

Fisiologia Respiratória & Ventilação Mecânica

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Brasília, 12 de agosto de 2014



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VM e Proteção Pulmonar

Parâmetros da VM



Resposta mecânica

Resposta fisiológica



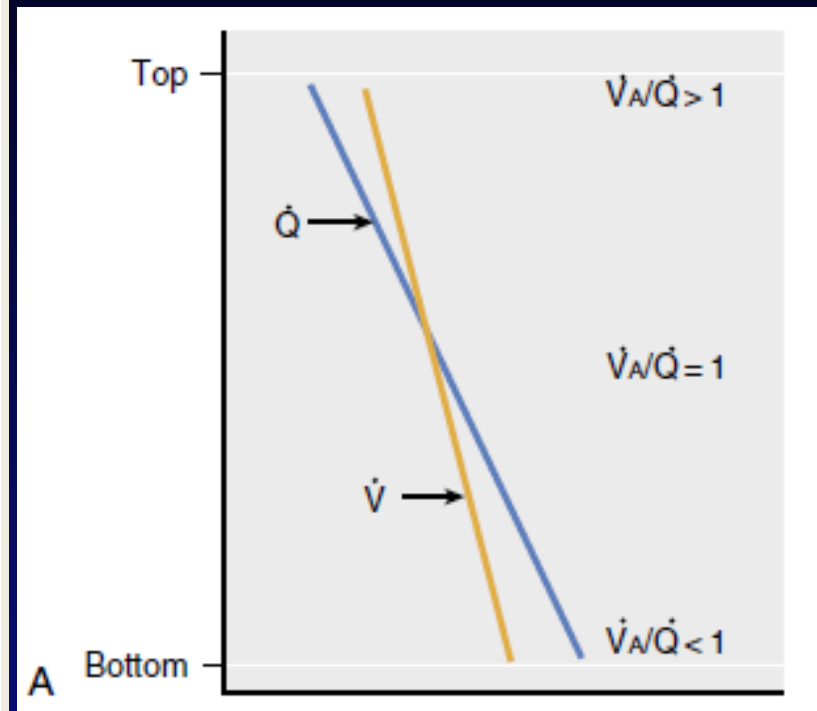
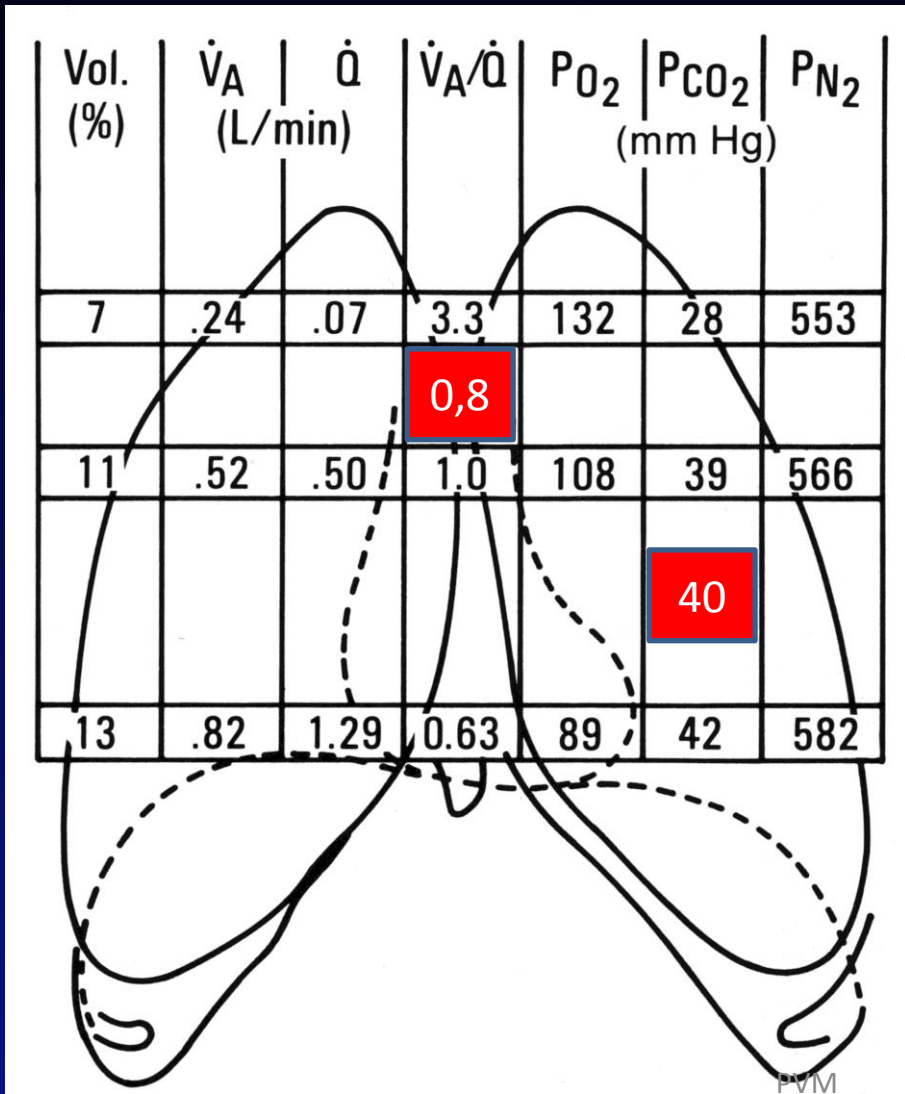
Monitorização Clínica

Monitorização Laboratorial

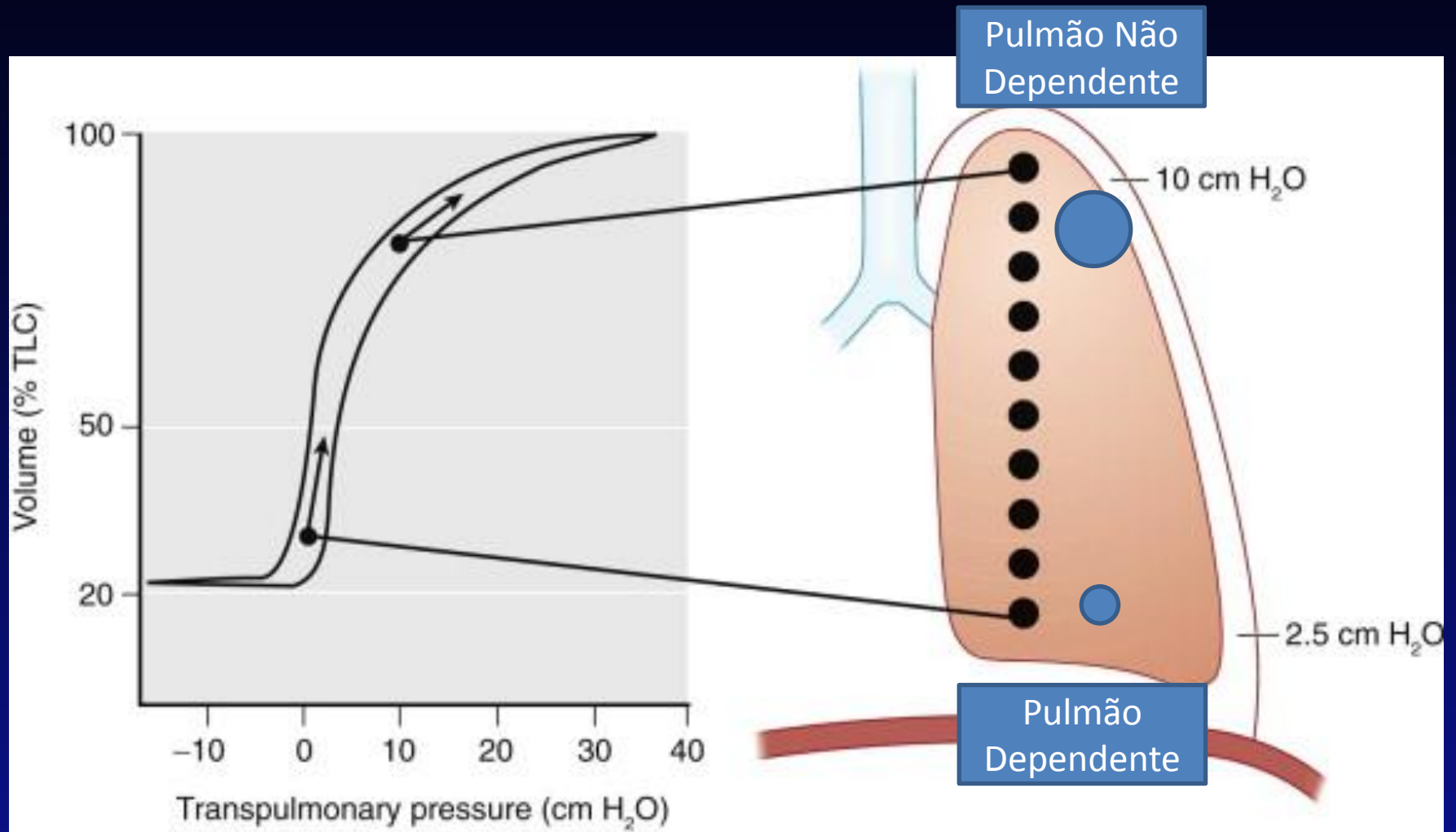
VM e Proteção Pulmonar



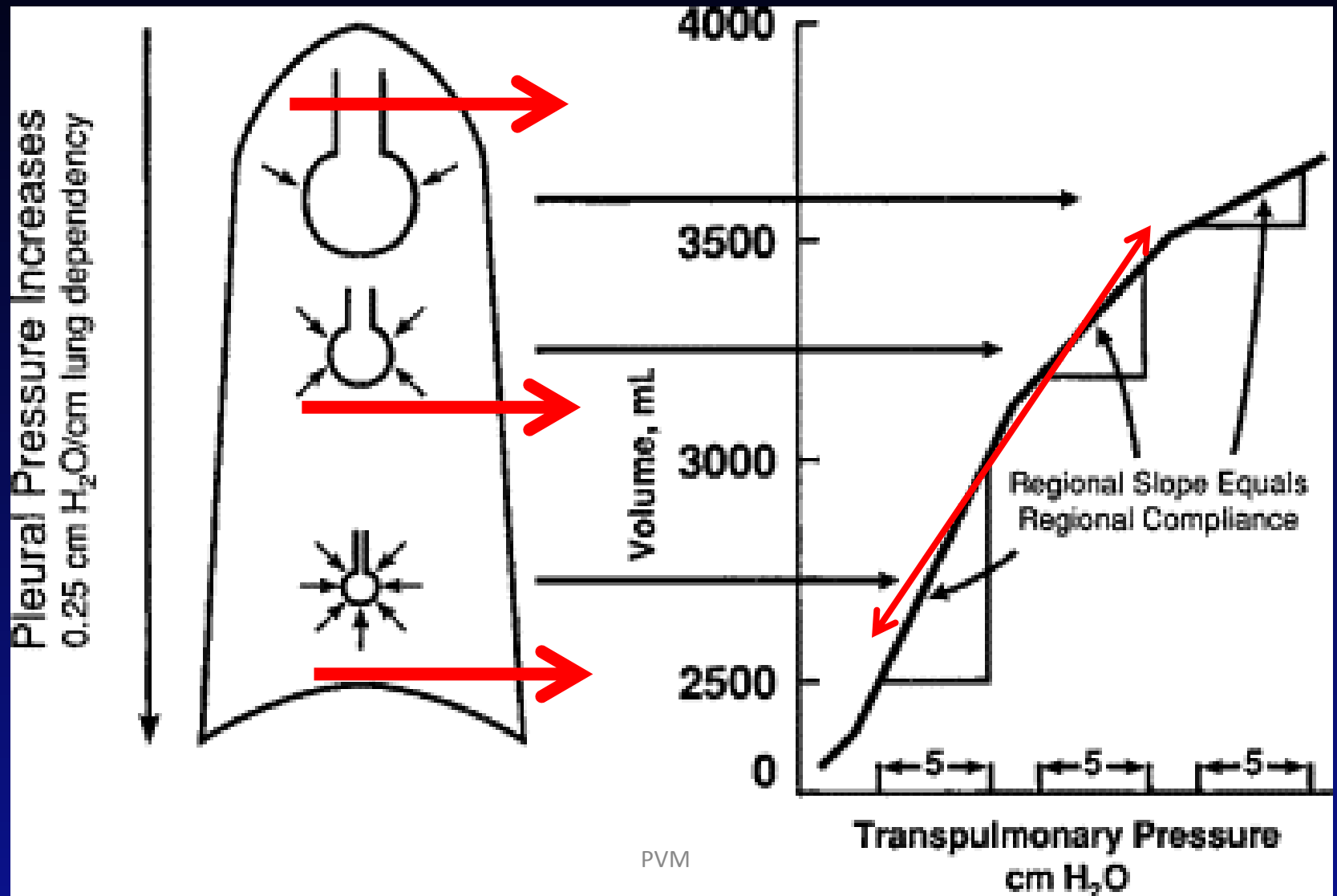
Fisiologia do Tórax



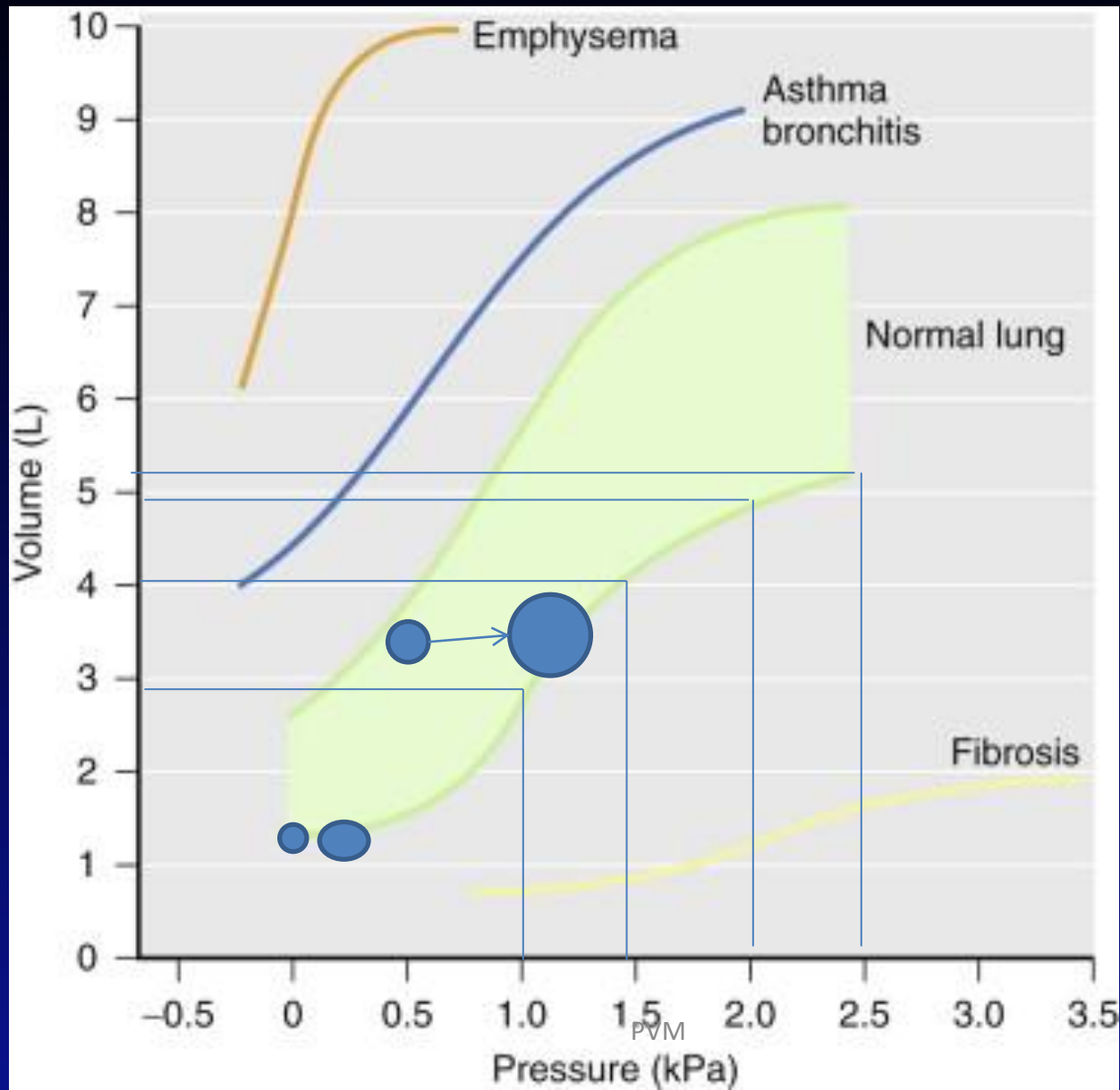
Fisiologia do Tórax



Complacência Torácica



Fisiologia do Tórax



Complacência Torácica

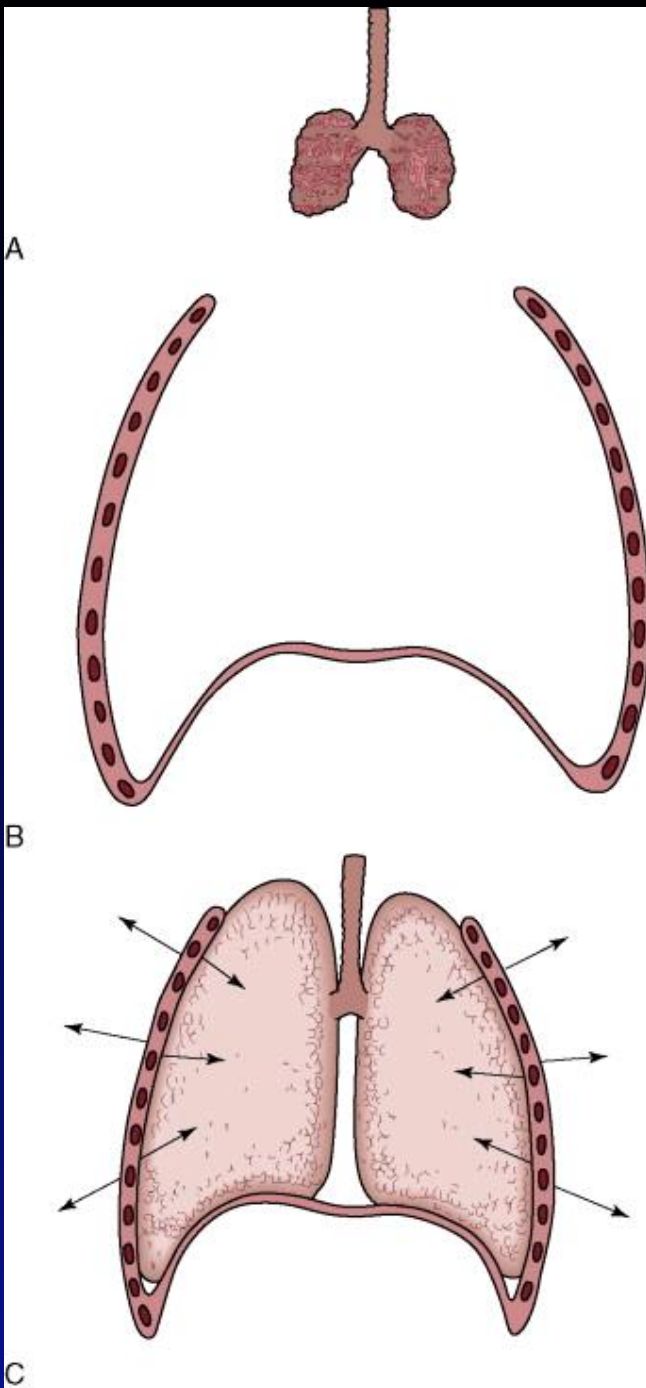
- O que mantém a CRF
 - Tórax: arcabouço ósseo e tônus da musculatura intercostal.
 - Surfactante (fosfatidil colina)
 - Mais eficiente nos alvéolos de menor raio.
 - PEEP natural: fechamento das cordas vocais antes do fim da expiração, alta resistência nasal.
 - Conteúdo alveolar: oxigênio e nitrogênio

X

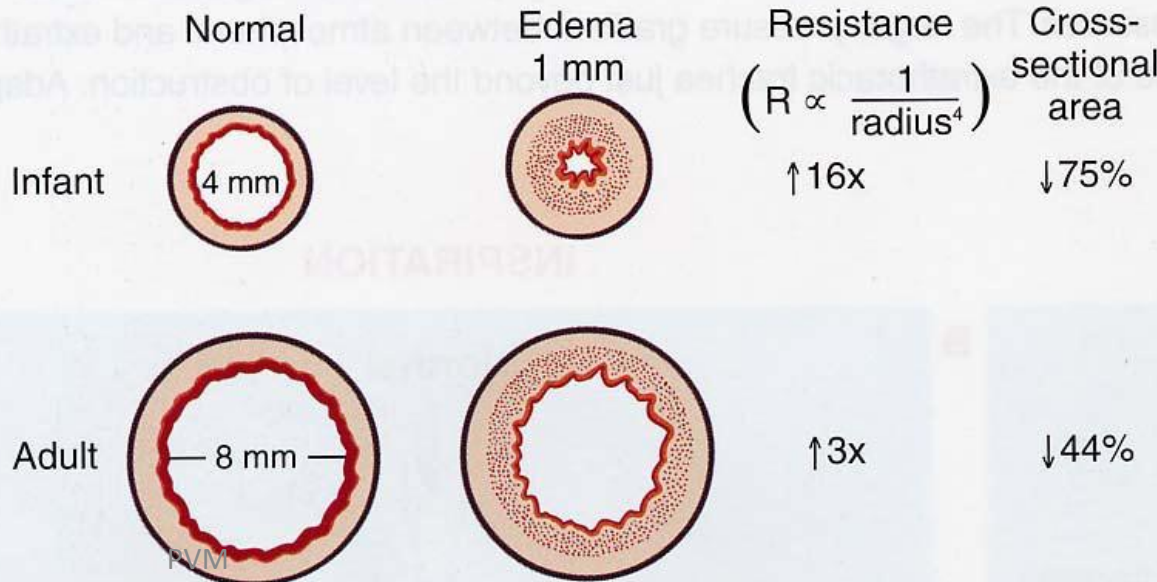
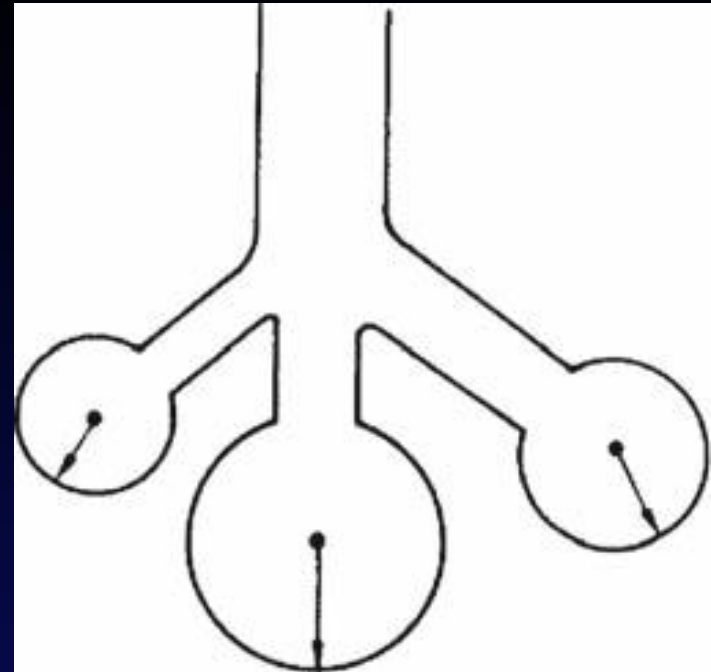
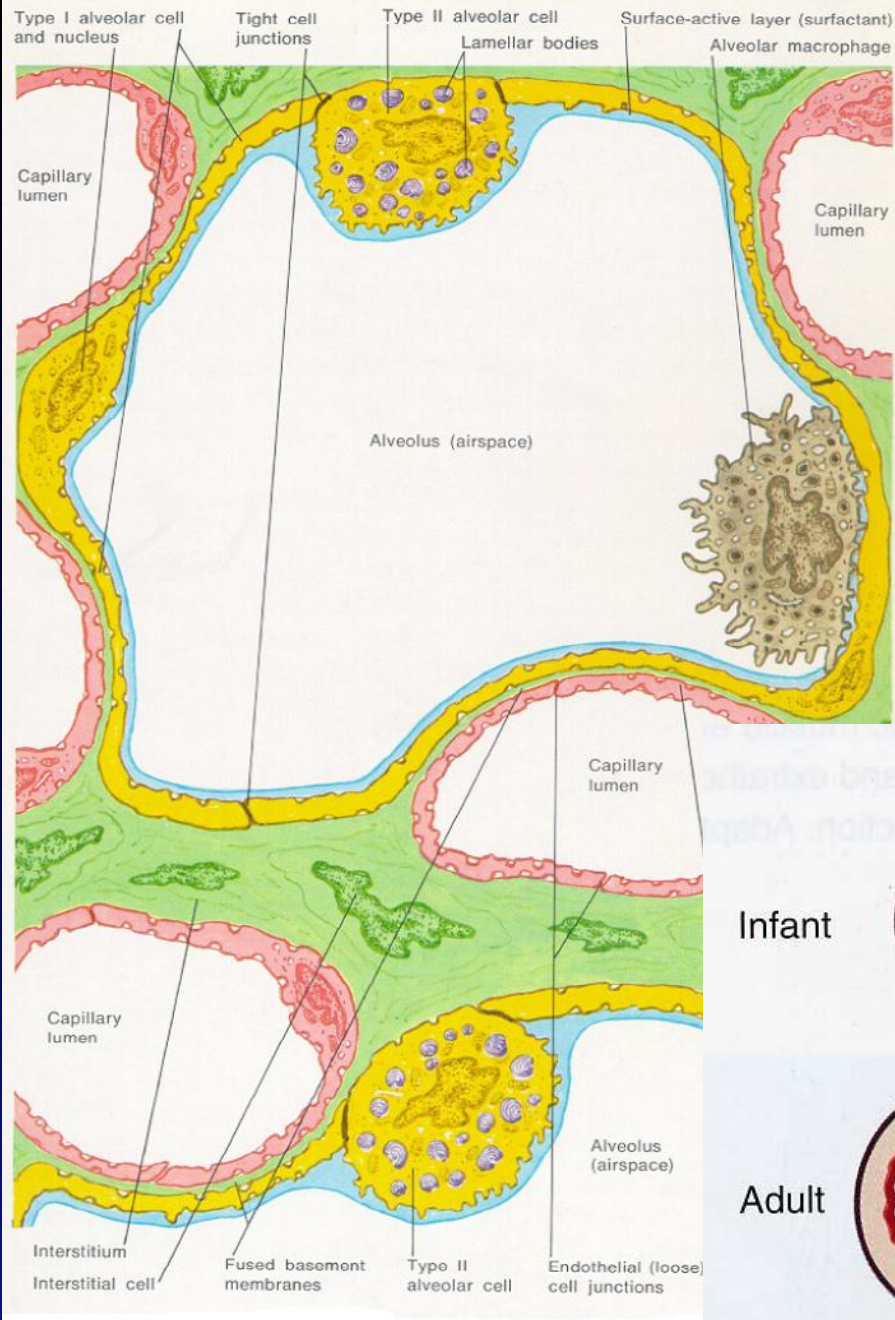
- Recolhimento elástico do pulmão

