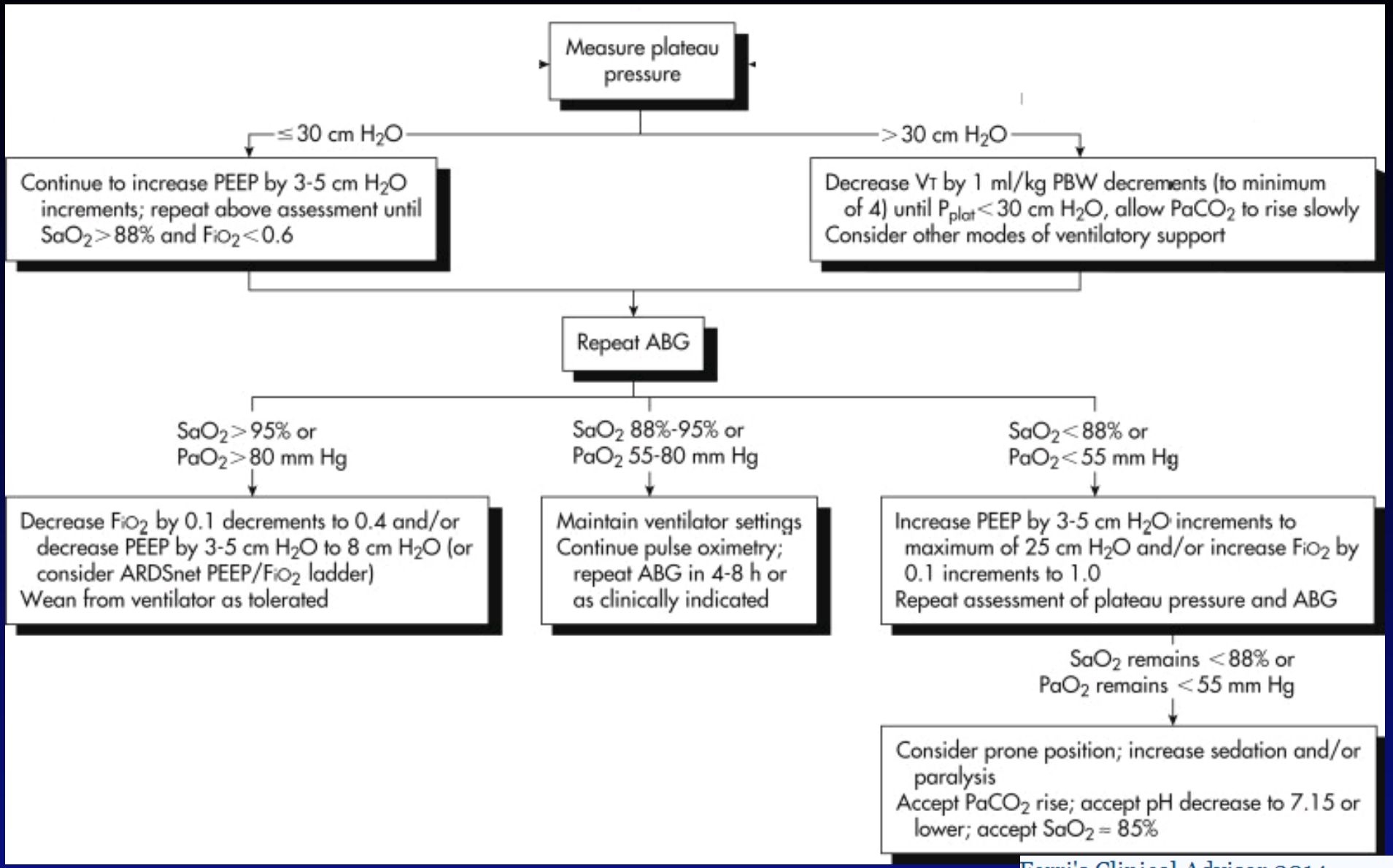
Klaus Markstaller and Hans-Ulrich Kauczor

VM prona resolve dois problemas:
Compressão das regiões dependentes do pulmão OK
Menor expansão da caixa torácica fixa no leito OK



“Bilhete do Pneumologista”:





Ferri's Clinical Advisor 2014

Fred F. Ferri

. 46-48.e3

Copyright © 2014 by Mosby, an imprint of Elsevier Inc.

"Bilhete do Pneumologista":

TABLE 90-3. Ventilation Protocol Used in the Acute Respiratory Distress Syndrome Network Study

Parameter	Protocol
Mode of ventilation	Volume assist-control
Tidal volume	≤6 mL/kg predicted body weight*
Plateau pressure	≤30 cm H_2O
Frequency	6–35 breaths/min, titrated for pH 7.30–7.45
I:E ratio	1:1 to 1:3
Oxygenation goal	Pa_{O_2} 55–80 mm Hg, or Sp_{O_2} 88%–95%
F_{IO_2}/PEEP (cm H_2O) combinations allowed	0.3/5, 0.4/5, 0.4/8, 0.5/8, 0.5/10, 0.6/10, 0.7/10, 0.7/12, 0.7/14, 0.8/14, 0.9/14, 0.9/16, 0.9/18, 1.0/18, 1.0/20, 1.0/22, 1.0/2
Weaning	By pressure support, required when F_{IO_2}/PEEP ≤ 0.4/8

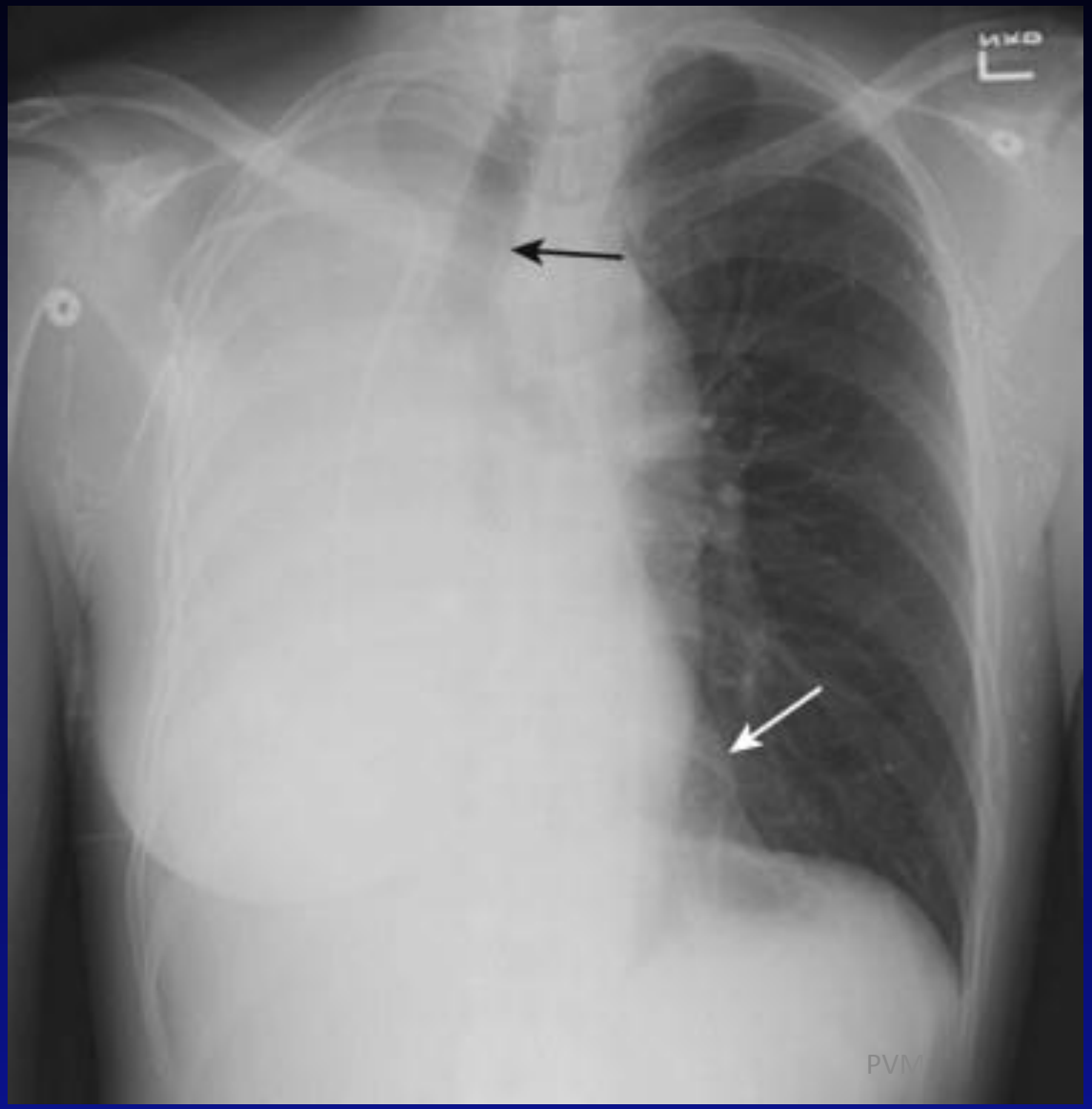
CHAPTER 90
ACUTE RESPIRATORY DISTRESS SYNDROME
Warren L. Lee, MD, PhD, FRCP(C) · Arthur S. Slutsky, MD