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.**



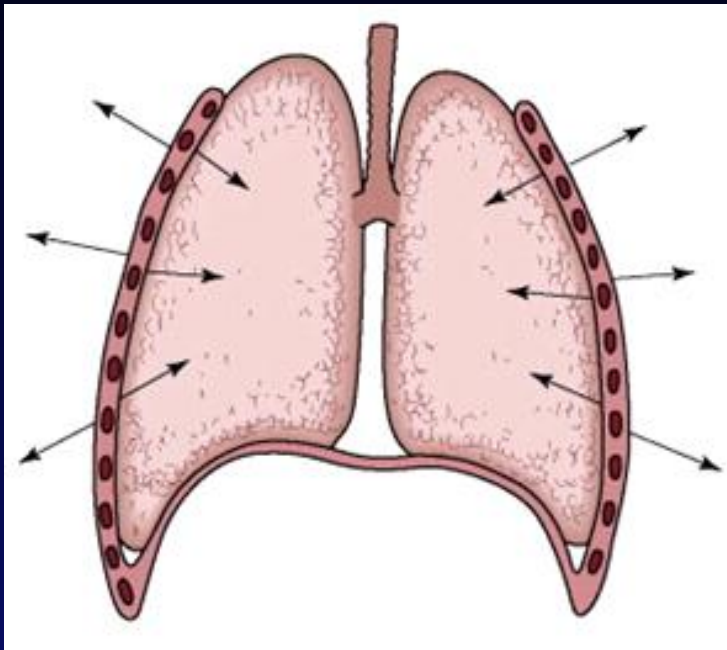
Ultrastructure of Pulmonary Alveoli and Capillaries



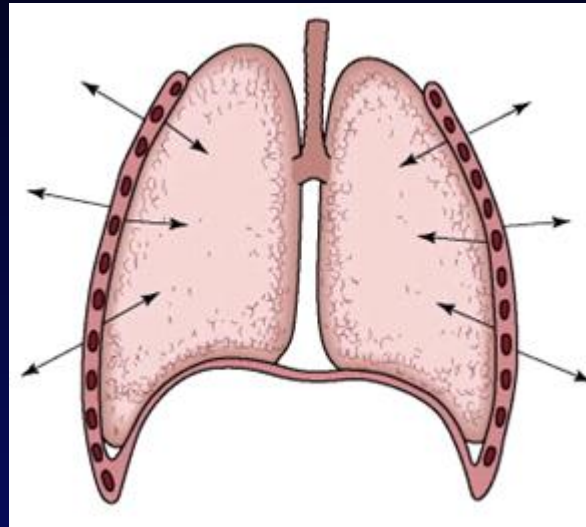
Volume de Fechamento (VF)

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

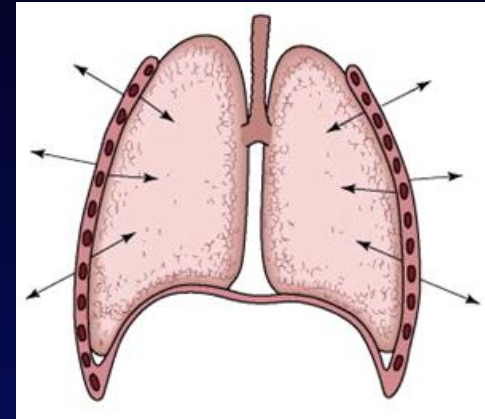
CRF



VF



CRF



Desejável

Atelectasia

PVM

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

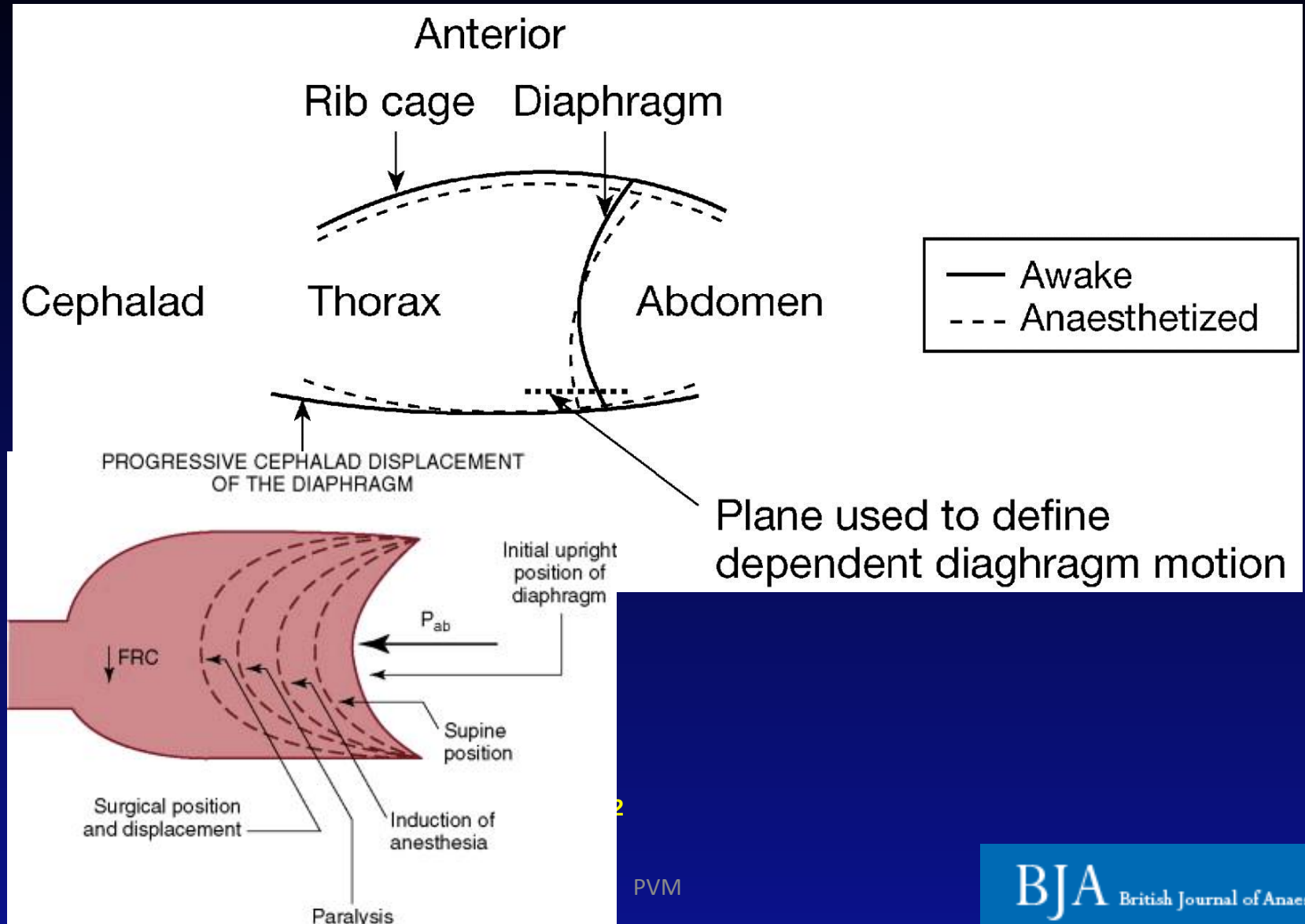
- Atelectasia
 - compressão mecânica do parênquima pulmonar
 - relaxamento da musculatura e deslocamento para dentro do tórax do diafragma relaxado
 - Peso do coração repousado sobre o parênquima pulmonar,
 - Compressão das regiões dependentes do pulmão
 - Limitação da expansão pulmonar
 - Menor expansão 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

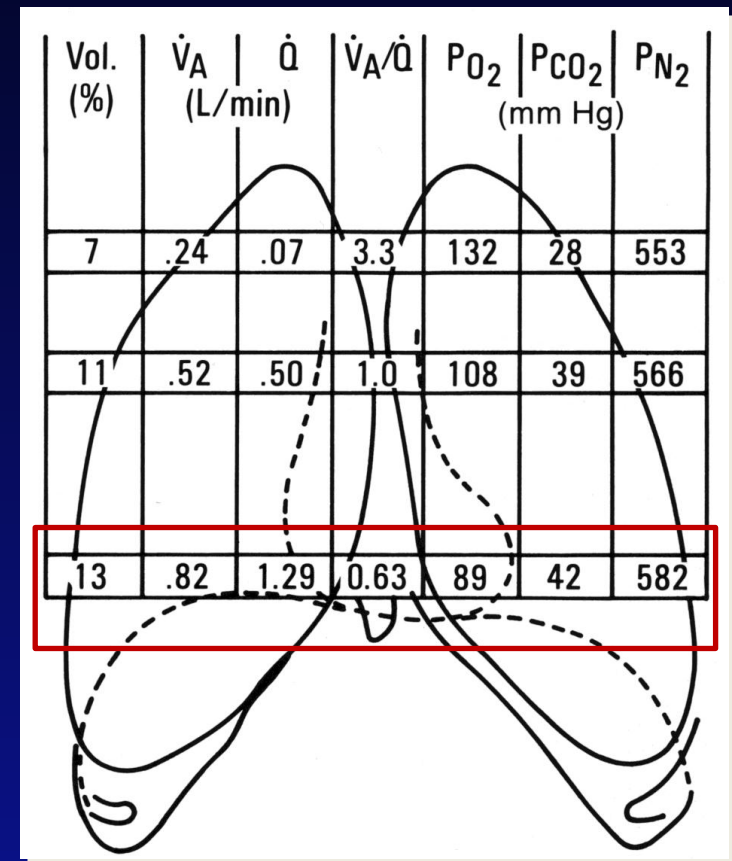
Colapso pulmonar → ATELECTRAUMA

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

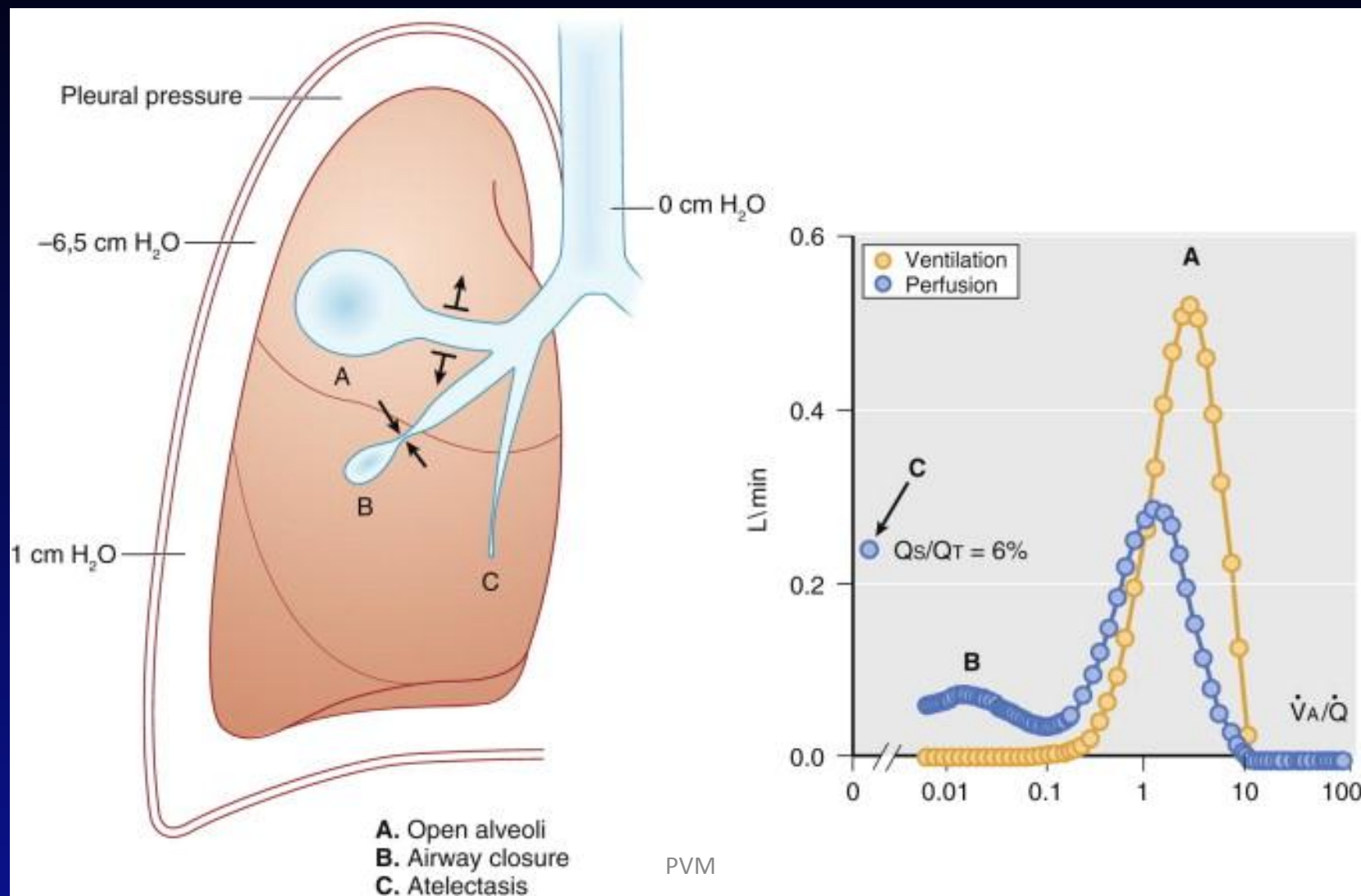


Atelectasia induzida pela VM

- Mistura de Gases
 - Atelectasia de reabsorção
 - Após oclusão completa
 - Relação v/Q baixa
 - FiO_2 alta

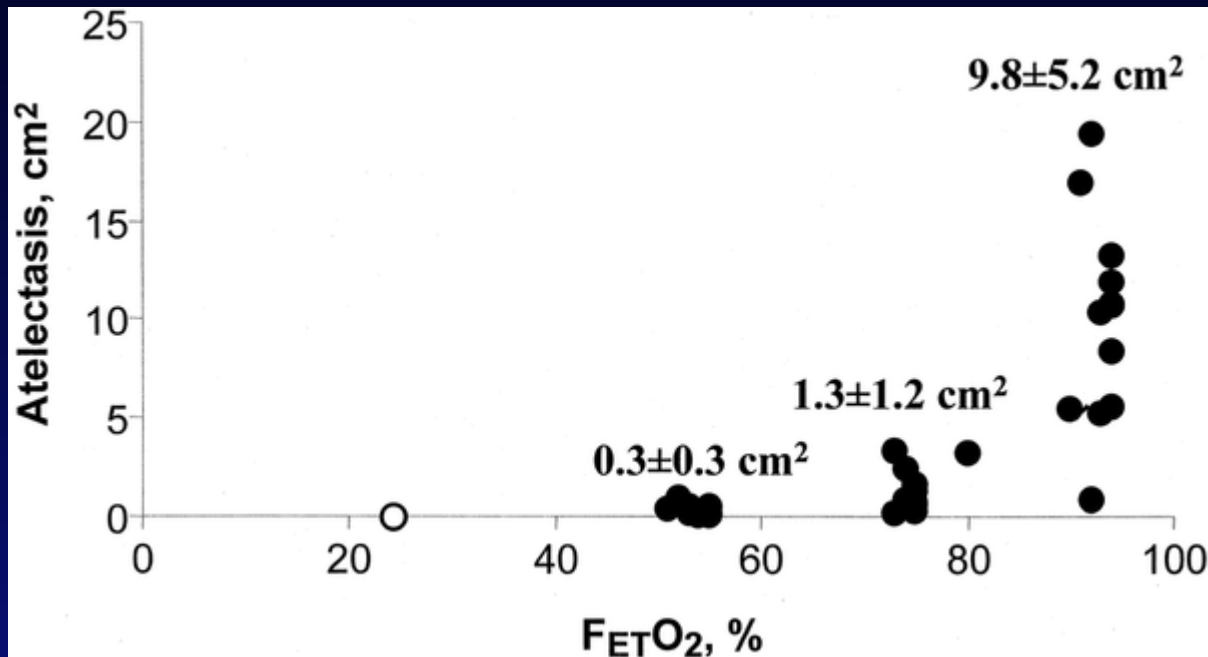


Atelectasia induzida pela VM



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.

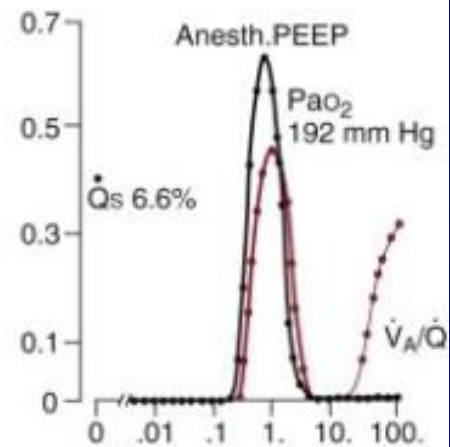
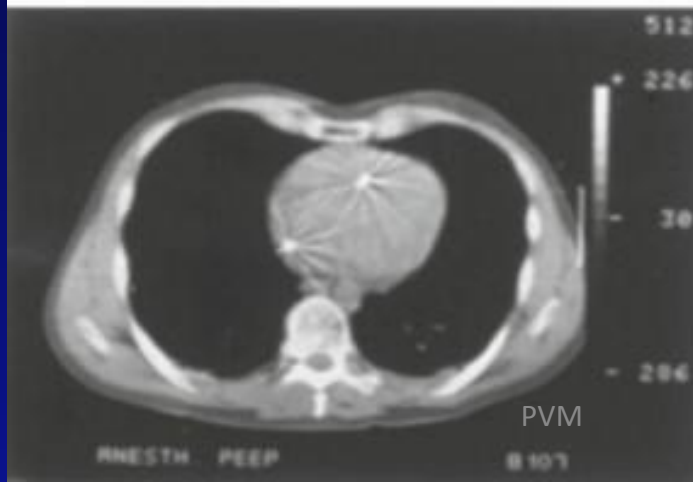
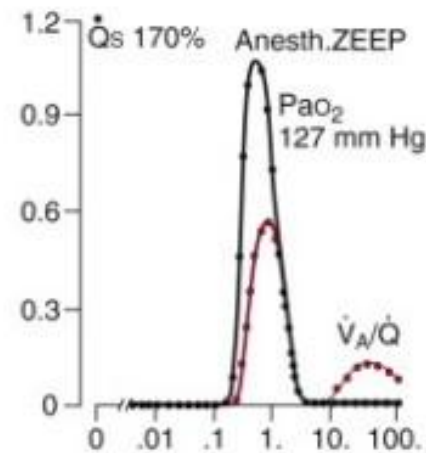
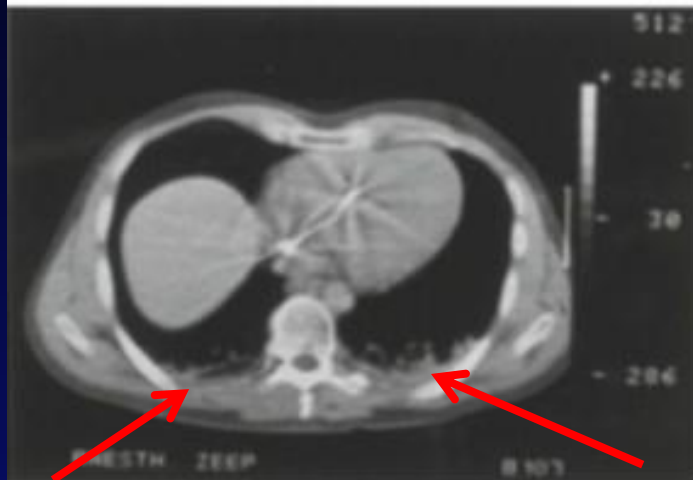
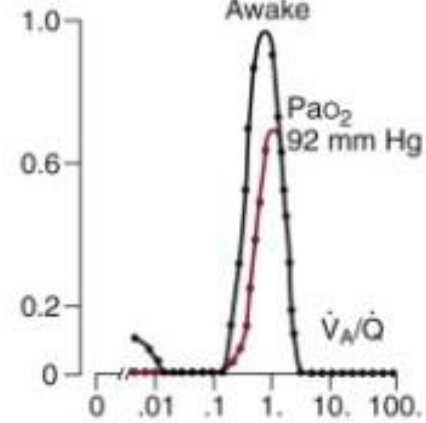
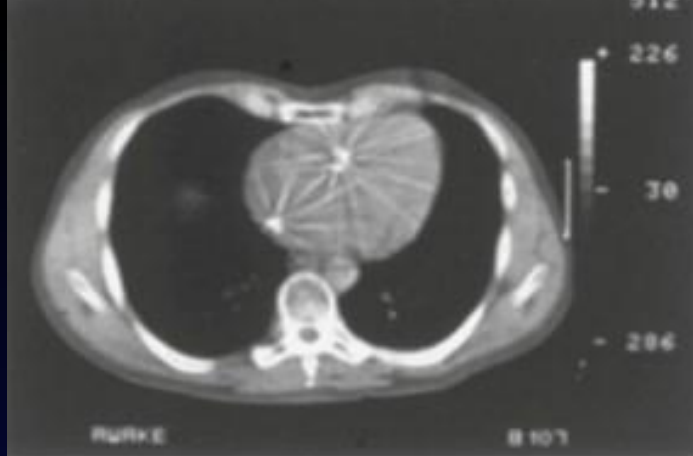
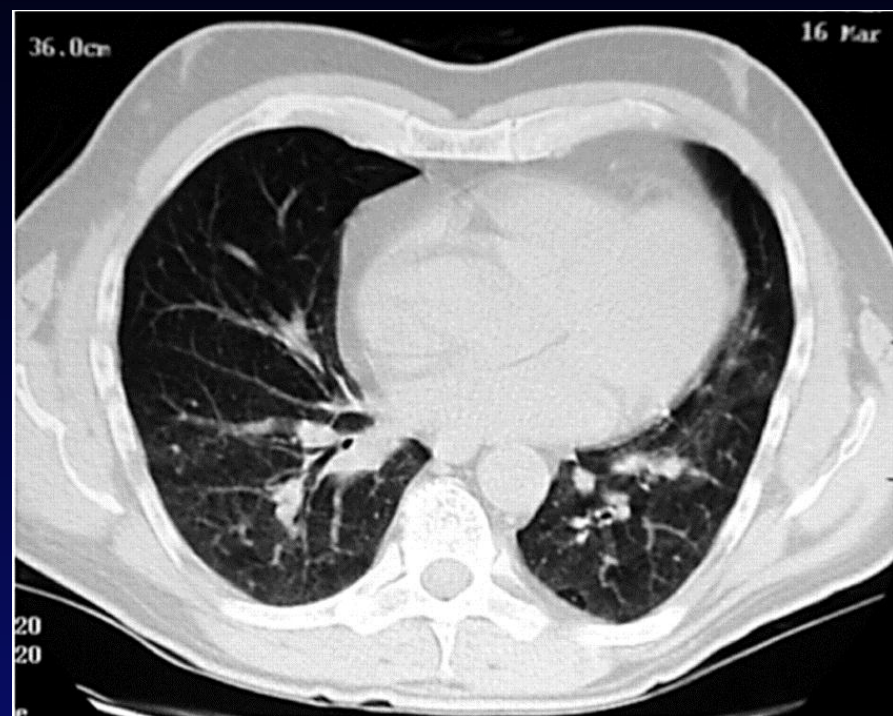
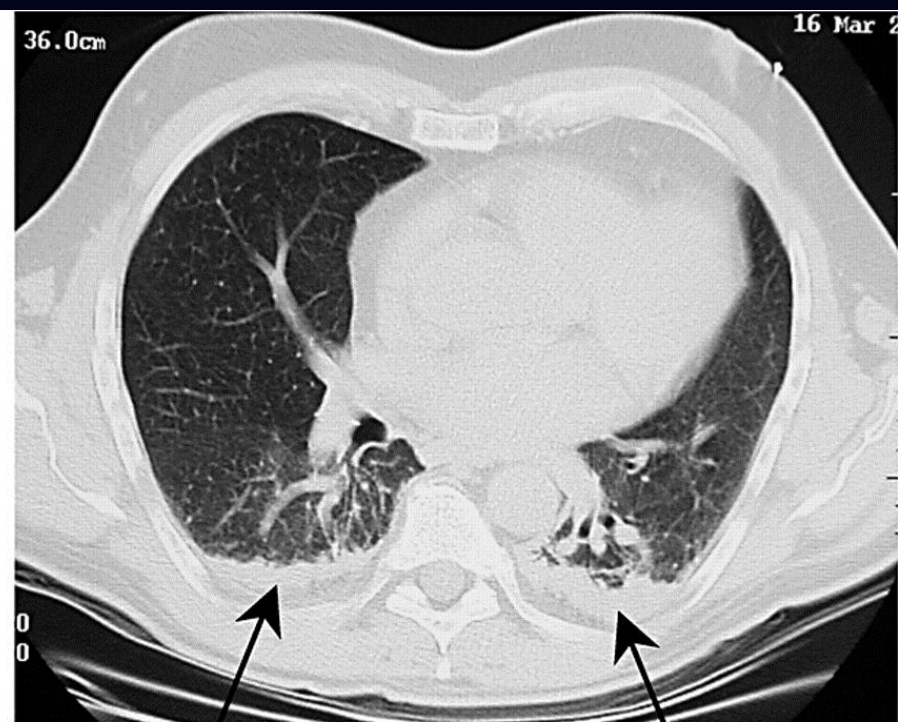


Fig 1 Examples of CT scans of a patient with healthy lungs, before and after induction of anaesthesia.



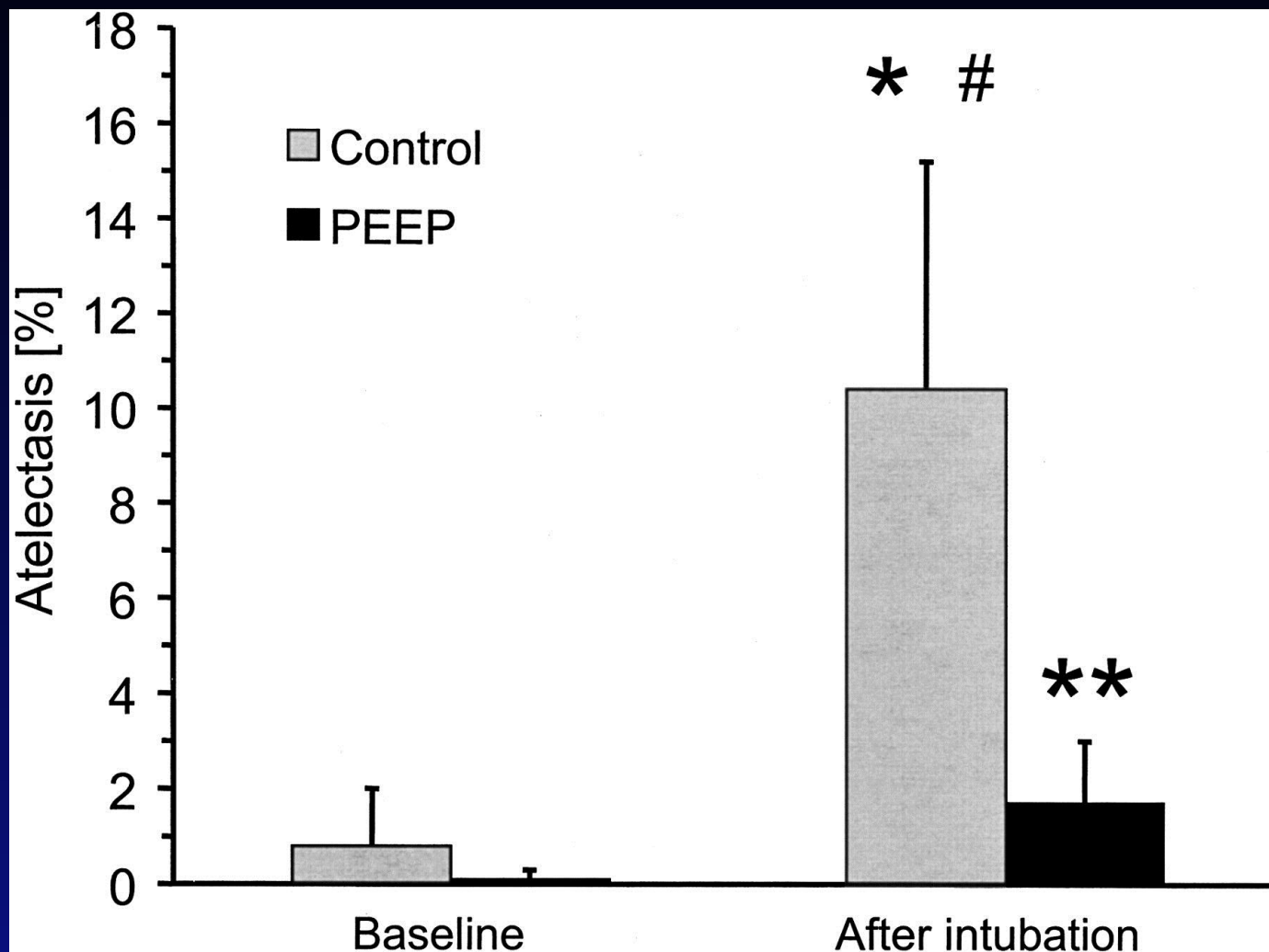
Before induction



After intubation

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

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 ...

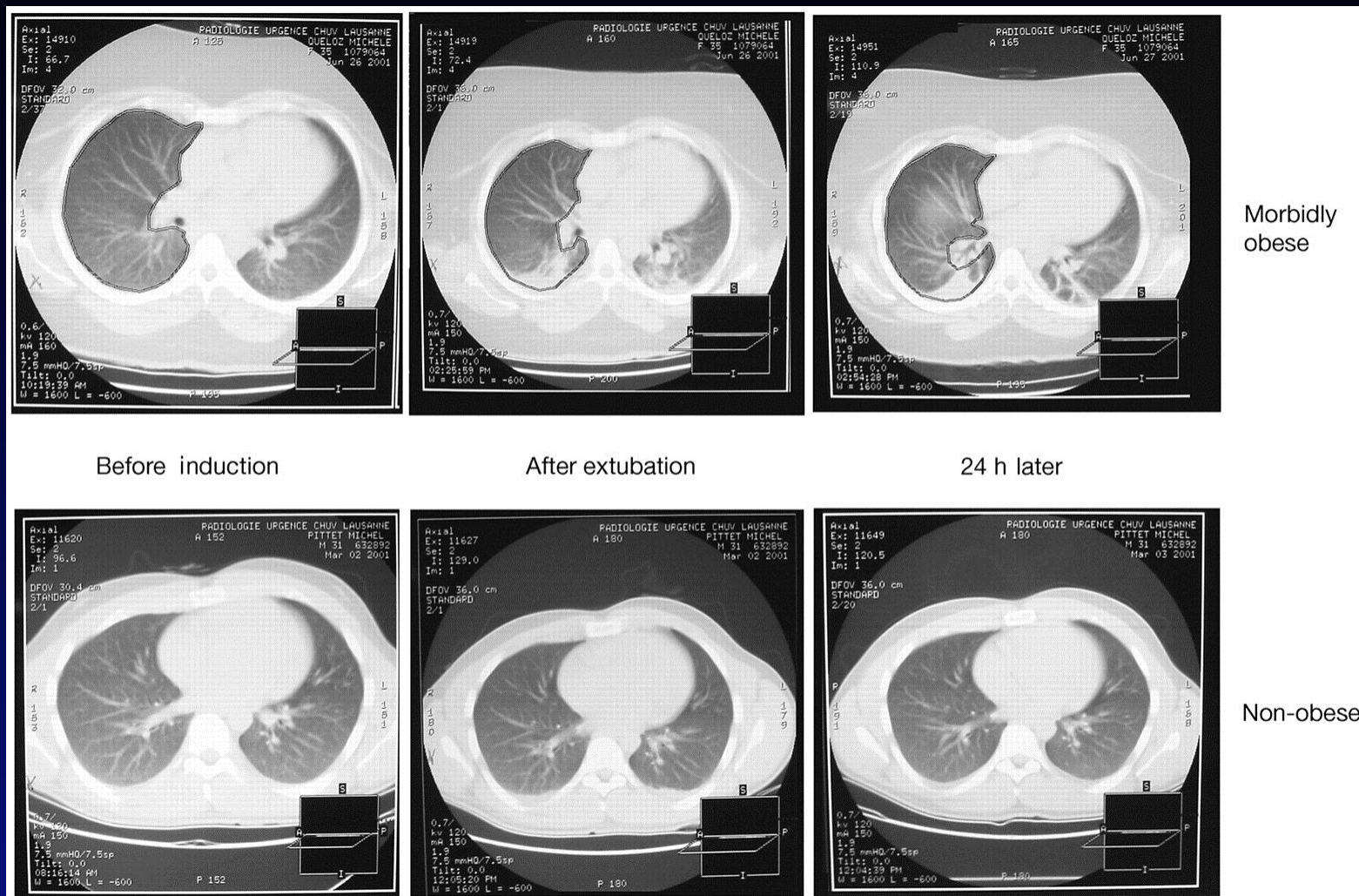


Coussa M et al. Anesth Analg 2004;98:1491-1495

PVM

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

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

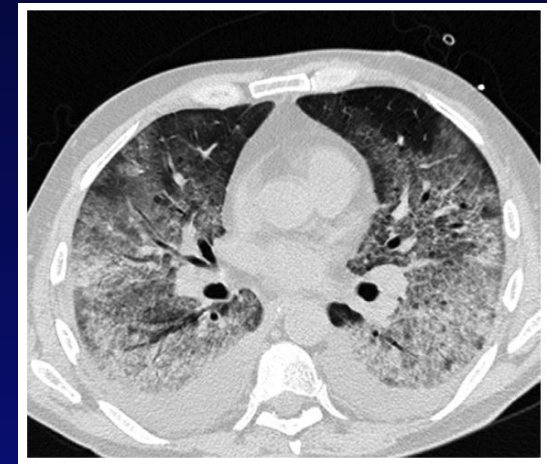
- Disfunção do sistema surfactante
 - Volume corrente elevado
 - Alteração na área de superfície
 - Atividade aumentada de protease no espaço aéreo
 - Aumenta propensão a colapso
 - Expansão desigual aumenta estresse regional
 - Aumento da pressão de filtração vascular promove formação de edema

Atelectasia induzida pela VM

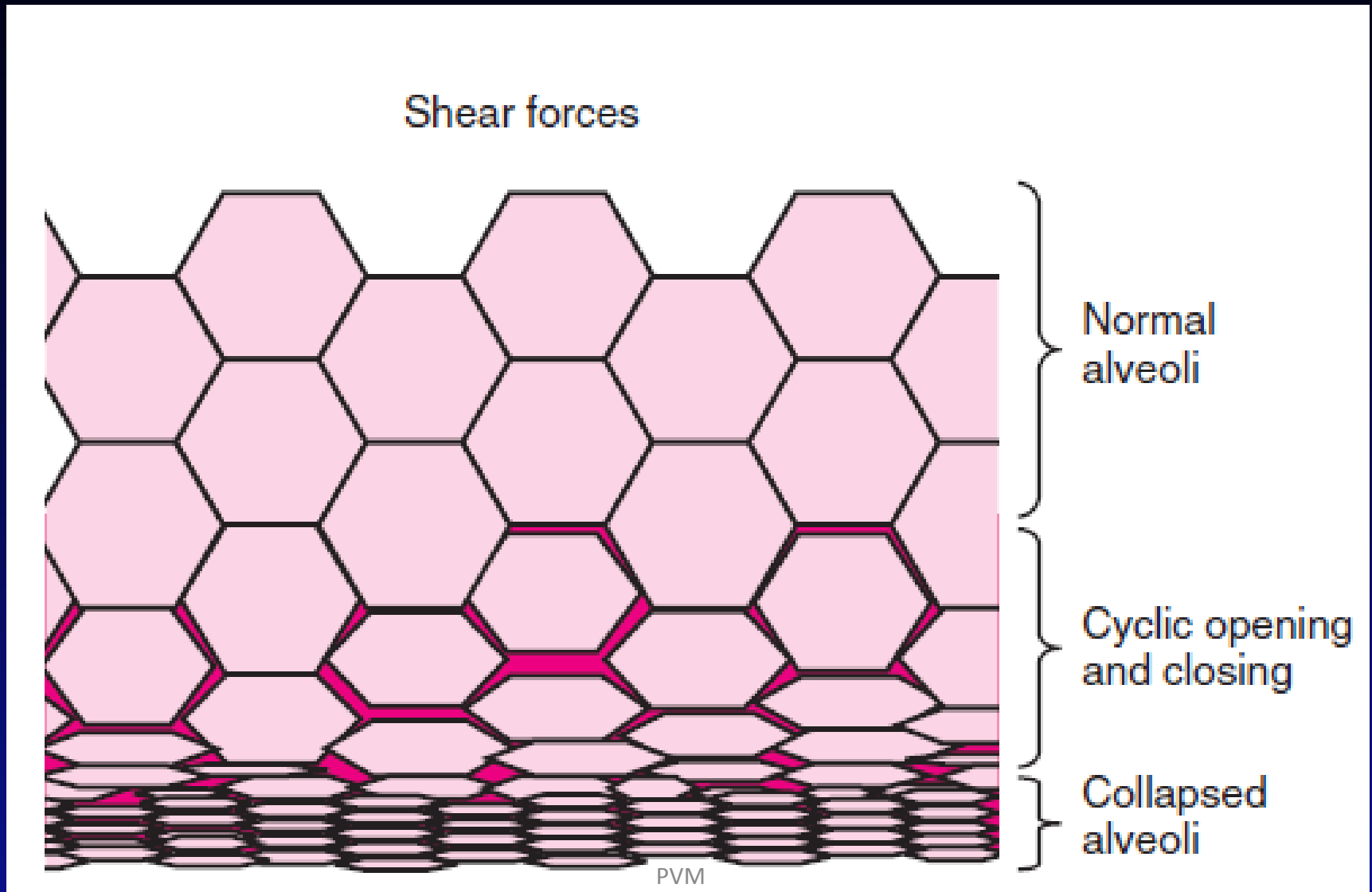
- Ateletrauma nas áreas colapsadas
- Diminuição da complacência
- Volutrauma e barotrauma nas regiões não colapsadas
- Hipoxemia
- Aumento da RVP



INFLAMAÇÃO



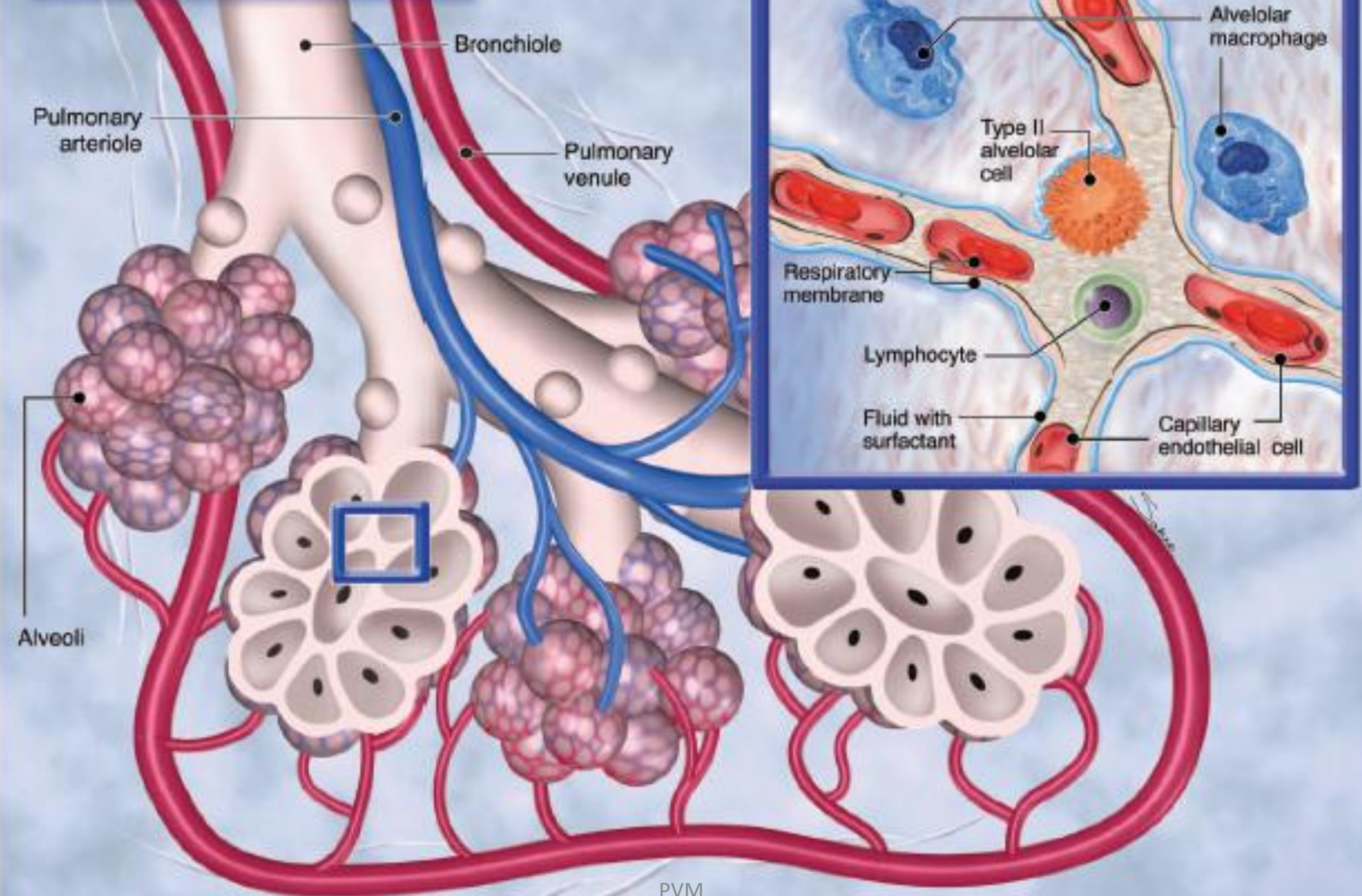
Atelectasia induzida pela VM

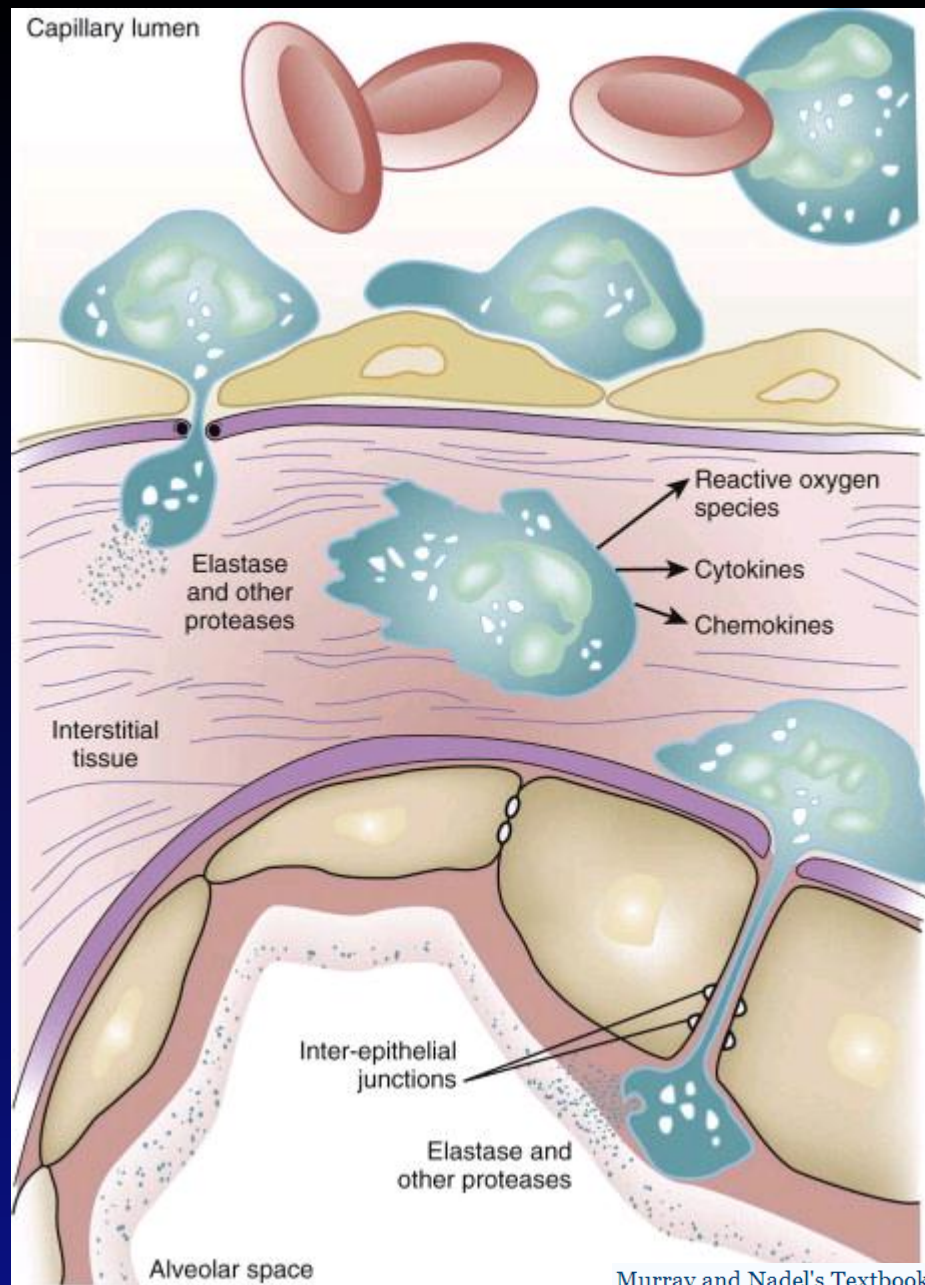


Mecanismos da Disfunção Pulmonar

- 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 importante que os níveis de pressão