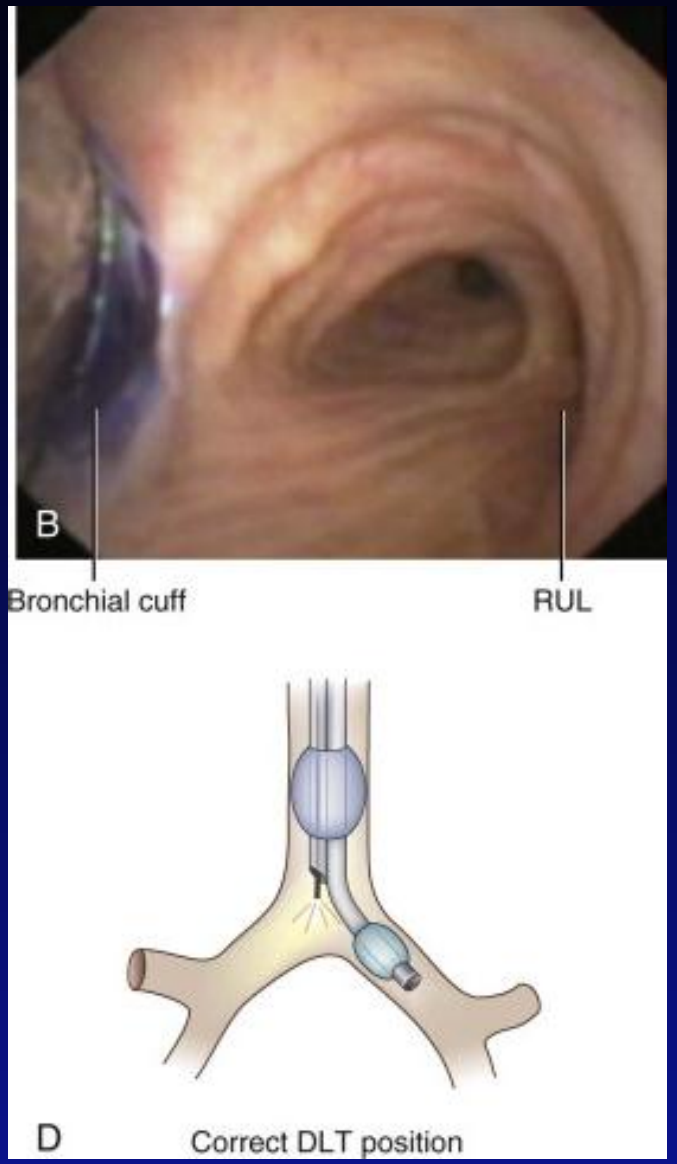
Dúvidas

- Fração de espaço morto está associado a mortalidade
  - Como vou reduzir espaço morto?

- Qual o nível ideal de PEEP?
  - O que usar para chegar na PPEP ideal?