A Normal Lung





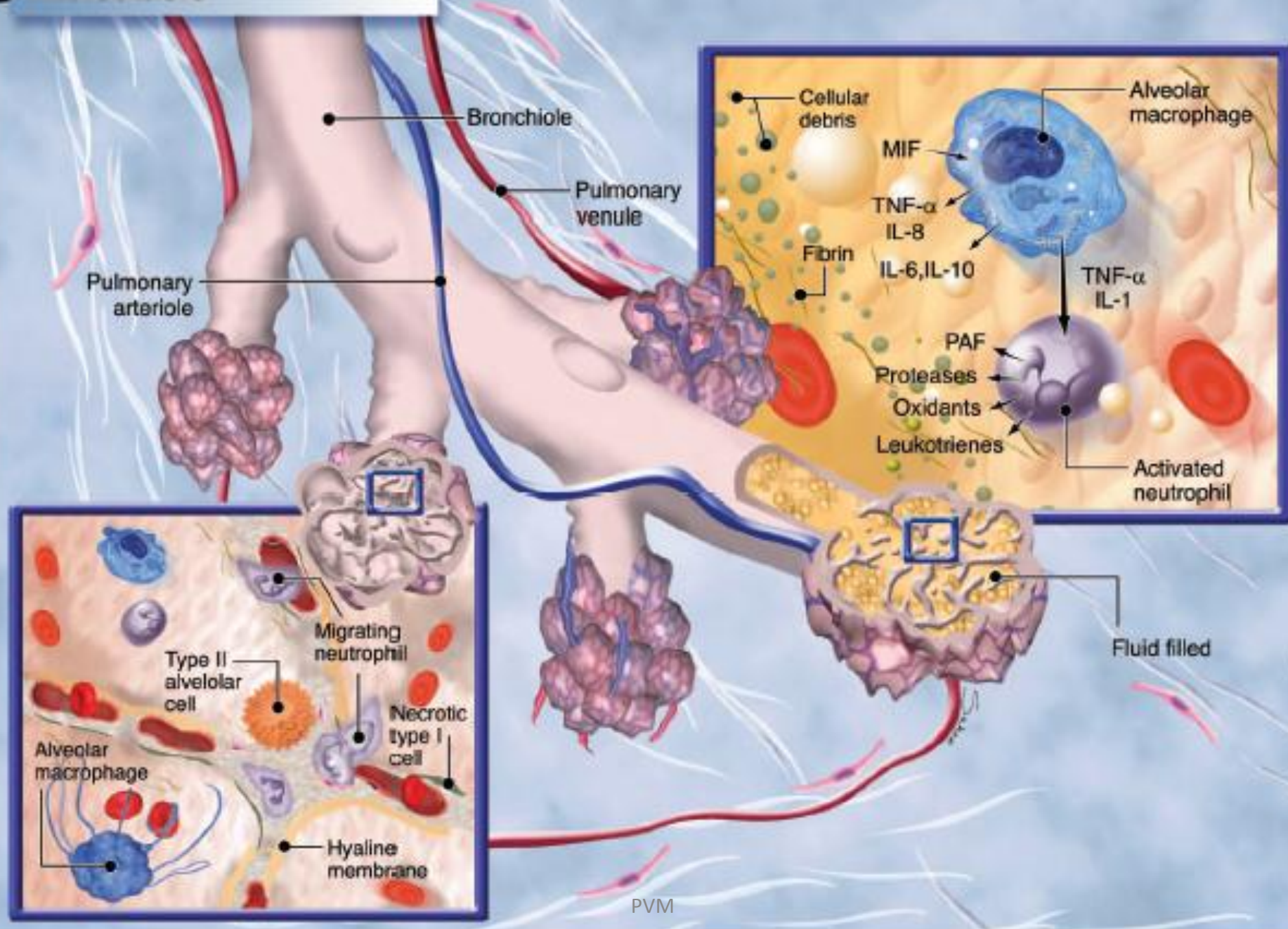
Murray and Nadel's Textbook of Respiratory Medicine , Fifth Edition

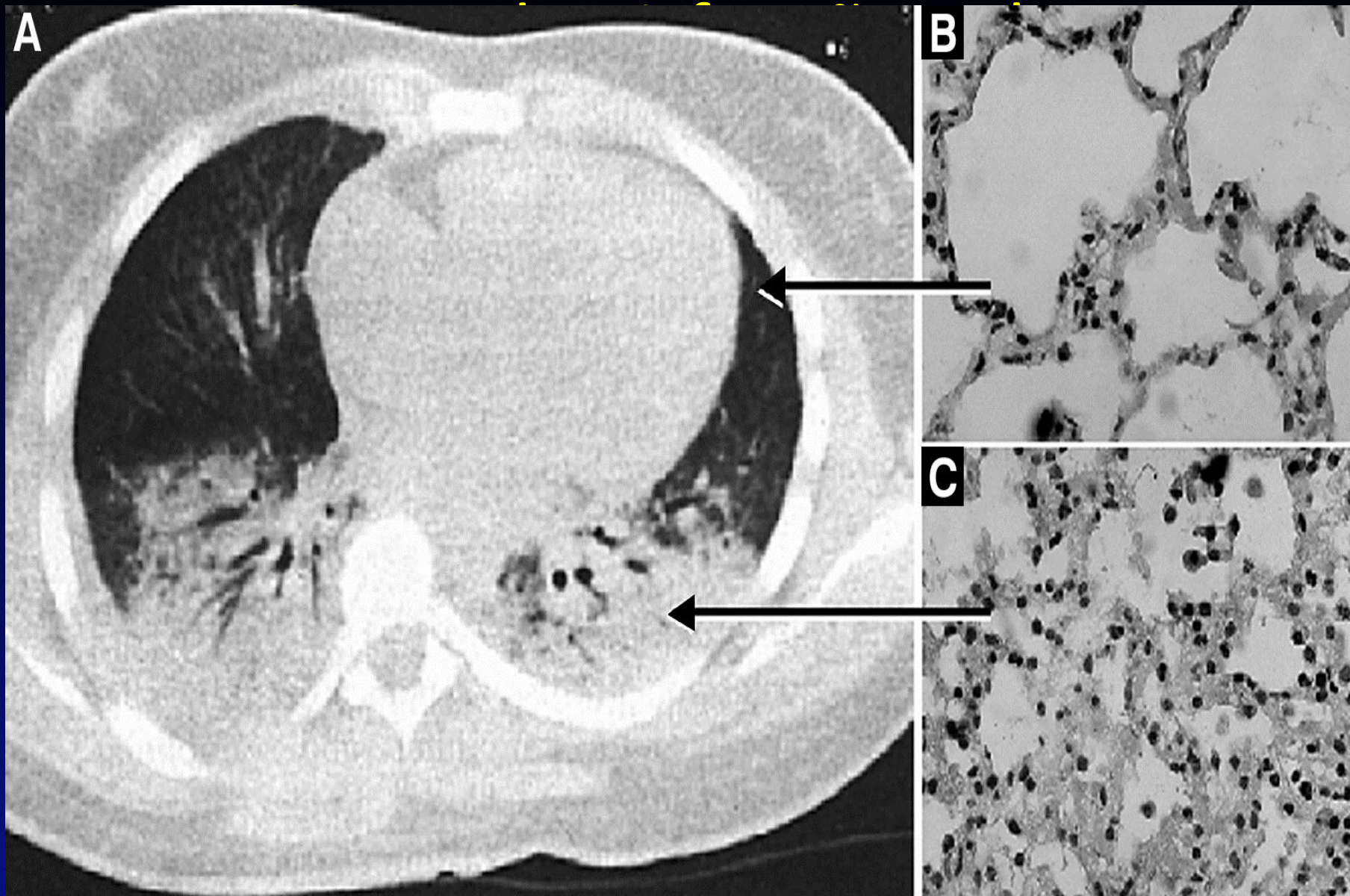
Robert J. Mason, V. Courtney Broaddus, Thomas R. Martin, Talmadge E. King, Dean E. Schraufnagel, John F. Murray, and Jay A. Nadel

Chapter 90, 2104-2129

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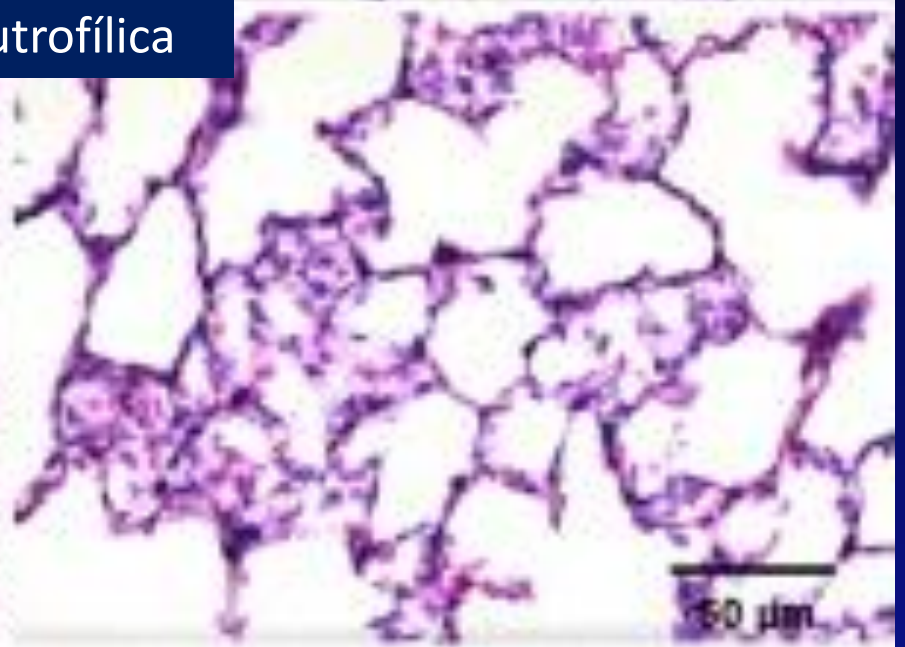
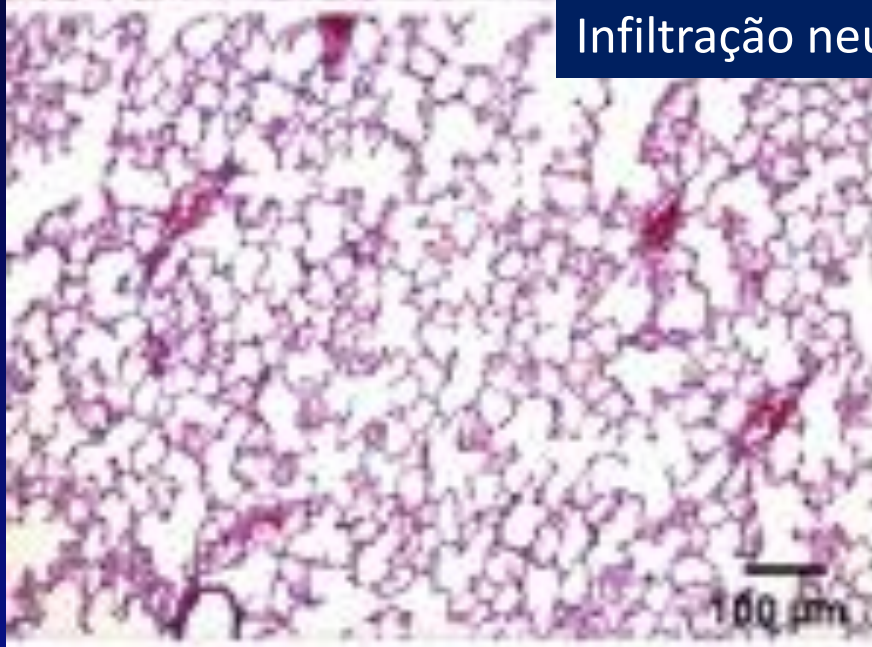
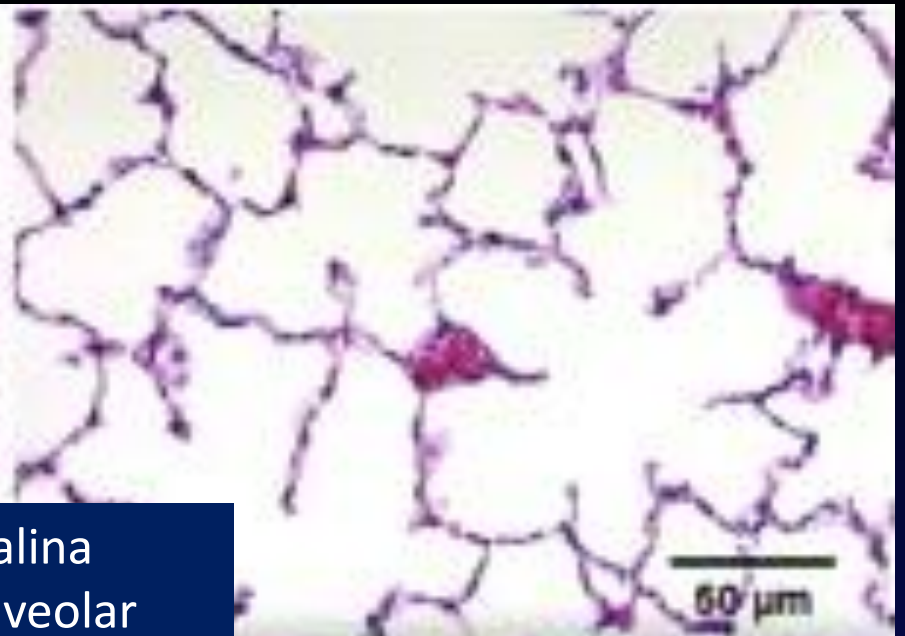
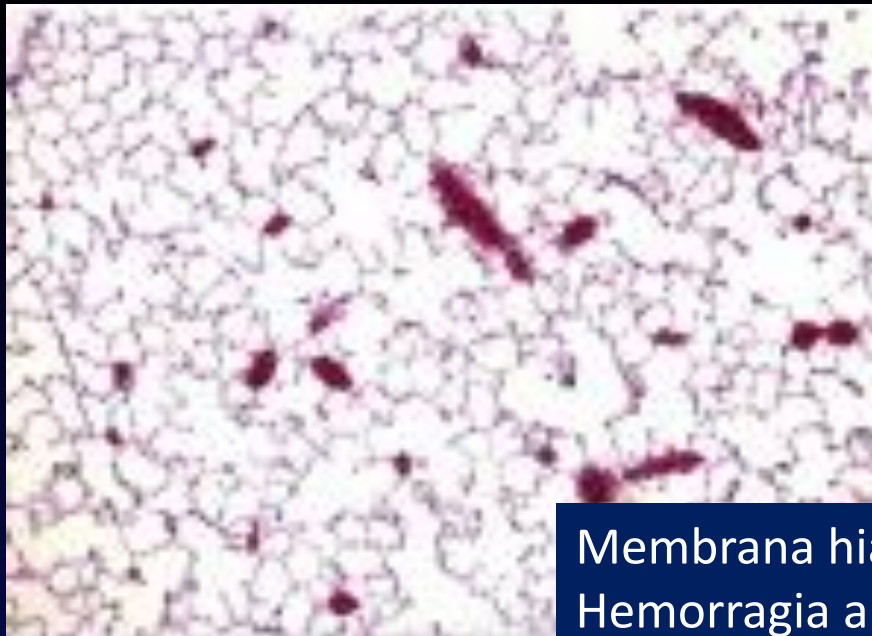
B Atelectasis

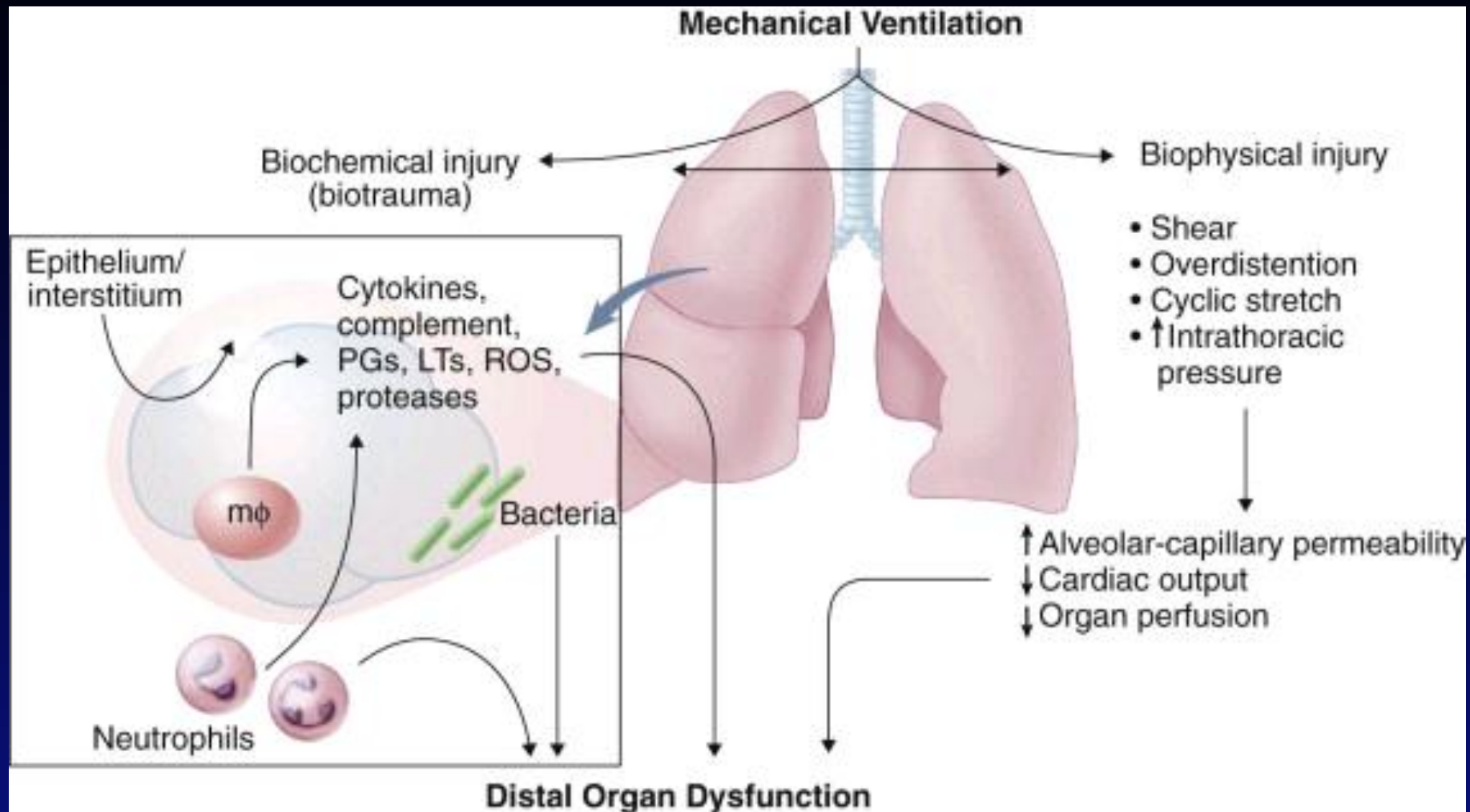




PVM

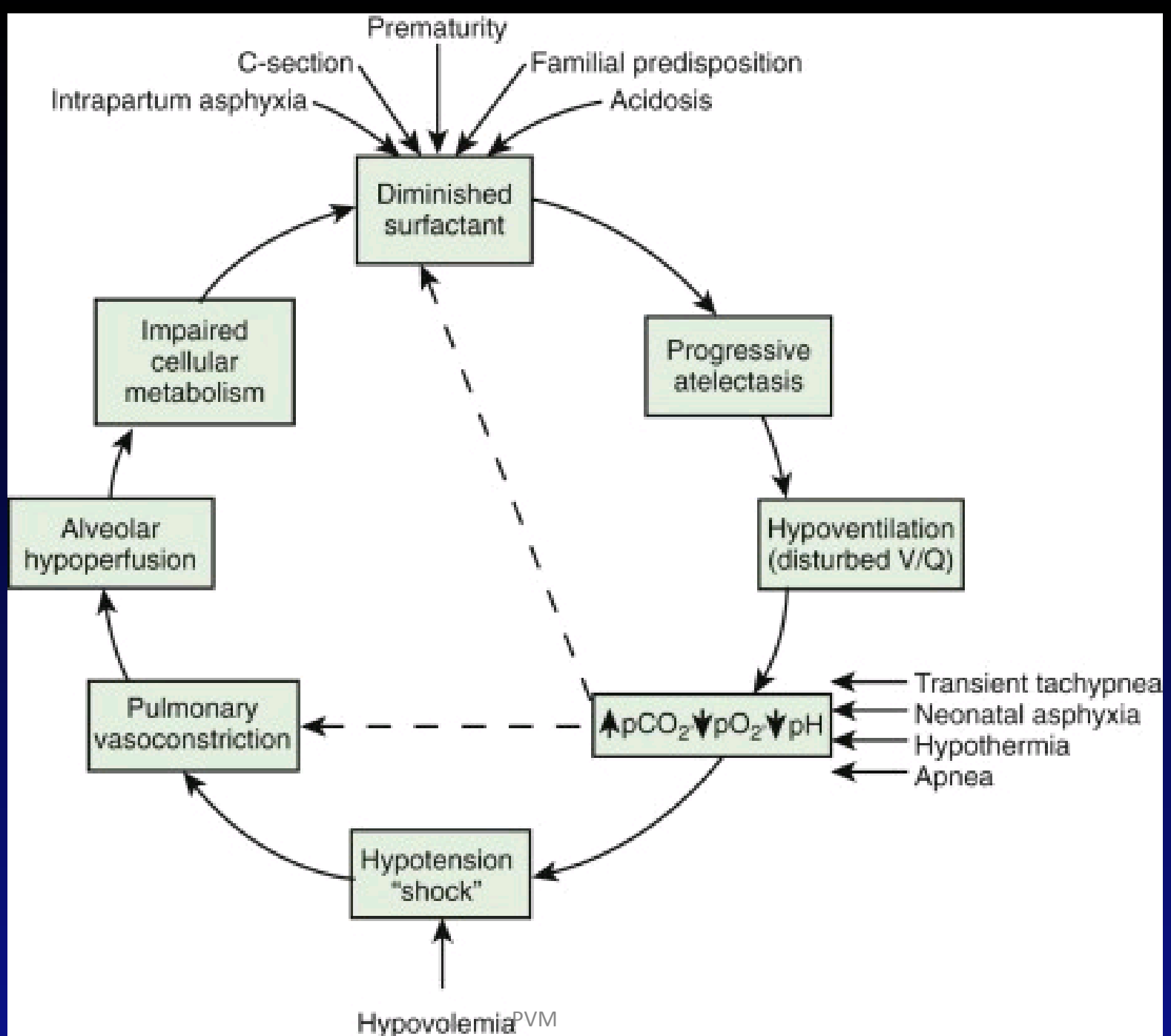
Membrana hialina
Hemorragia alveolar
Infiltração neutrofílica

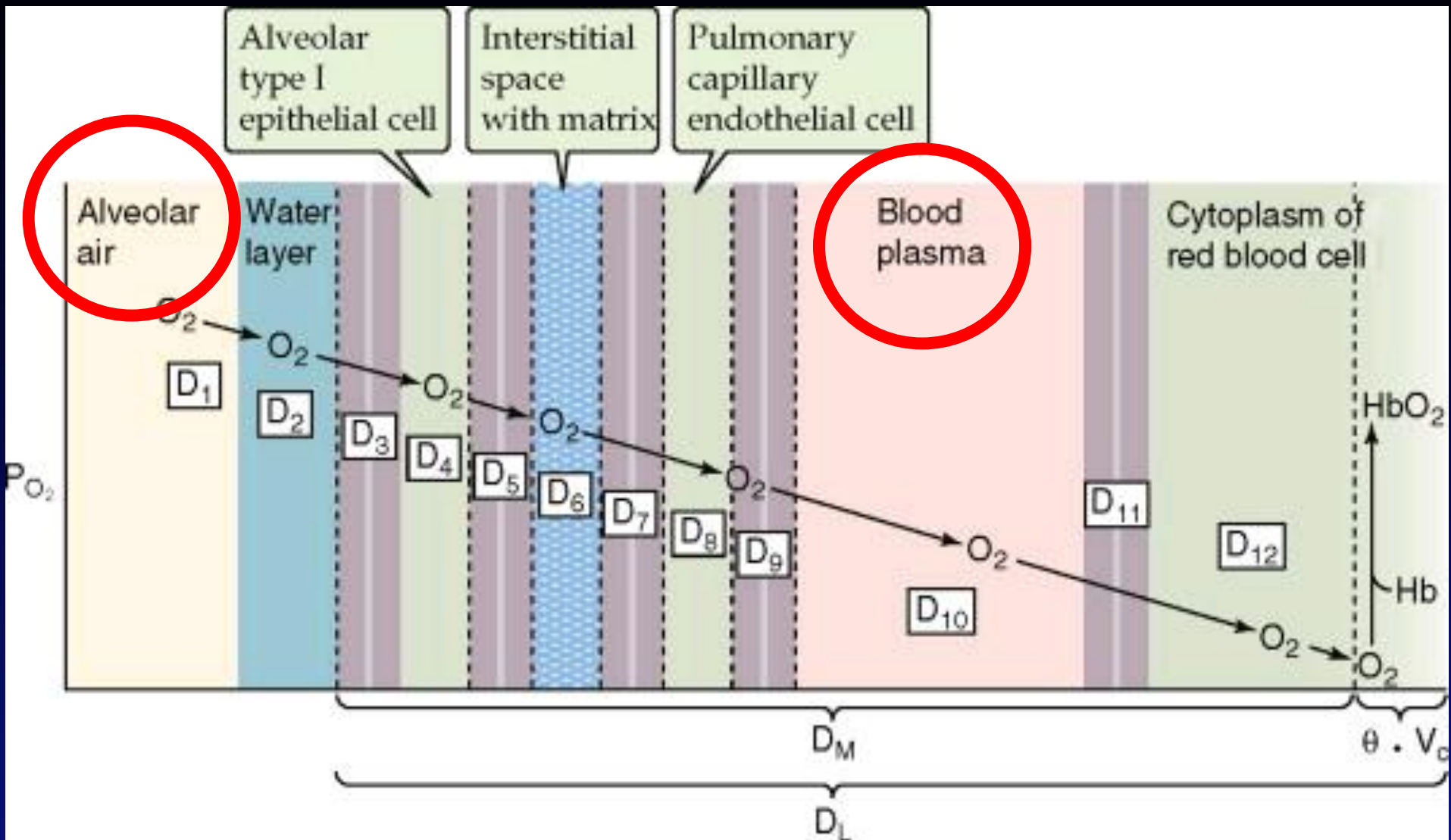




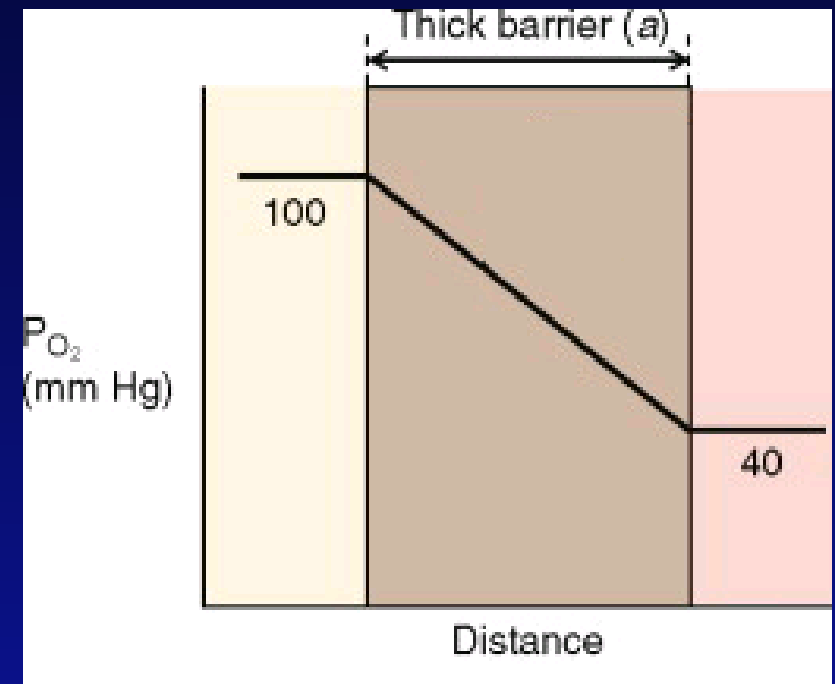
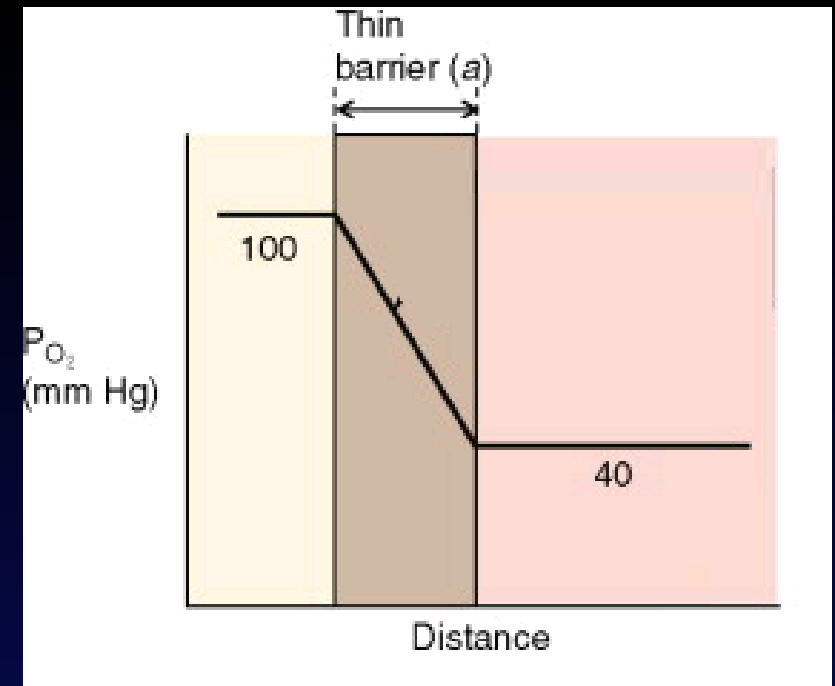
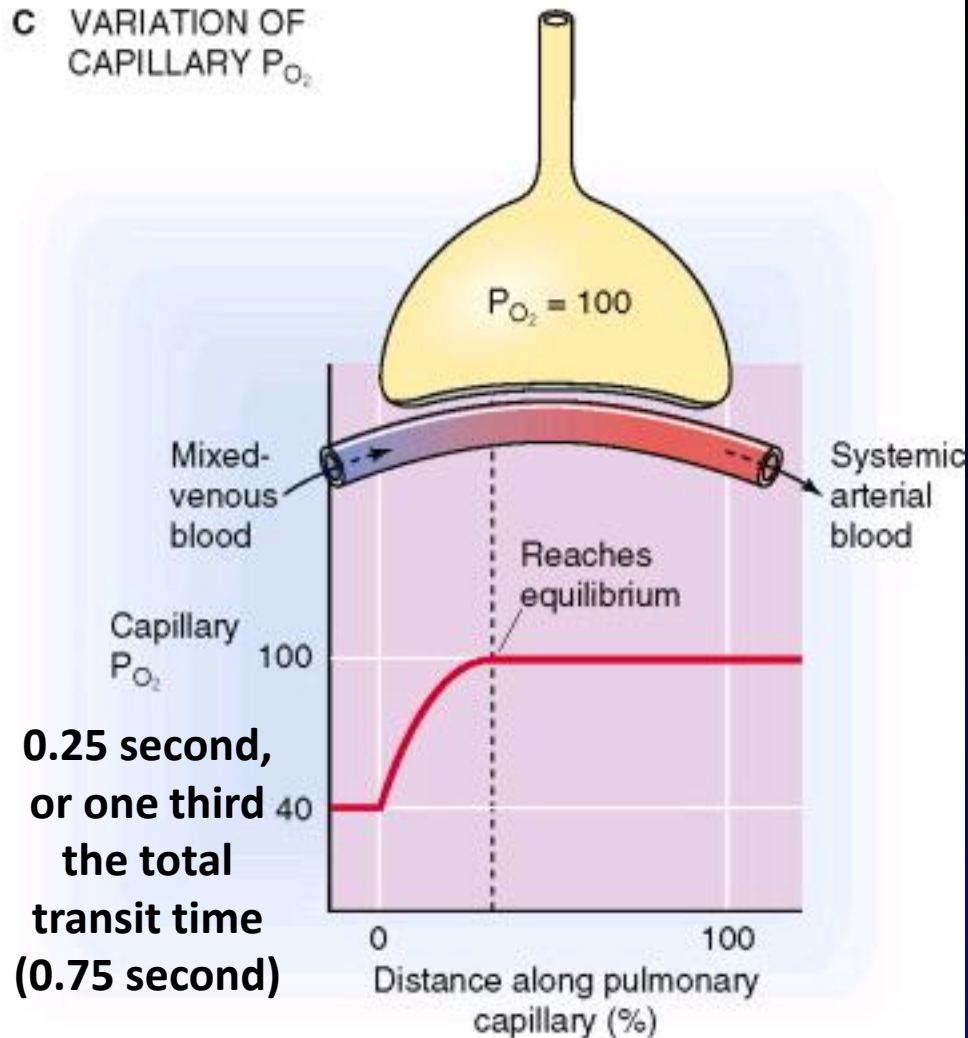
Goldman's Cecil Medicine , Twenty-Fourth Edition

Lee Goldman, and Andrew I. Schafer





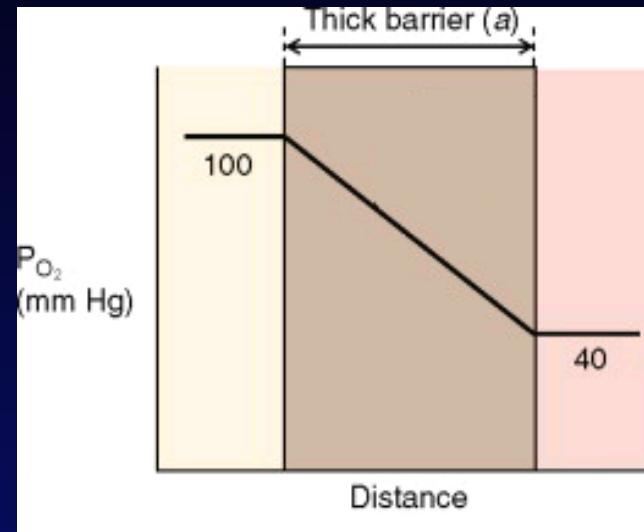
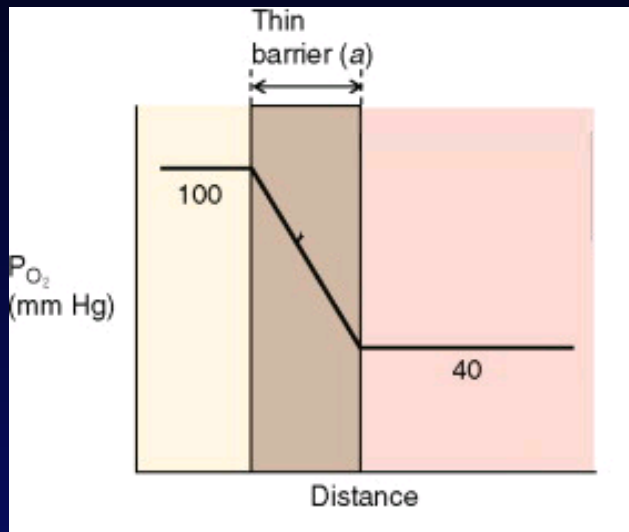
C VARIATION OF CAPILLARY P_{O_2}



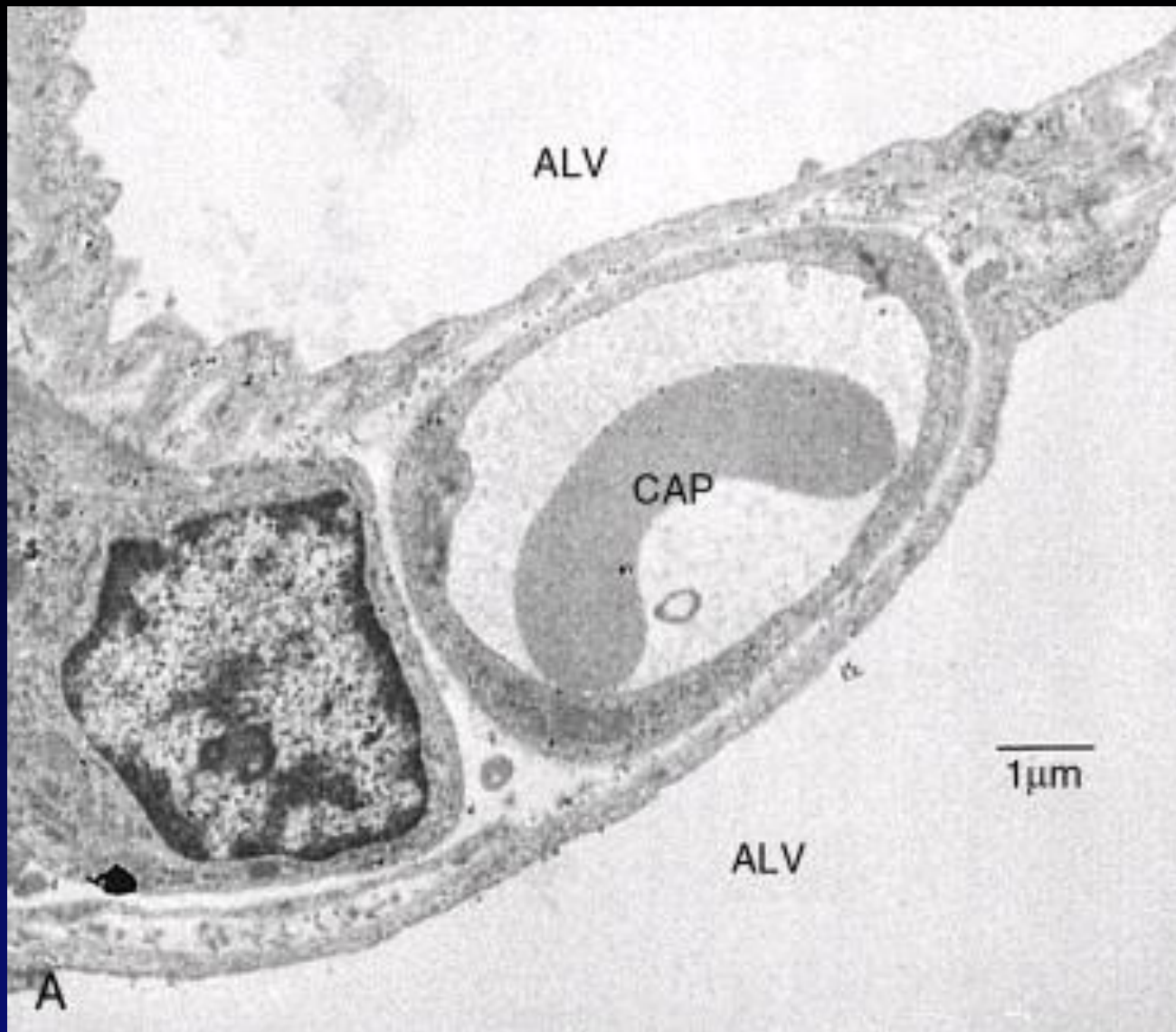
Medical Physiology , Updated Second Edition

Walter F. Boron, and Emile L. Boulpaep
CHAPTER 30, 685-699

Inflamação

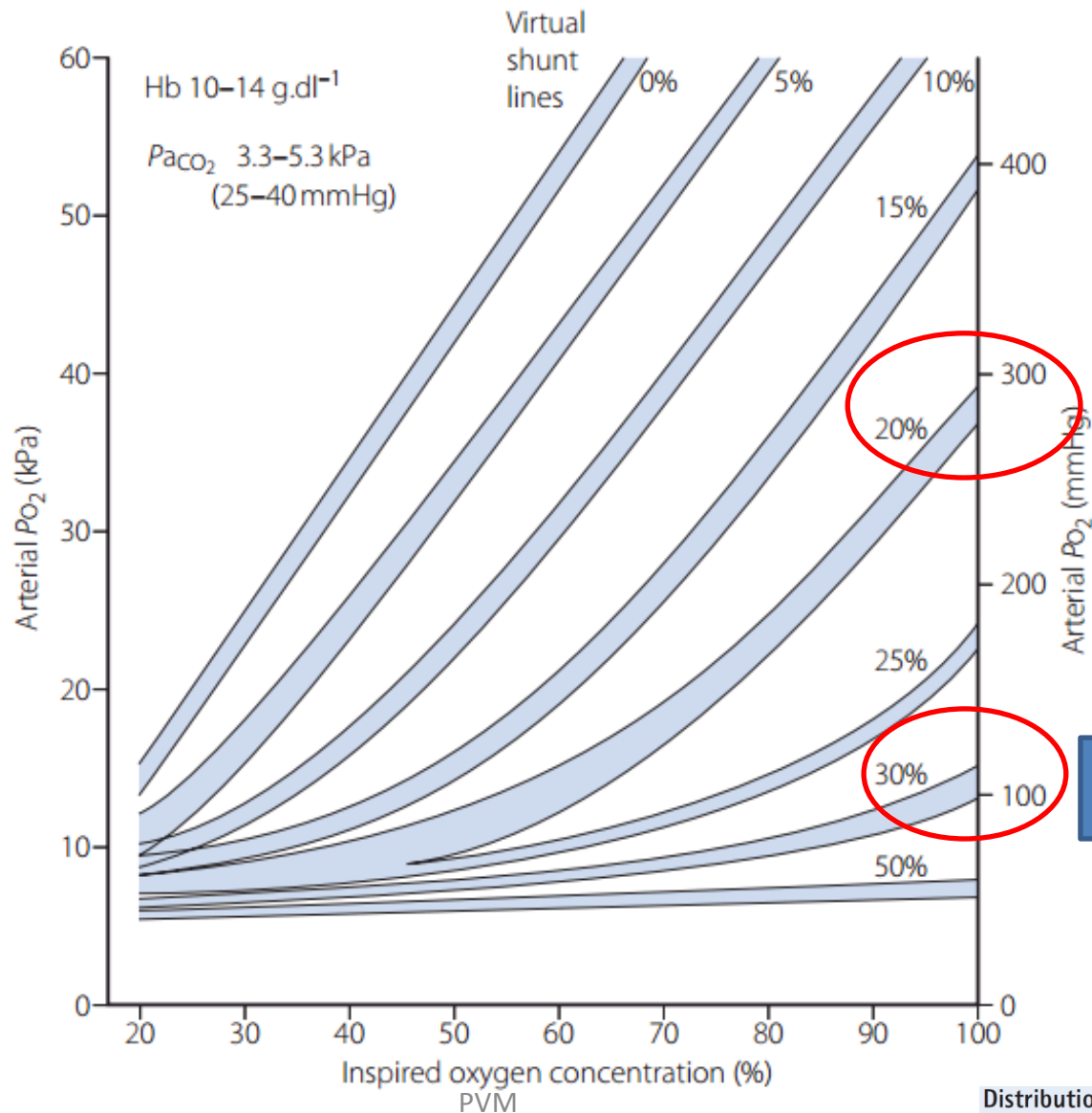


- Peep, FiO_2 , I/E, Aumentar fluxo, Pausa Ins.



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

Distribution of pulmonary ventilation and perfusion

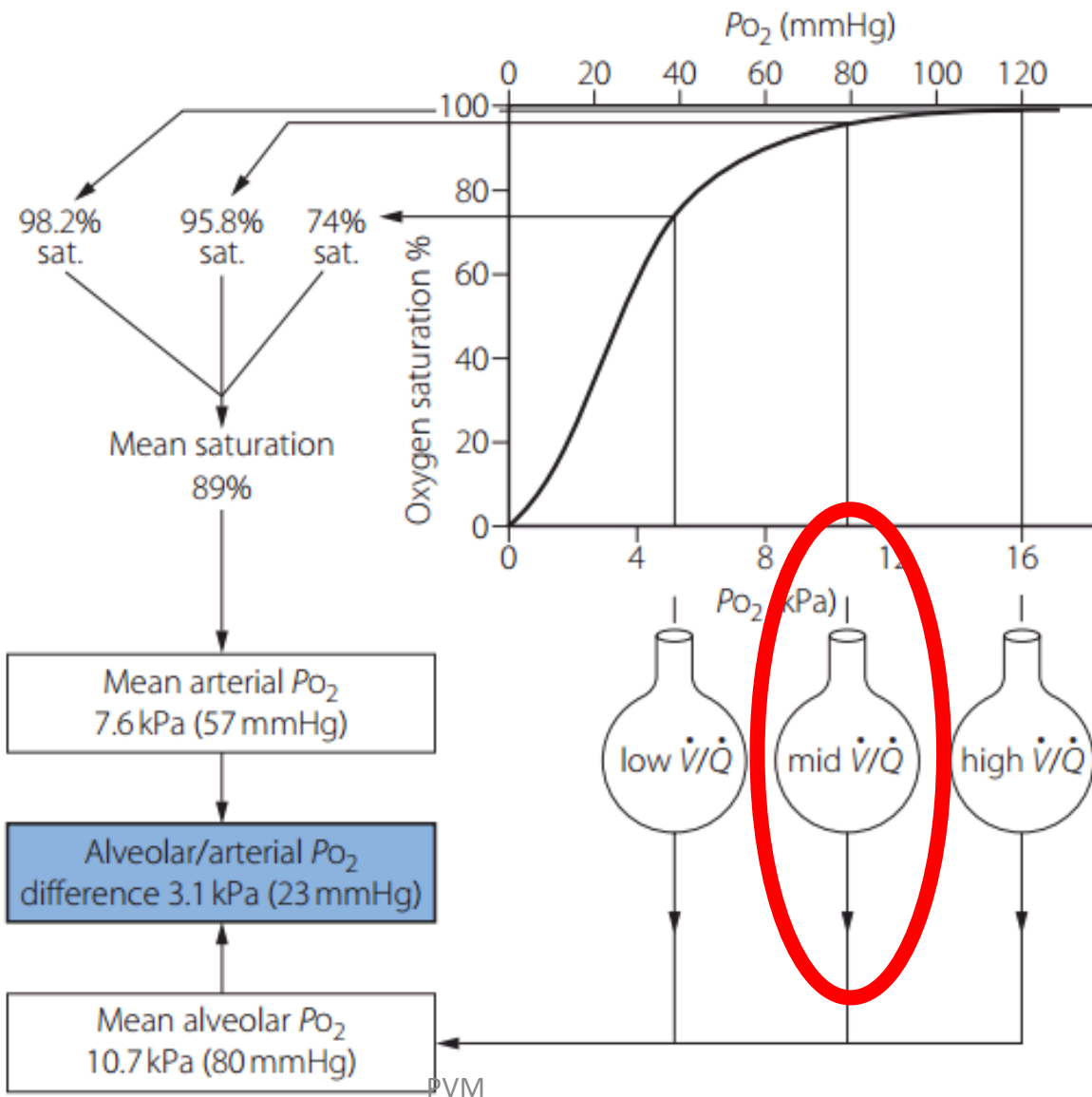


P/F = 285

P/F = 100

Distribution of pulmonary ventilation and perfusion

Distribution of pulmonary ventilation and perfusion

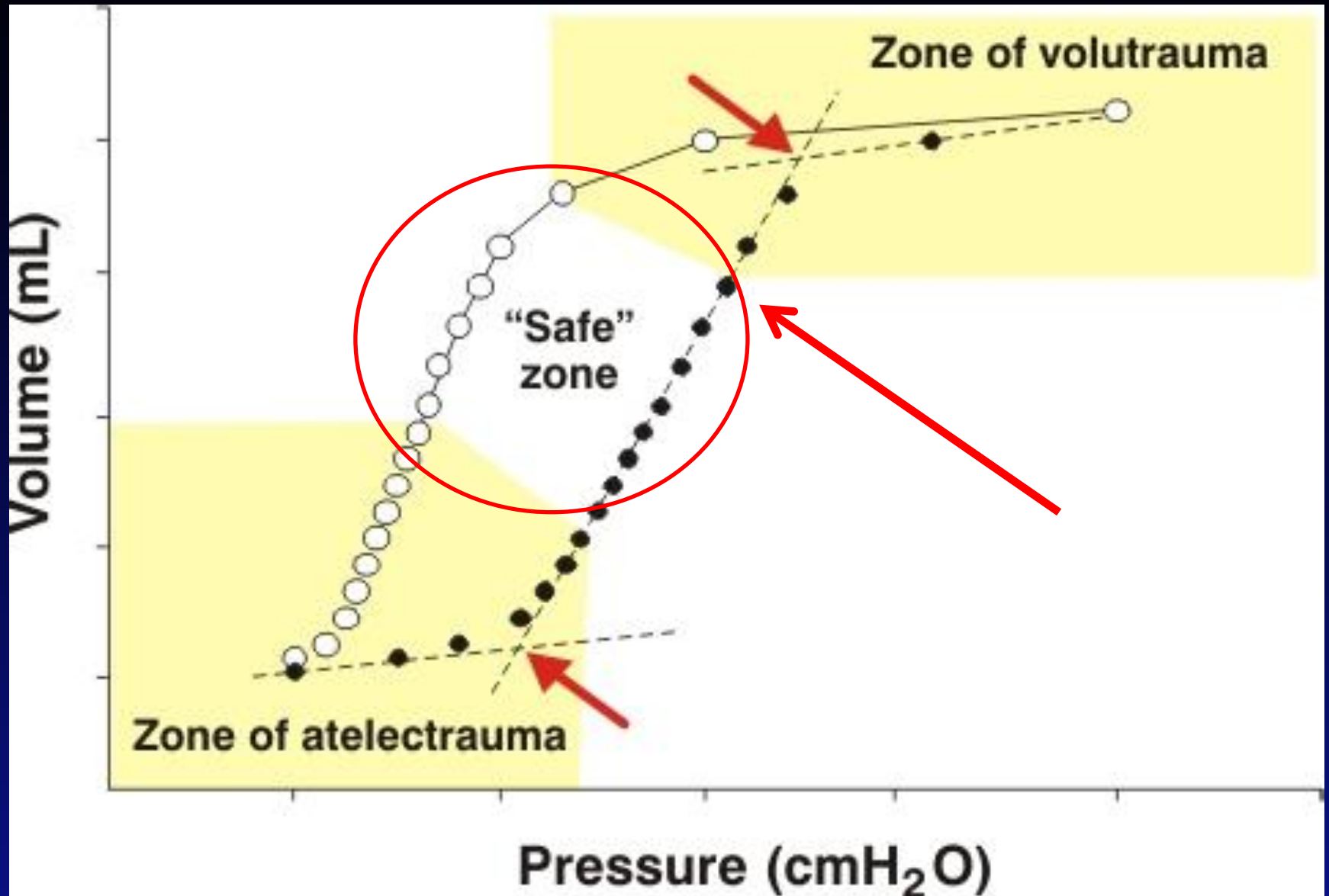


Abordagem da Disfunção Pulmonar

PEEP IDEAL

+

PARÂMETROS MÍNIMOS DE
VENTILAÇÃO

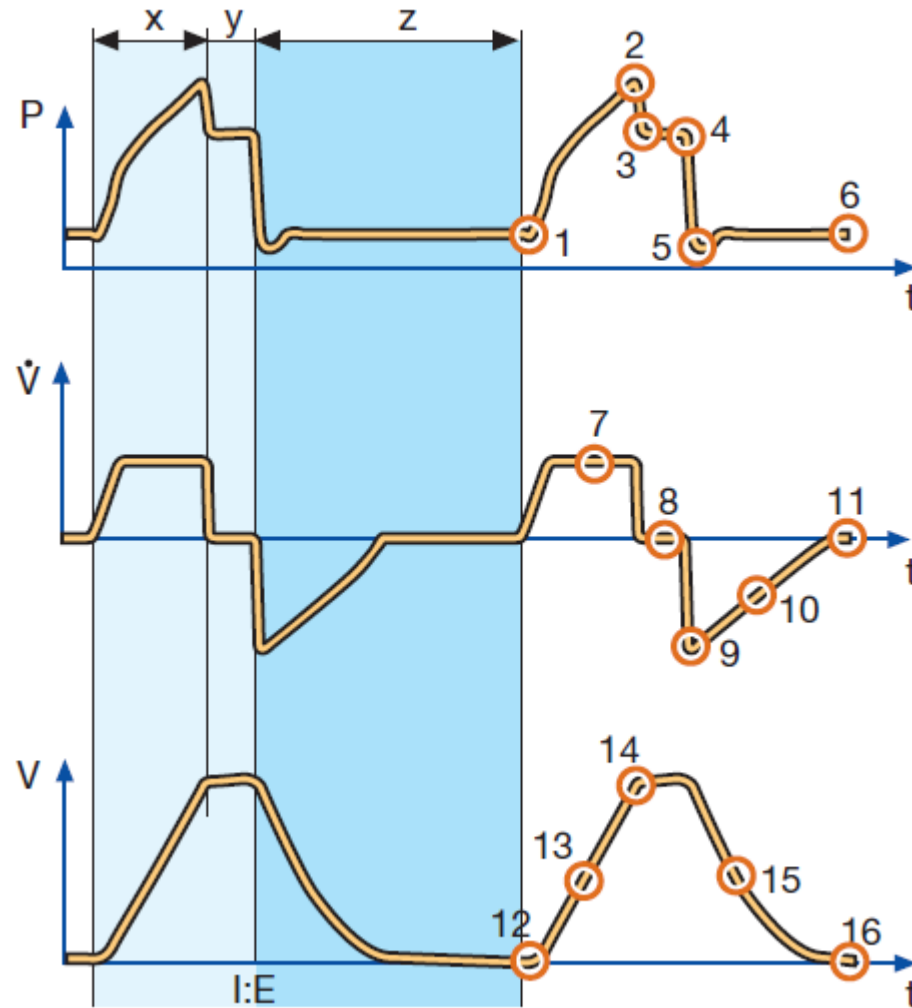


Objetivos da VM

- 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 injúria pulmonar

Volume corrente, FR, I:E

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



Fluxo: calculado baseado no V_t e no tempo inspiratório.