Estratégias diferenciadas





Case 1: patient with severe ARDS in a supine position with a 2-kg weight iron bar in front of the chest bilaterally. Saturation started improving within 1 hour of chest wall compression

Case 2: patient with severe ARDS in a supine position with 2-L water bags in front of the chest bilaterally.

Supine chest compression: alternative to prone ventilation in acute respiratory distress syndrome
Sukhen Samanta, Sujay Samanta, and Kapil Dev Soni
American Journal of Emergency Medicine, 2014-05-01, Volume 32, Issue 5, Pages 489.e5-489.e6

RVM

“Bilhete do Pneumologista”: X Saber “sair do protocolo”

The New England
Journal of Medicine

© Copyright, 2000, by the Massachusetts Medical Society

VOLUME 342 MAY 4, 2000 NUMBER 18

VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

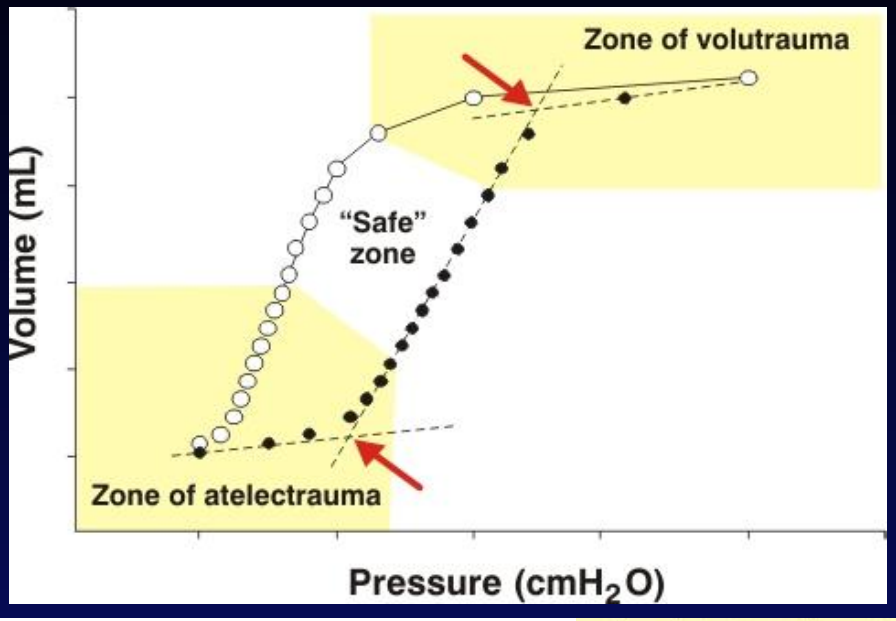
THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*