Ciclo a volume

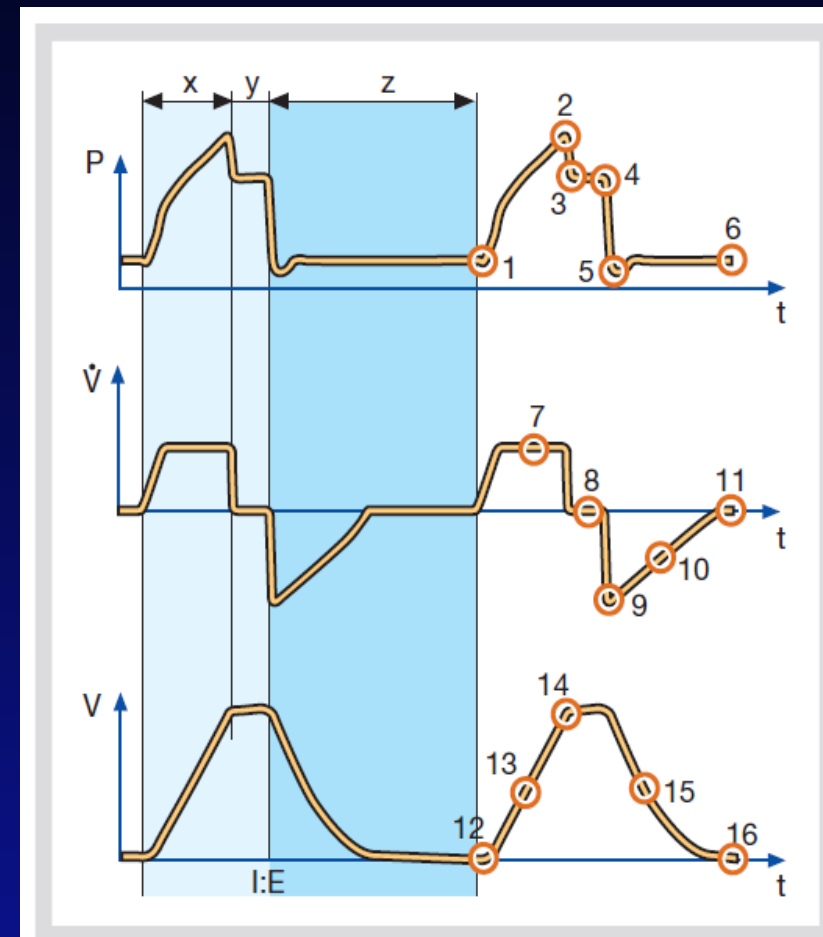
- Ex: FR 10; I:E 1:2; Vt 500ml

60segundos:10= 6segundos/ciclo

I:E 1:2 2:4

500ml/2= 150ml/s

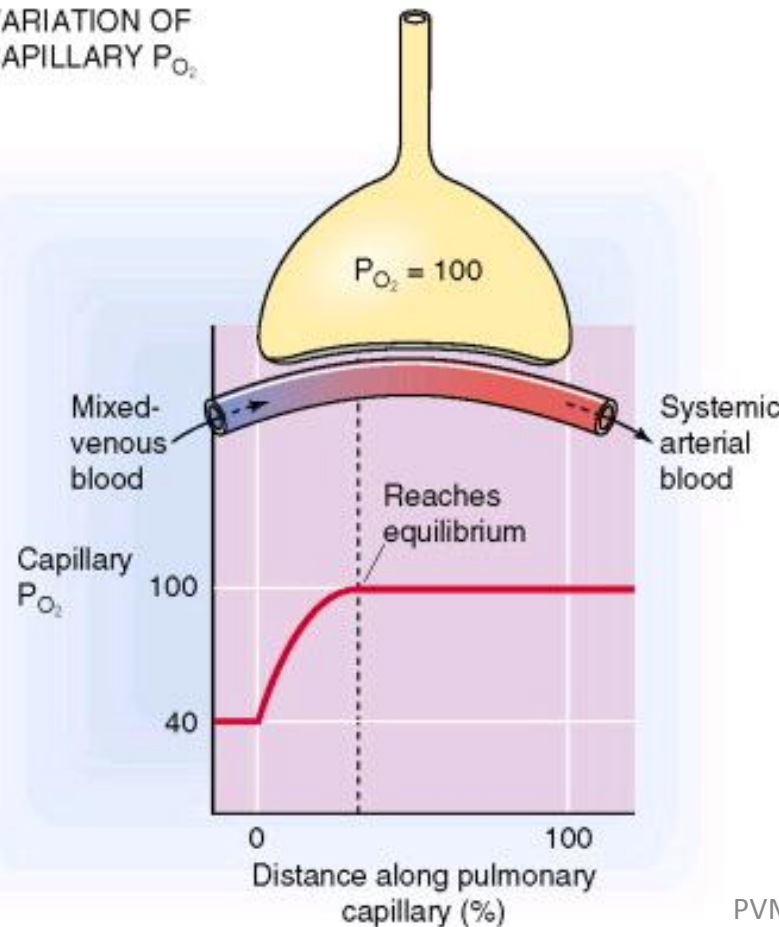
50%de pausa: 500ml/1s= 500ml/s



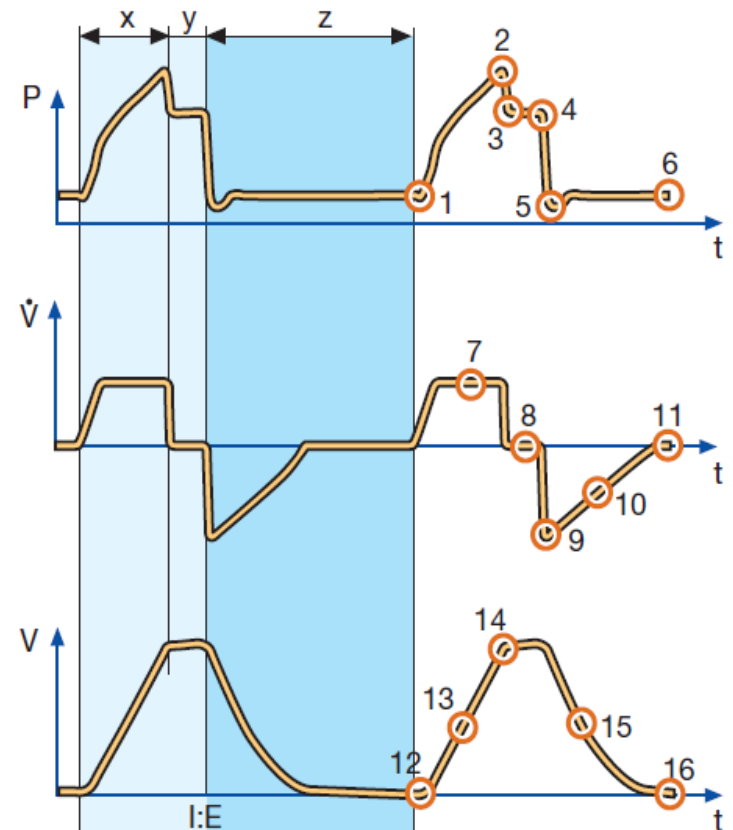
Ciclo a volume

- Pausa inspiratória

C VARIATION OF CAPILLARY P_{O_2}



PVM



H2O

Pva



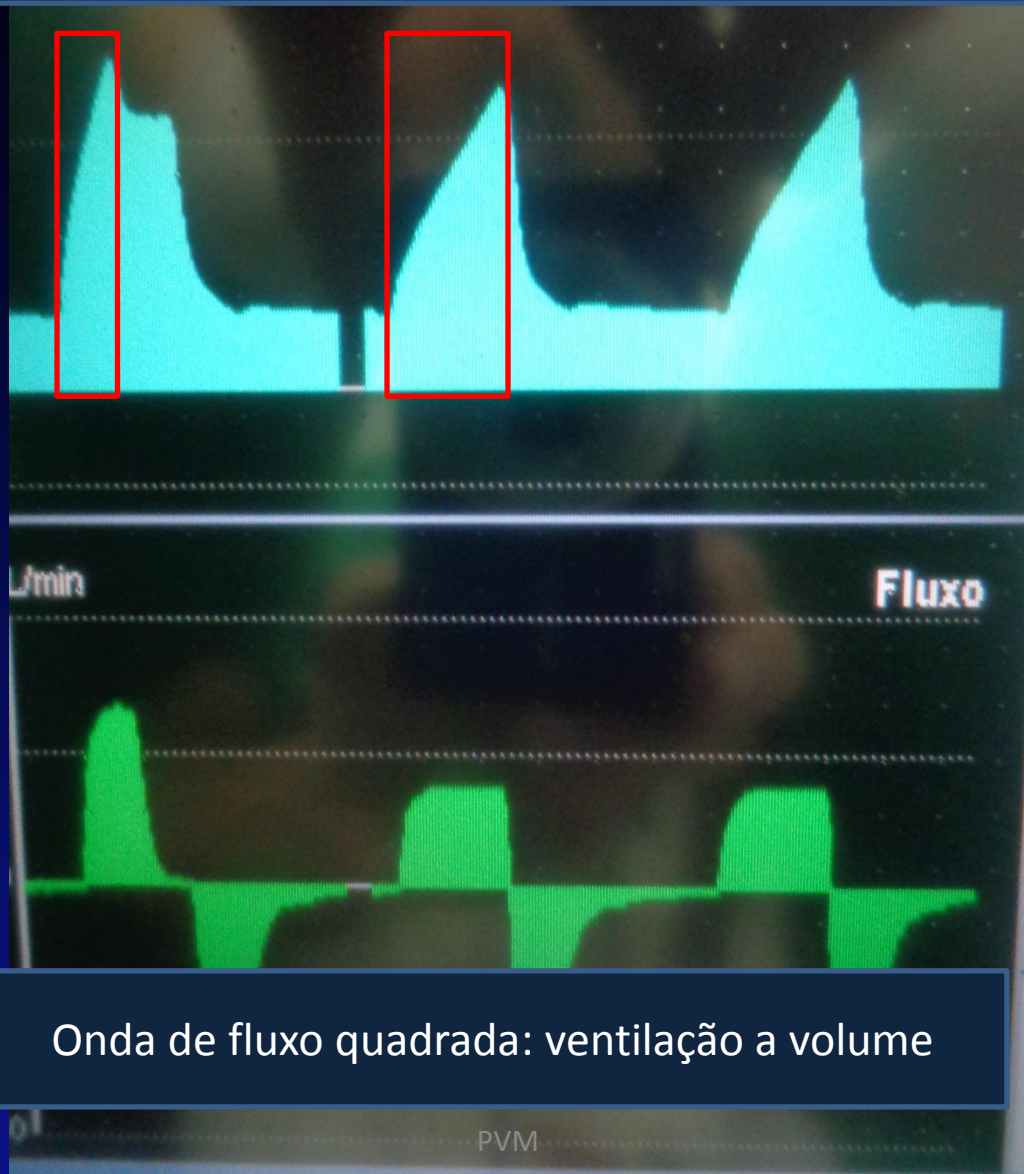
L/min

Fluxo



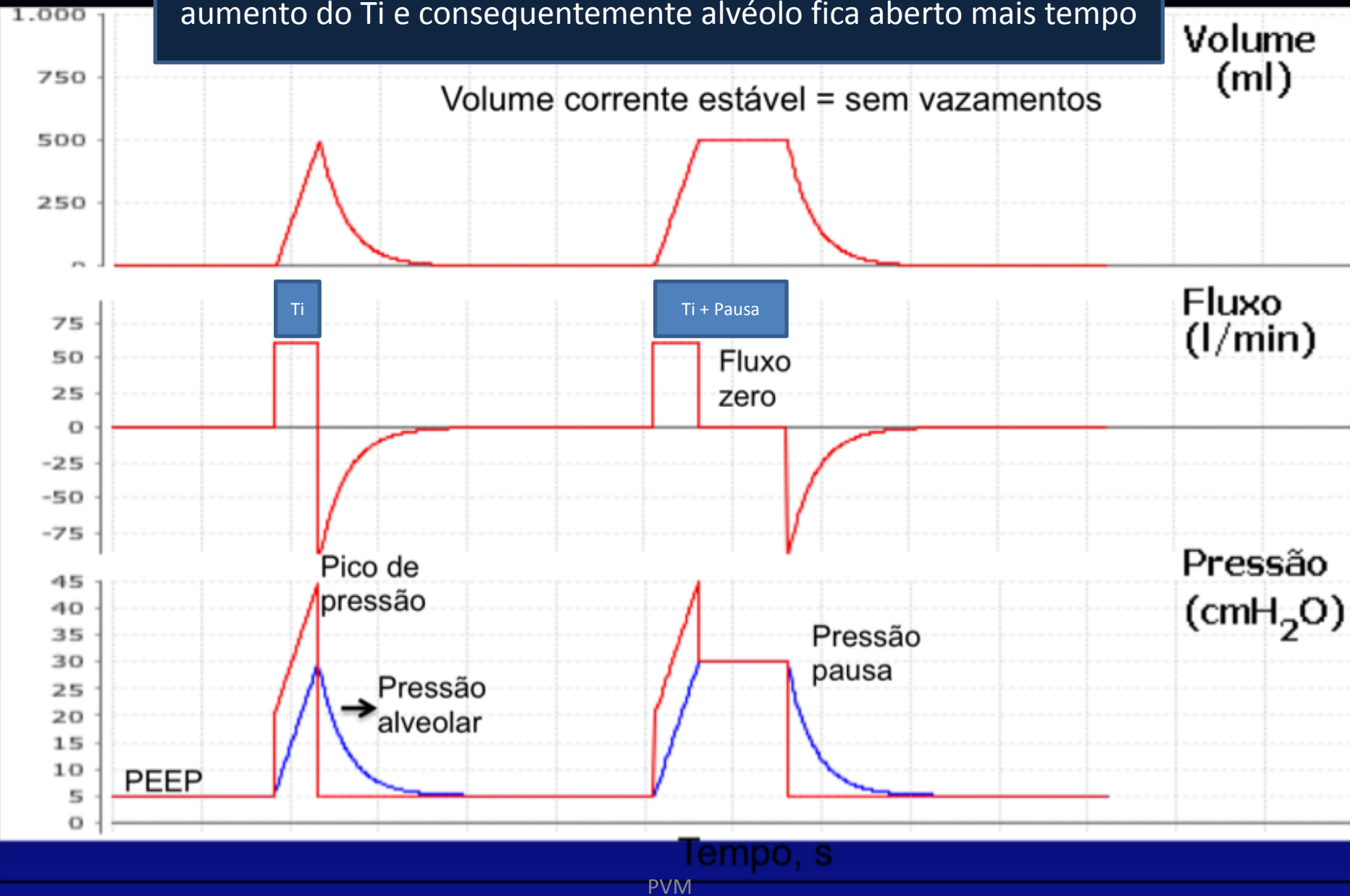
PVM

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

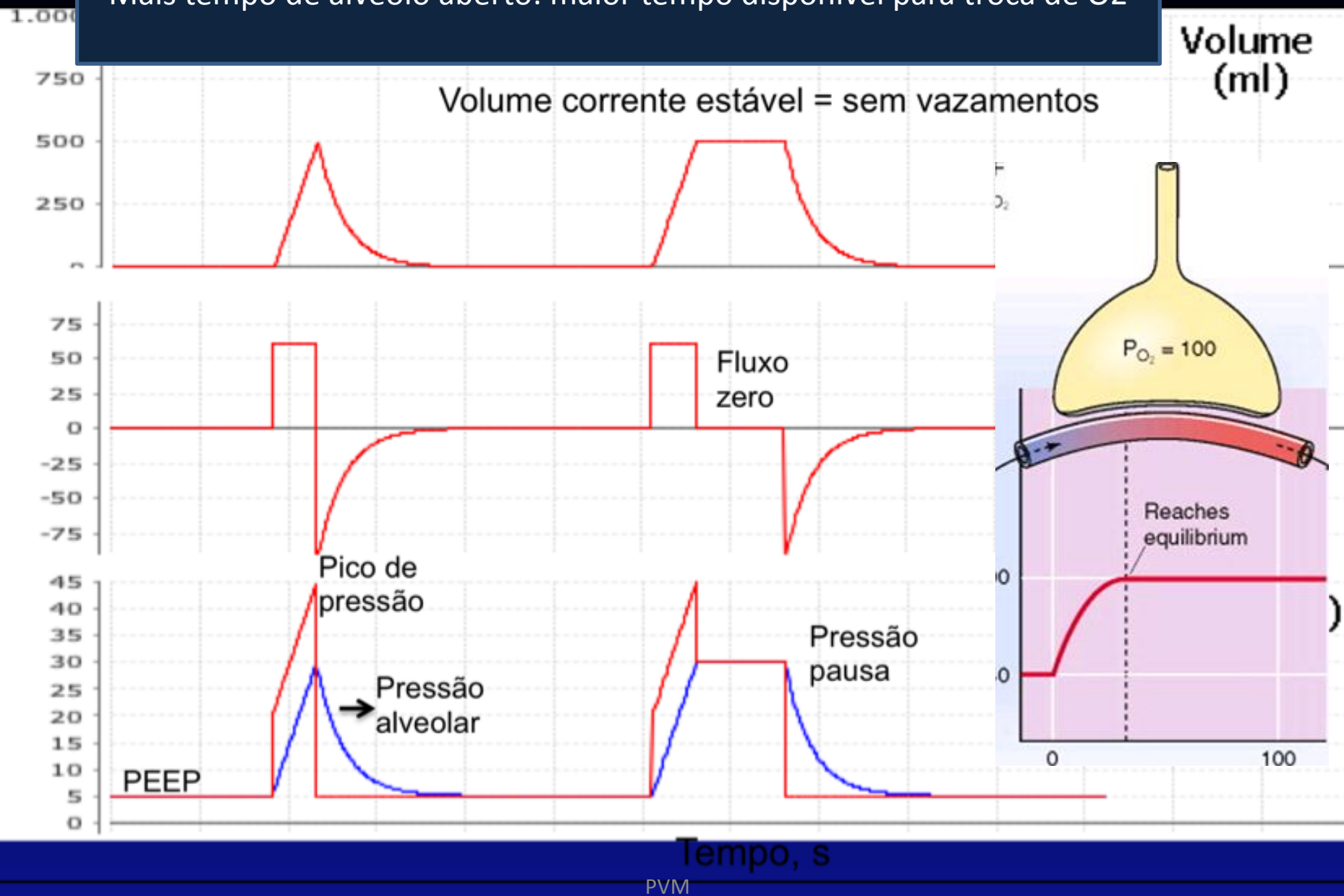


Onda de fluxo quadrada: ventilação a volume

Onda de fluxo quadrada: ciclo a volume. Pausa inspiratória: observe aumento do T_i 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

$$Raw = (P_{\text{pressão}} - P_{\text{pausa}}) / \text{Fluxo}$$

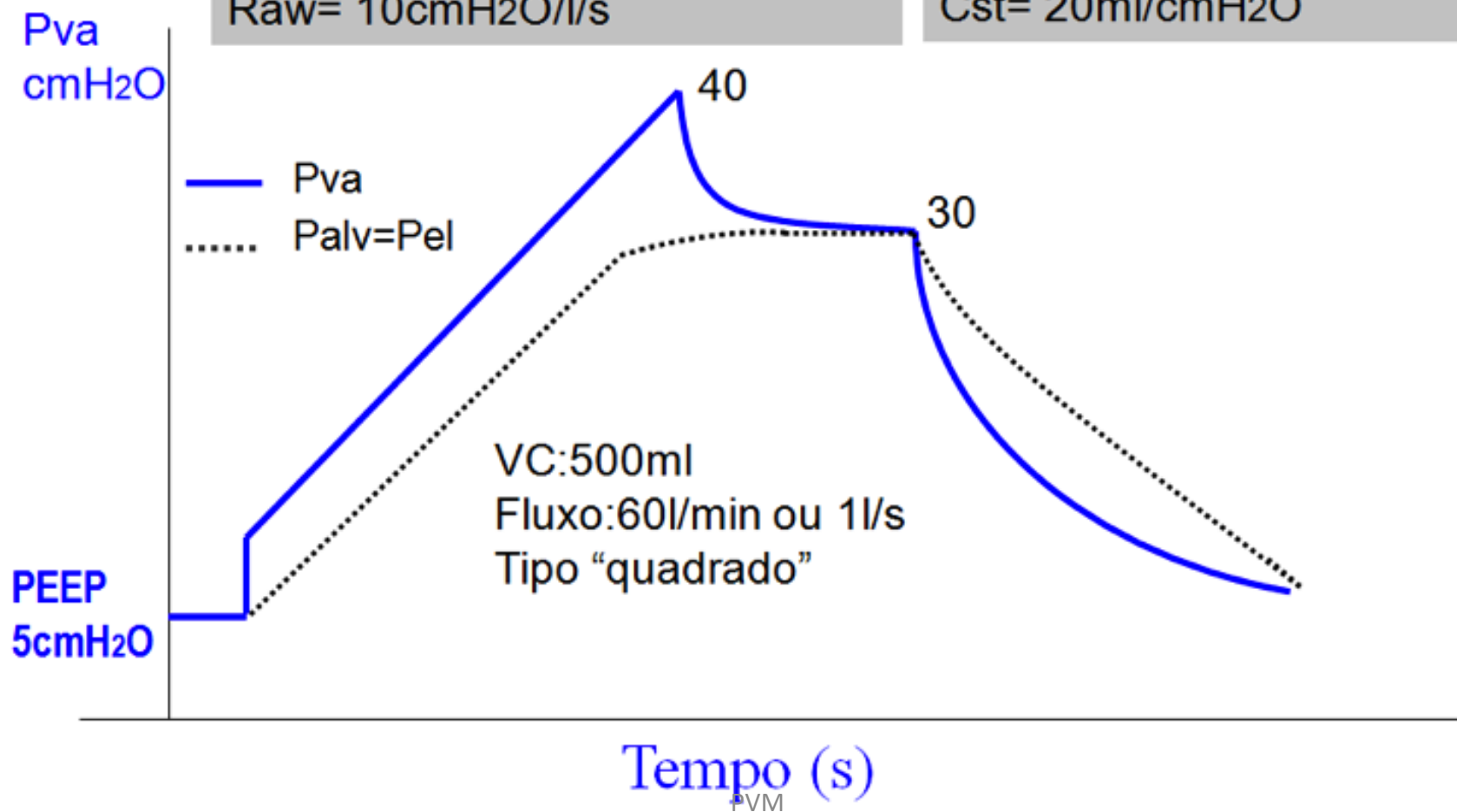
$$Raw = 40 - 30 / 1$$

$$Raw = 10 \text{ cmH}_2\text{O} / \text{l/s}$$

$$Cst = VC / (P_{\text{pausa}} - PEEP)$$

$$Cst = 500 / 30 - 5$$

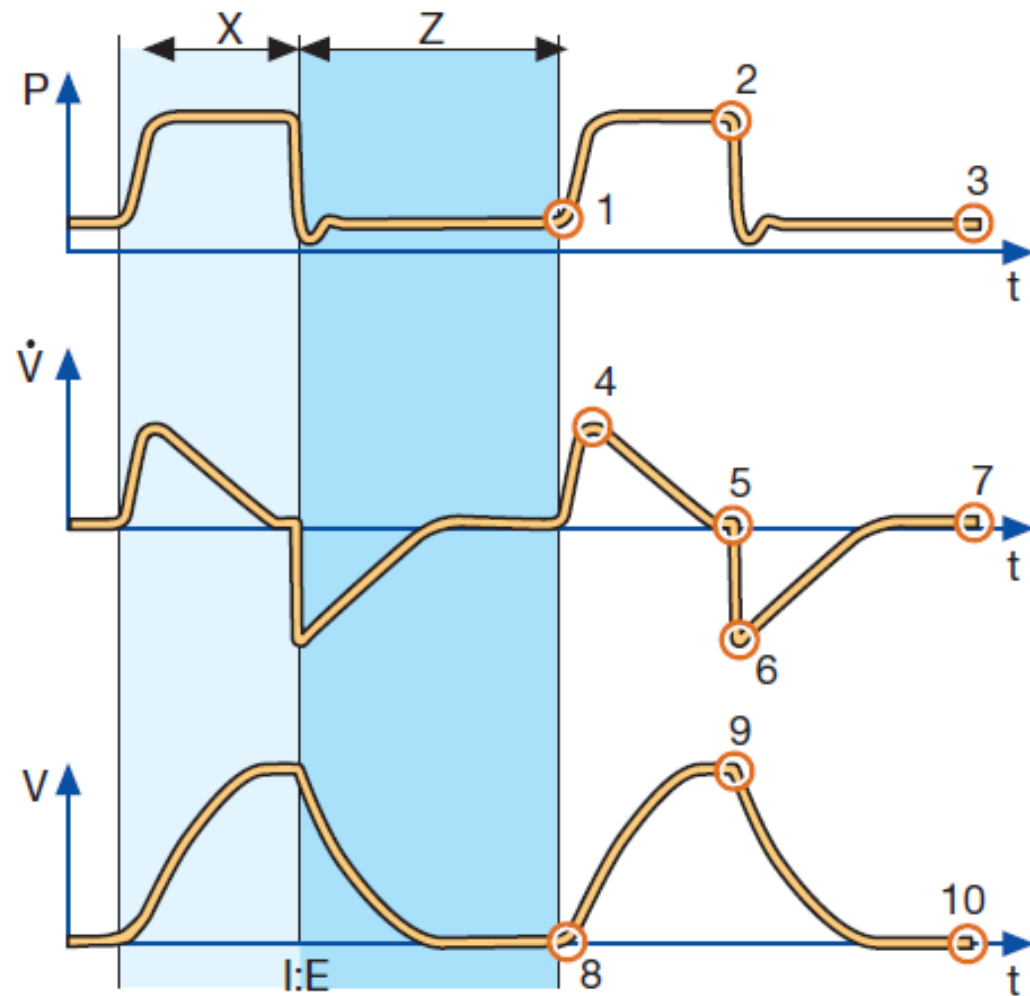
$$Cst = 20 \text{ ml/cmH}_2\text{O}$$



Pressão inspiratória, FR, I:E

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

Fluxo: descendente.

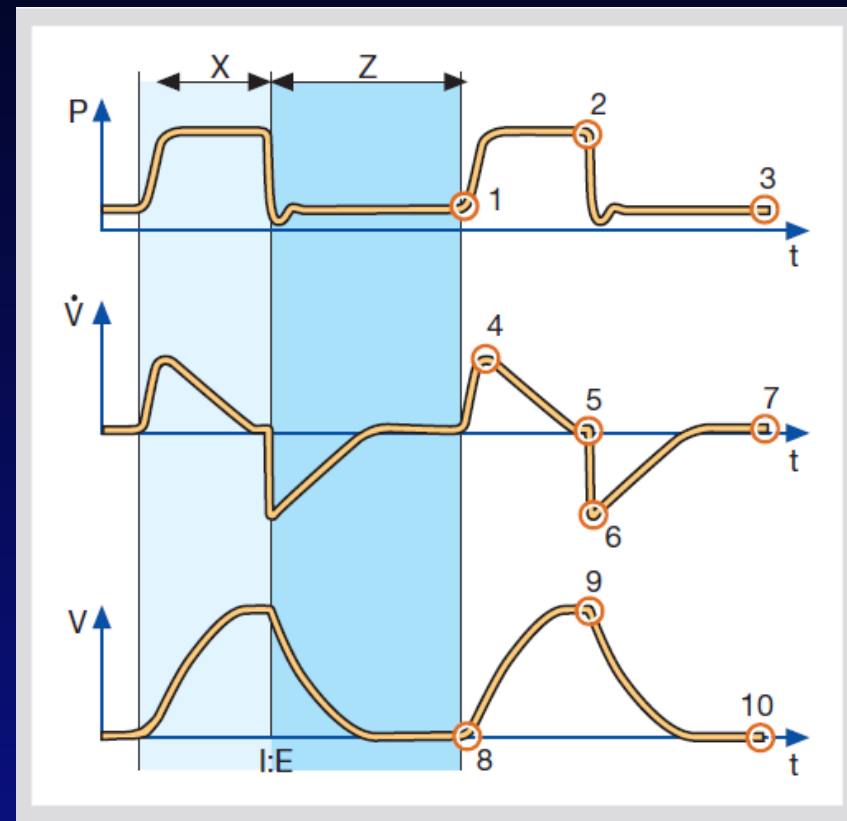


PVM

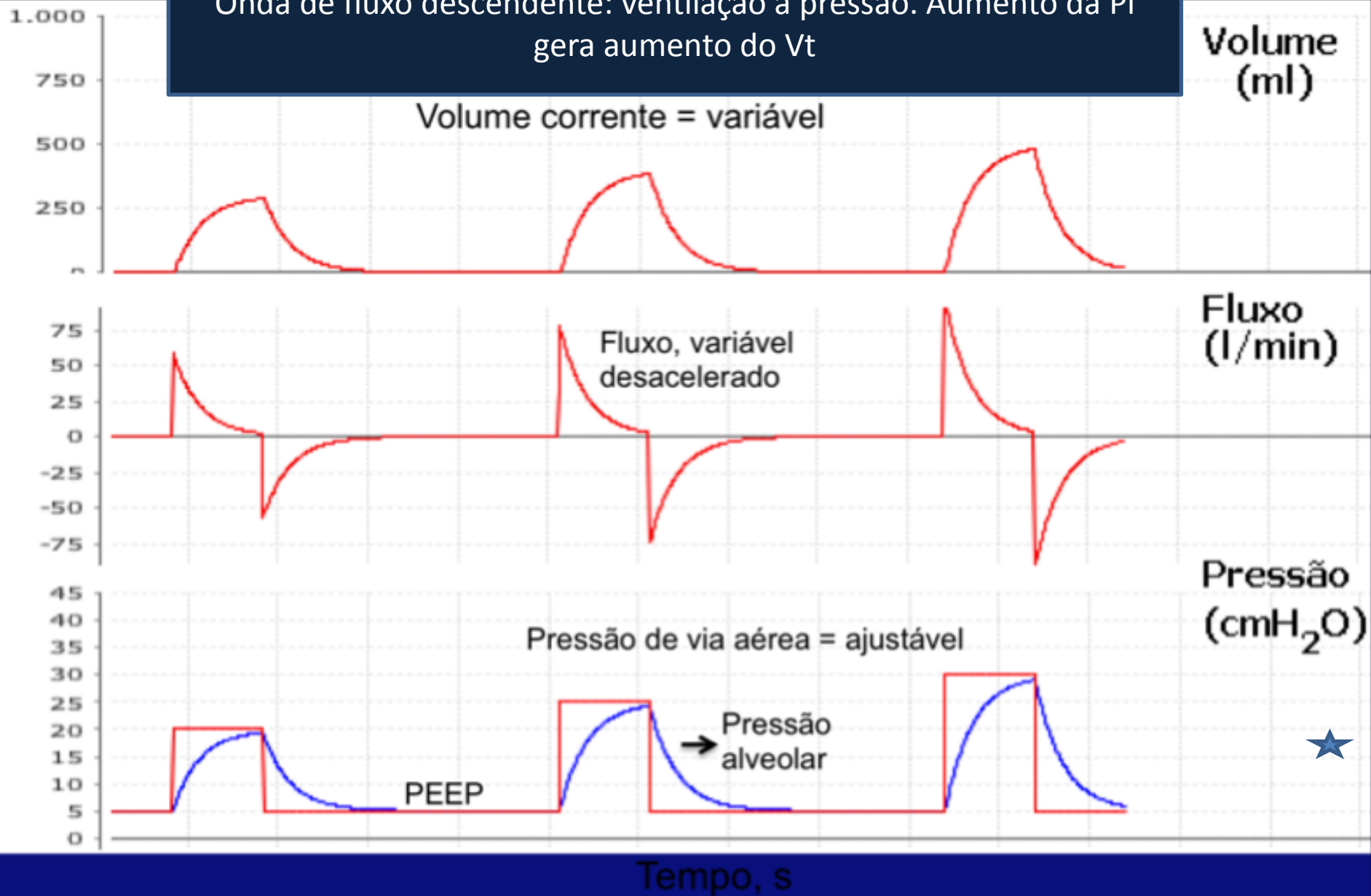
Ciclo a Pressão

- Ex: FR 40; I:E 1:2; Pi 20
60segundos:40= 1,5segundos/ciclo
I:E 1:2 0,5:1

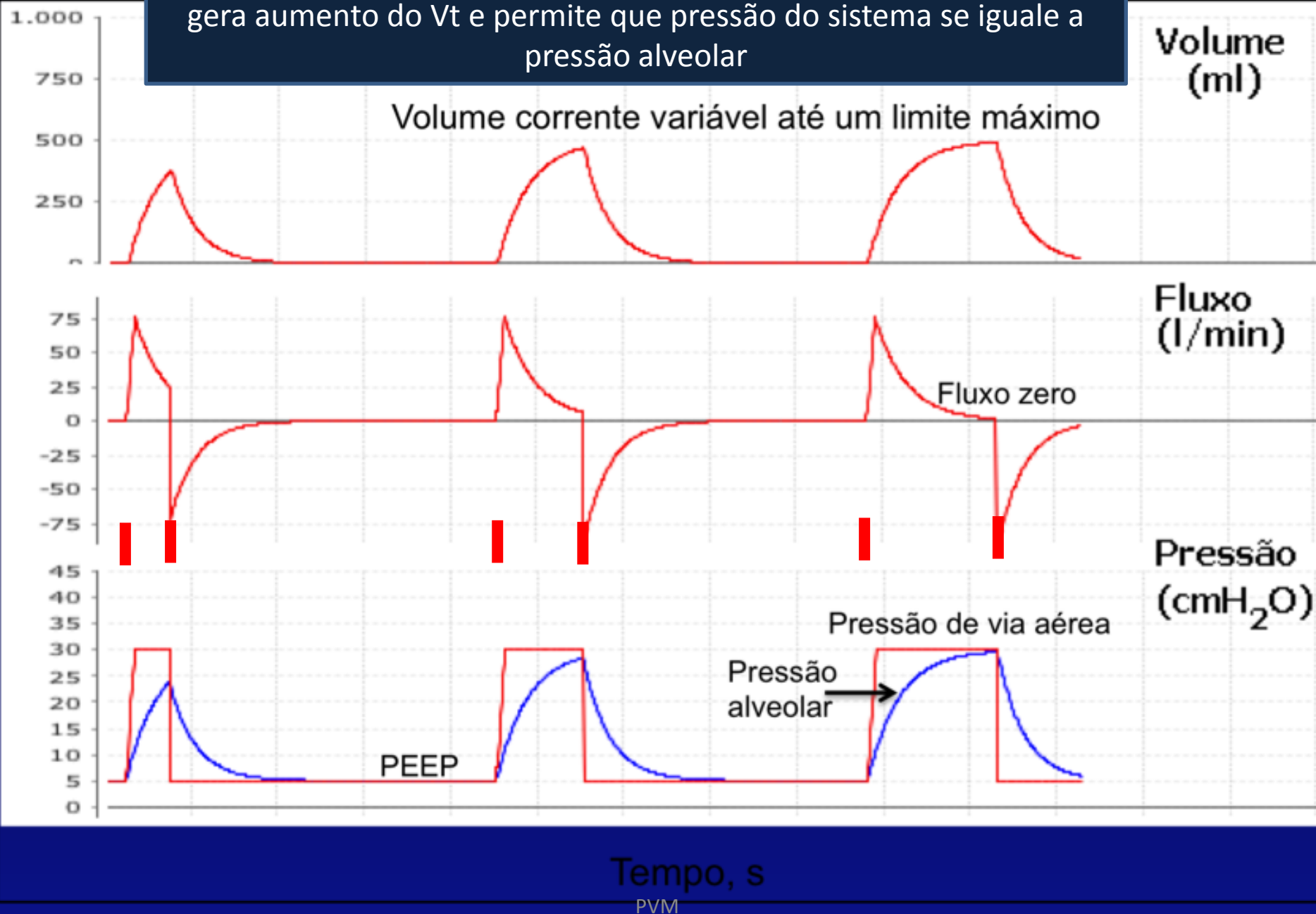
Ajusta fluxo para manter pressão
Sempre em 20cmH2O

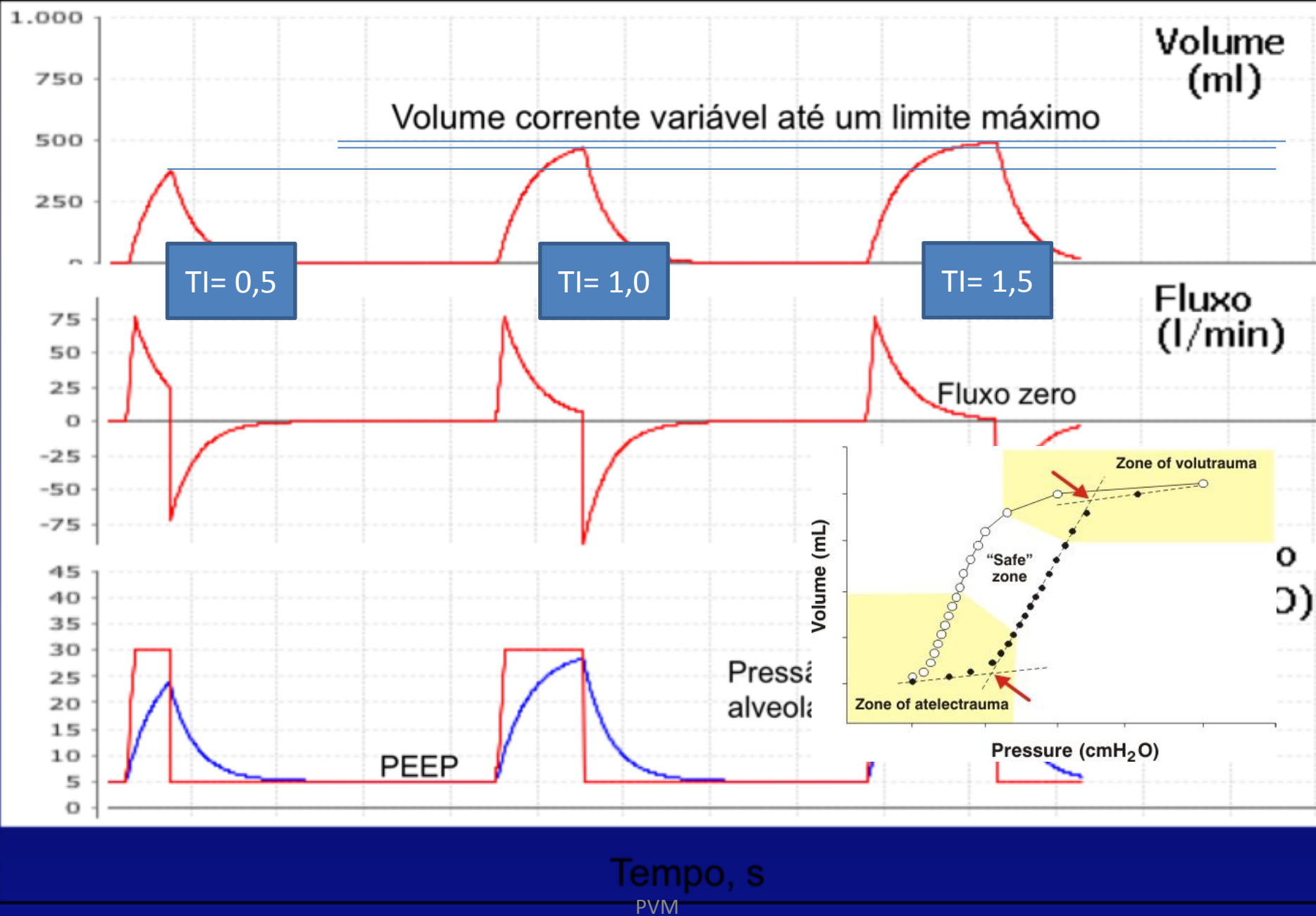


Onda de fluxo descendente: ventilação a pressão. Aumento da P_i gera aumento do V_t

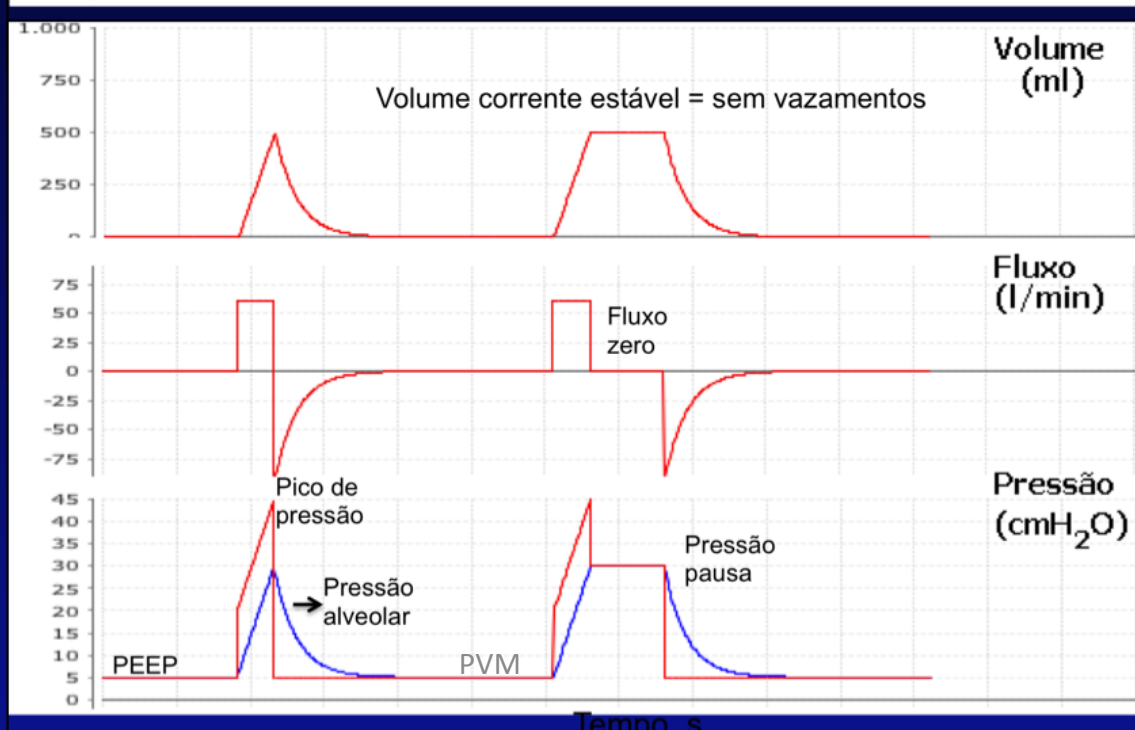
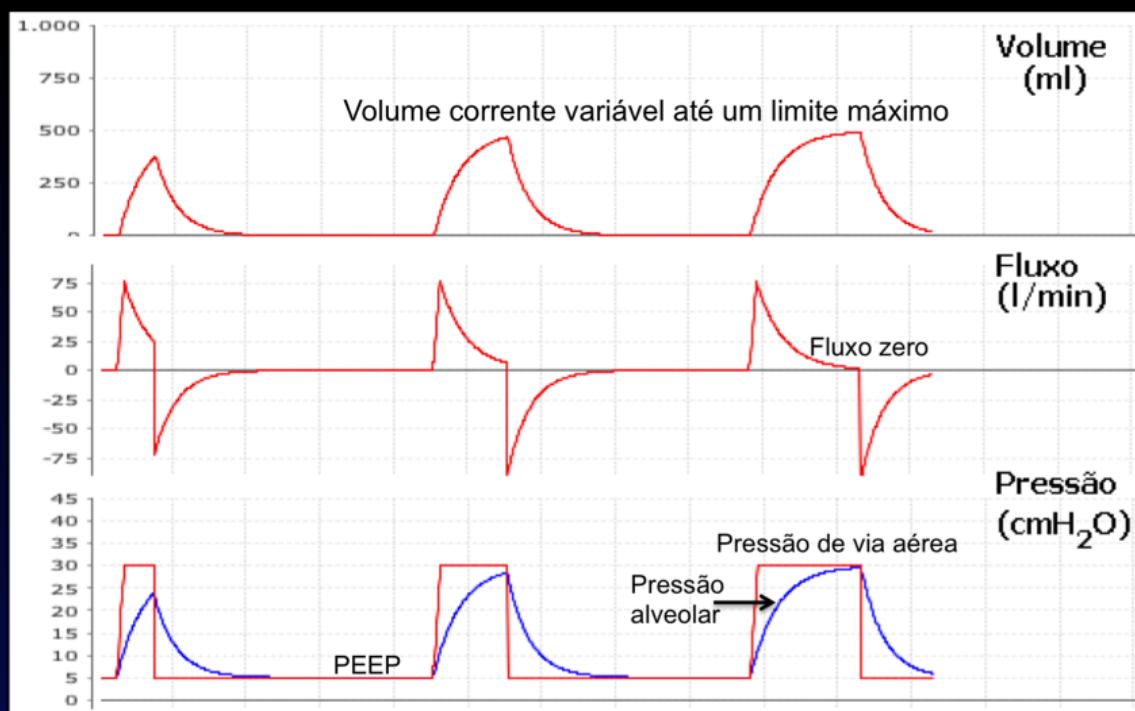


Onda de fluxo descendente: ventilação a pressão. Aumento do T_i gera aumento do V_t e permite que pressão do sistema se iguale a pressão alveolar