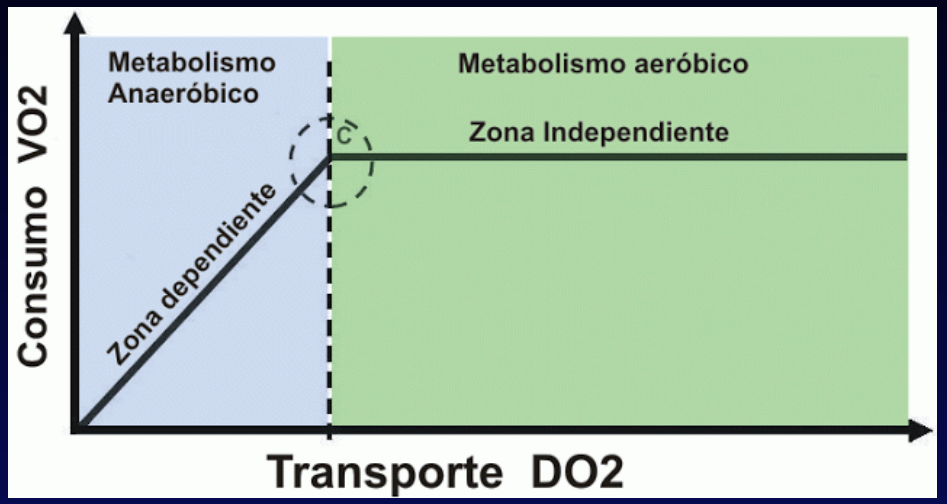
X

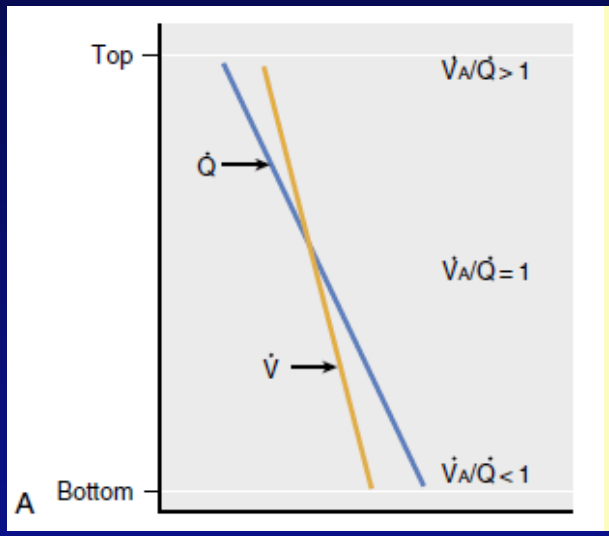
O que eu posso fazer

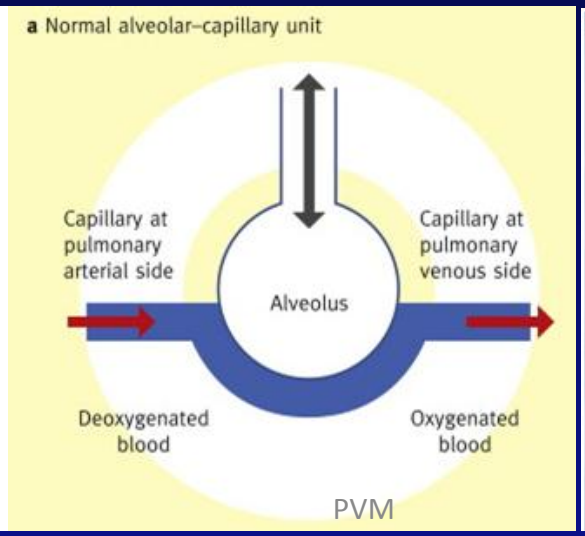
- VM protetora – ARDS net
- BUSCAR A PEEP IDEAL
  - Melhorar P/F sem aumentar dano: EM alveolar, DC, volutrauma.
  - Gradiente PaCO2-PETCO2
  - Capnografia volumetrica
- Não deixar atelectasiar e recrutar
- Diminuir espaço morto anatômico
- Superficialização intermitente da sedação
- Nutrição
- Suporte hemodinâmico adequado

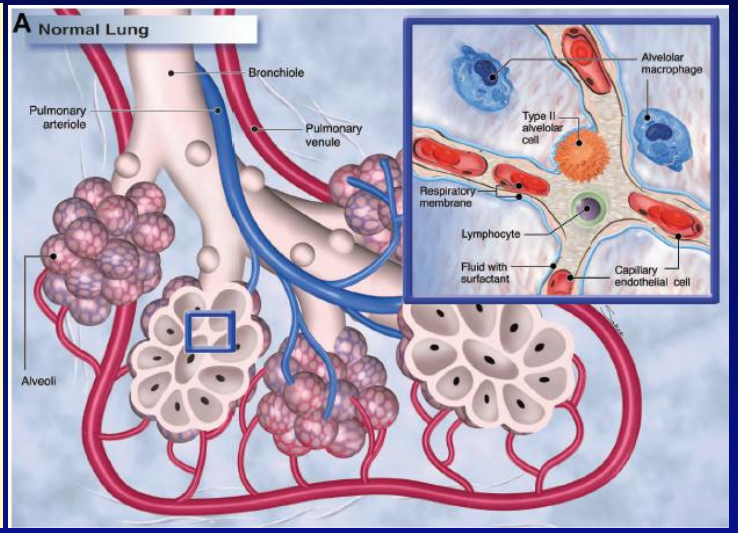
O que eu posso fazer











PVM

O que eu posso fazer