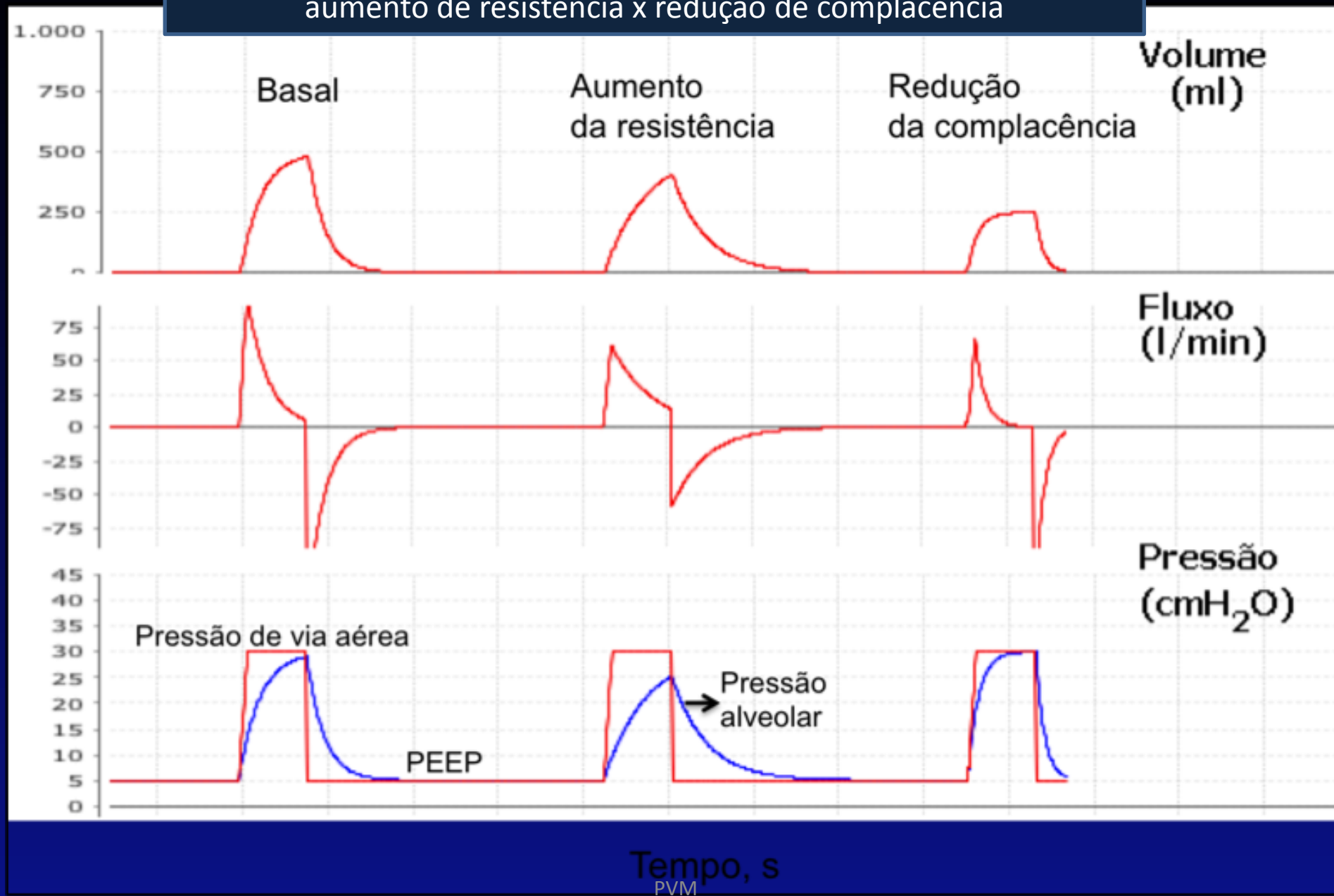




X



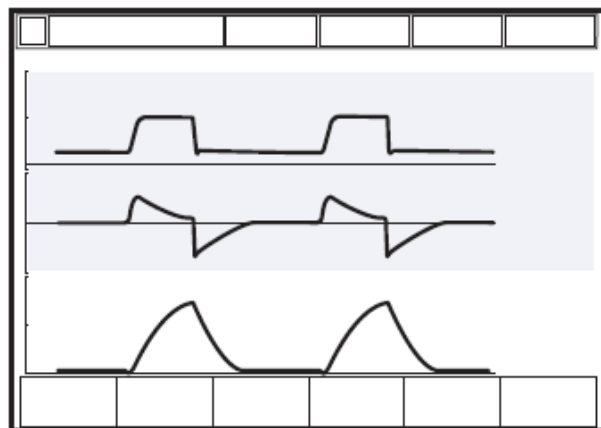
Onda de fluxo descendente: ventilação a pressão. Observe efeito de aumento de resistência x redução de complacência



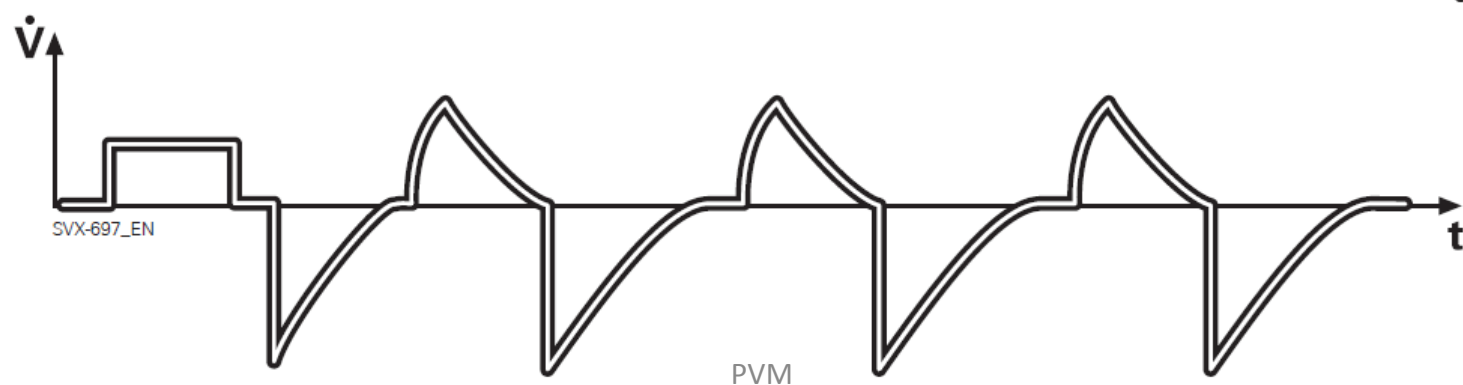
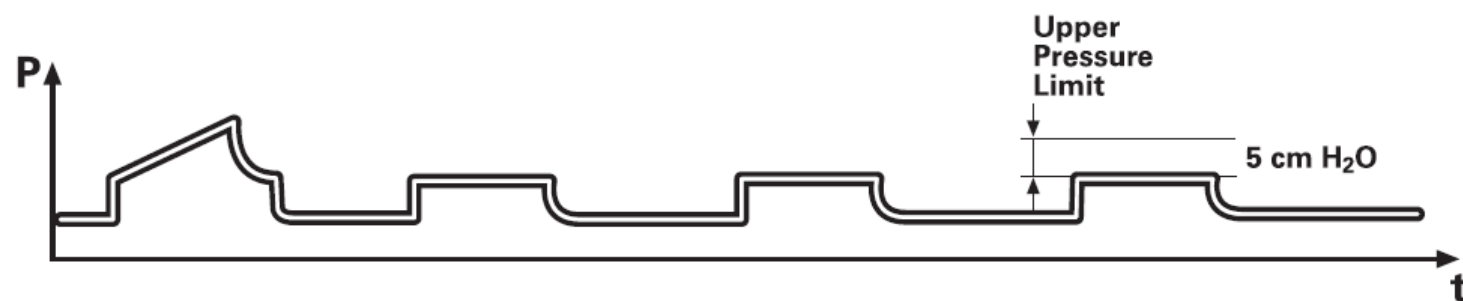
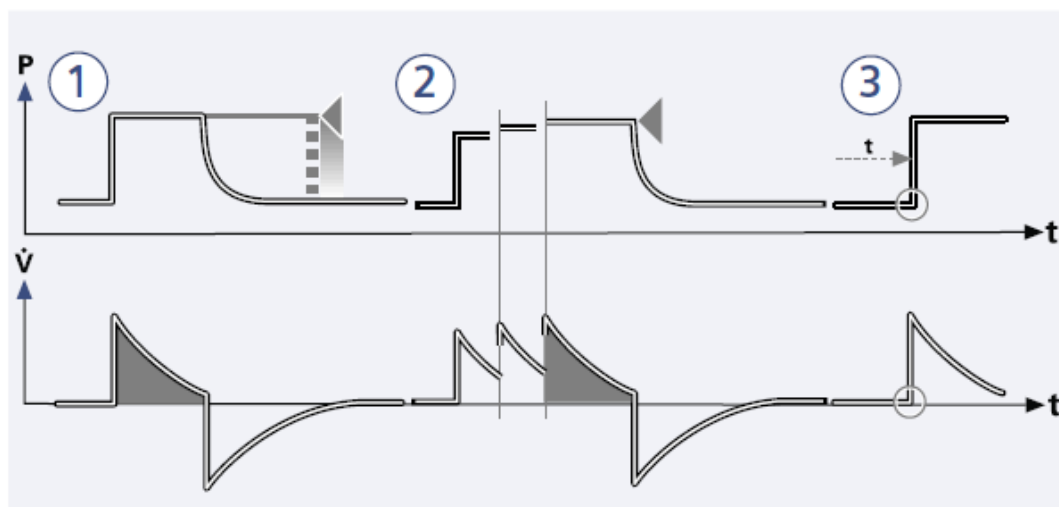
Ciclo a pressão com volume alvo

- 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



SVX-697_EN

PVM

Ciclo a pressão com volume alvo

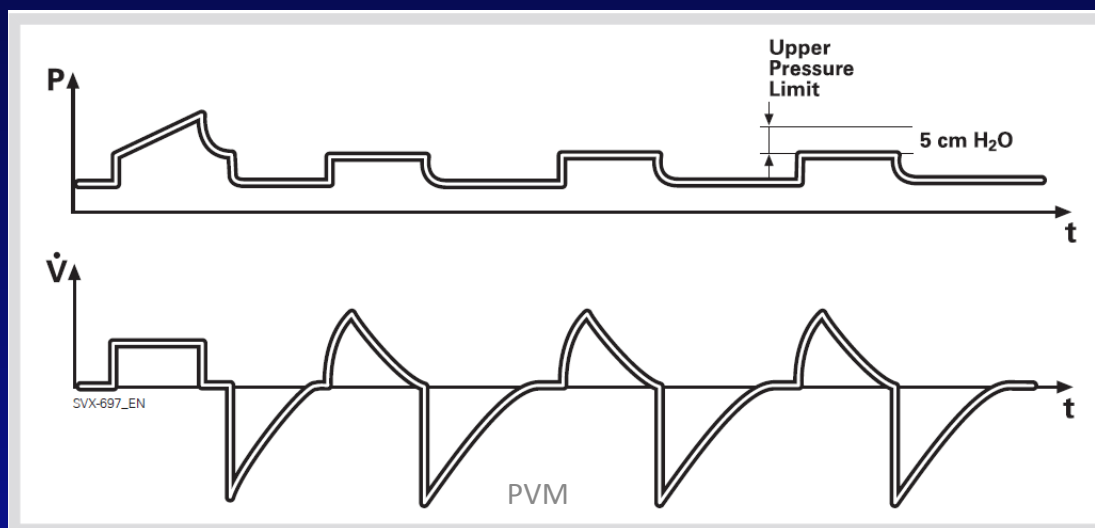
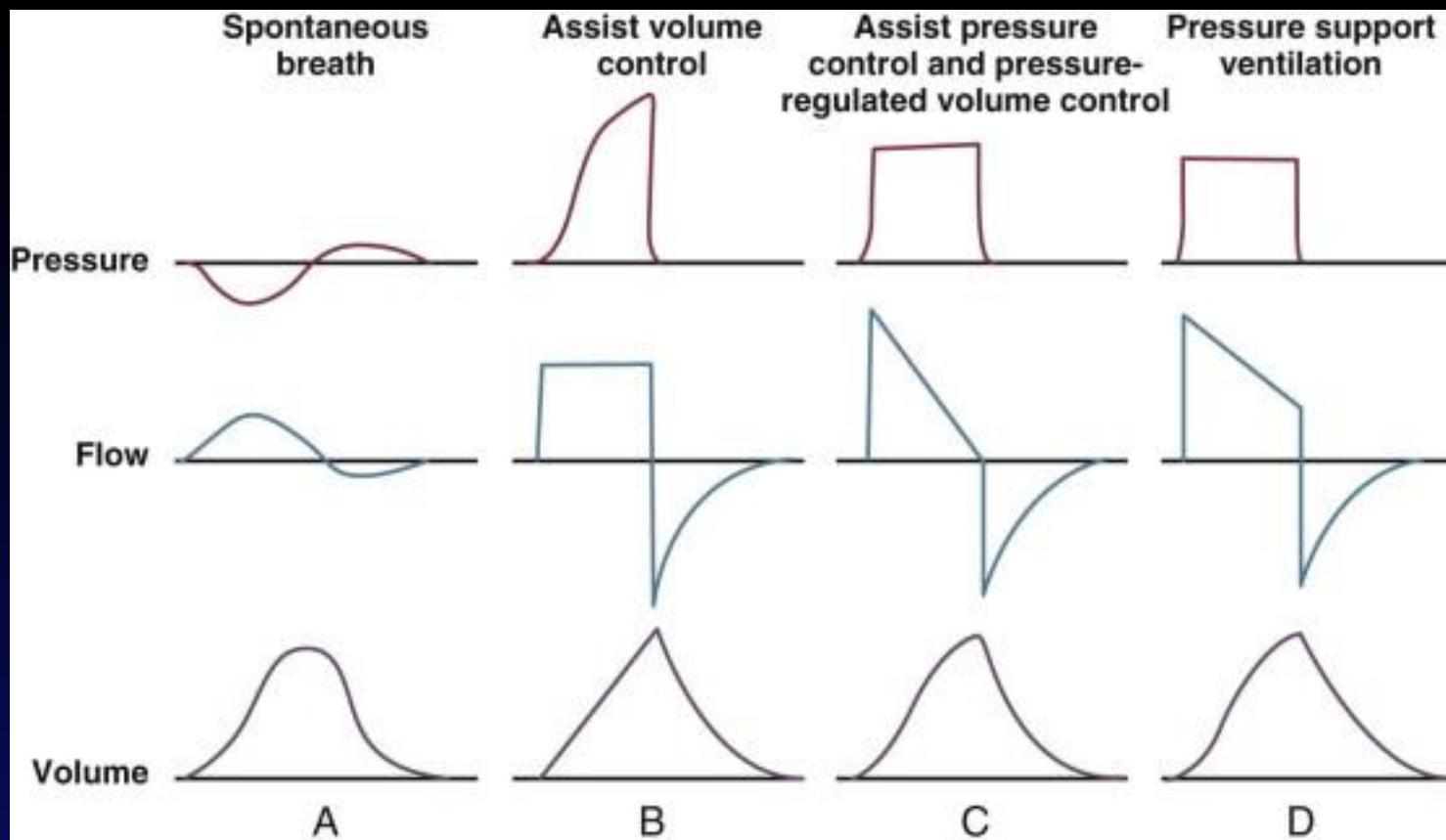
- Bird VIP Gold (Viasys Healthcare, Palm Springs, CA)
 - Modo híbrido
 - PS com volume assegurado
 - Limitado a pressão, ciclado a tempo
 - Se V_t não é atingido: ciclo passa a fluxo e aumenta a PI
 - Não ajusta para garantir V_t pequeno se complacência melhora.

Ciclo a pressão com volume alvo

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

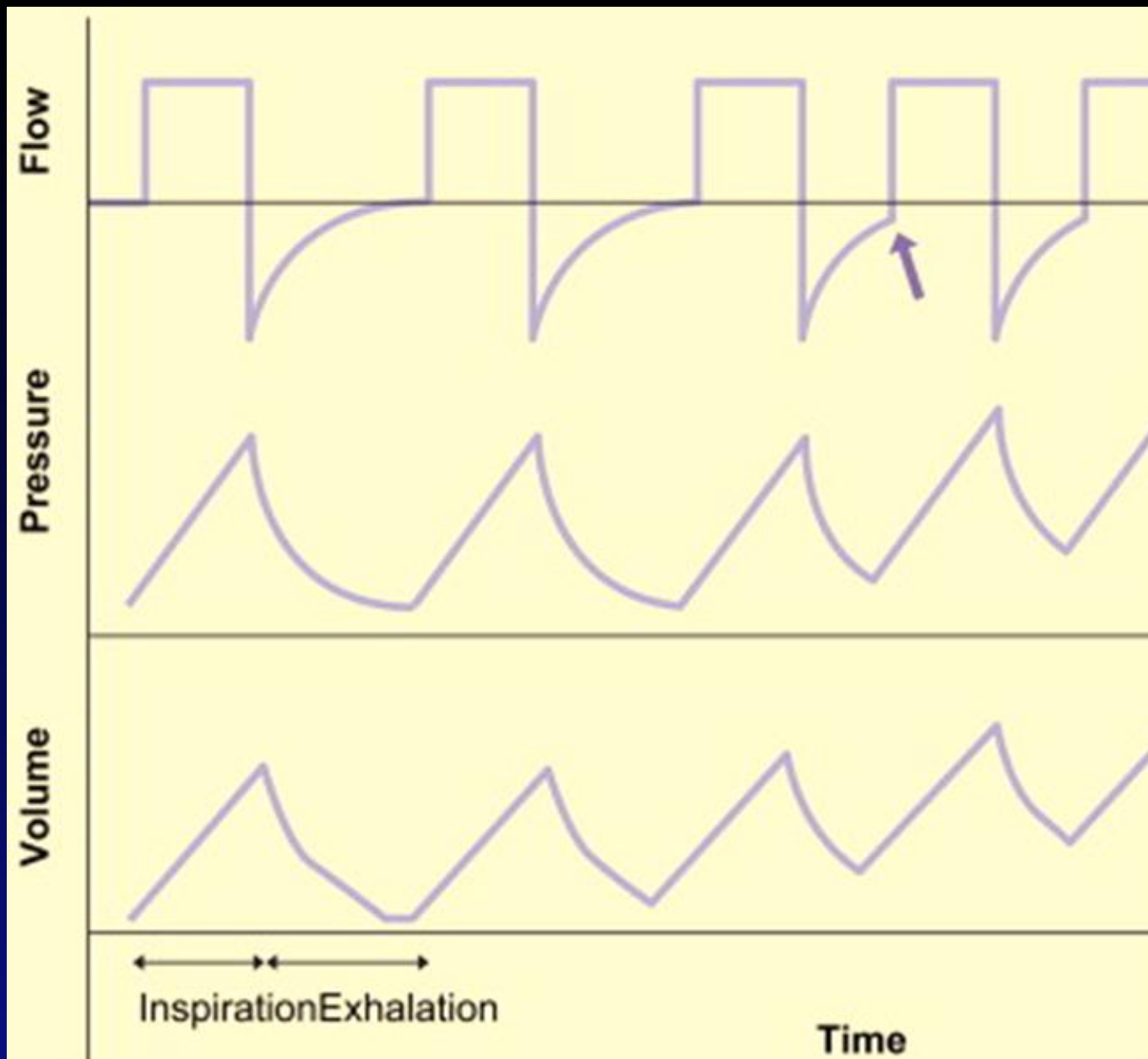
Ciclo a pressão com volume alvo

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



Abordagem da Disfunção Pulmonar

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

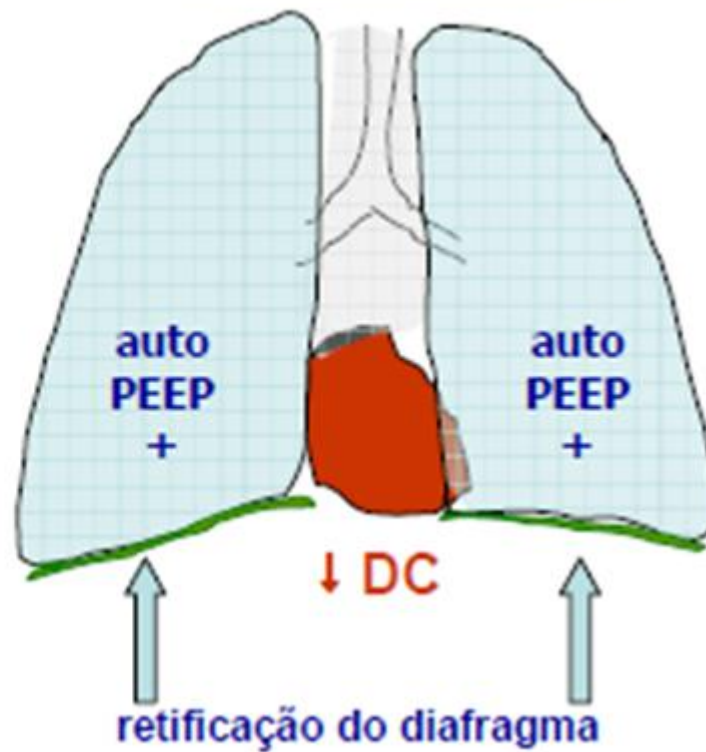
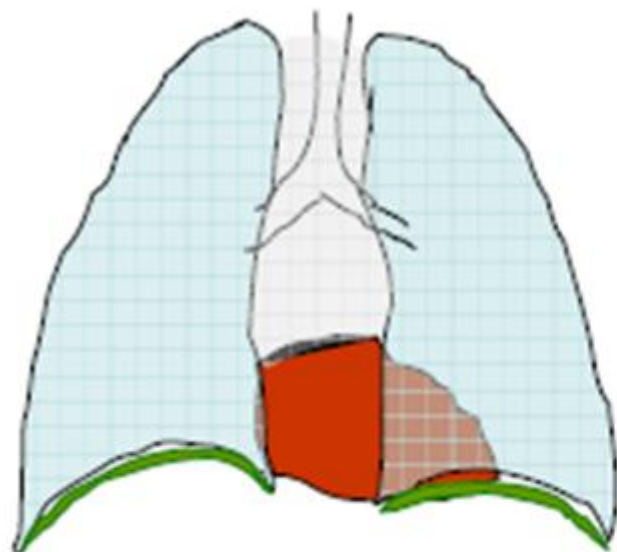


PVM

Respiratory monitoring during mechanical ventilation

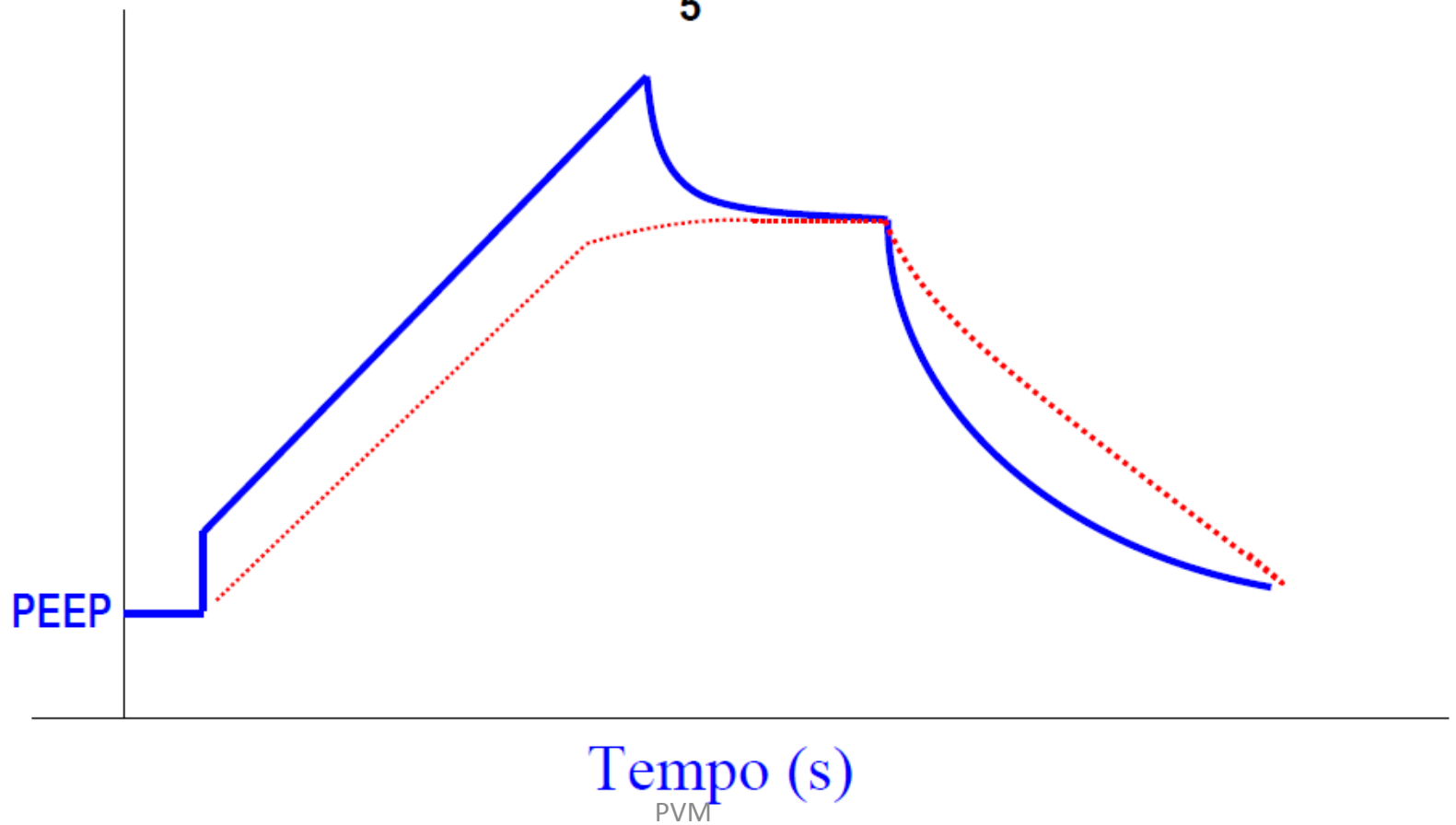
Robinder G Khemani, Robert D Bart, and Christopher JL Newth
Paediatrics and Child Health, 2007-05-01, Volume 17, Issue 5, Pages 193-201

Piora da mecânica



Mensuração da P alveolar

P via aérea

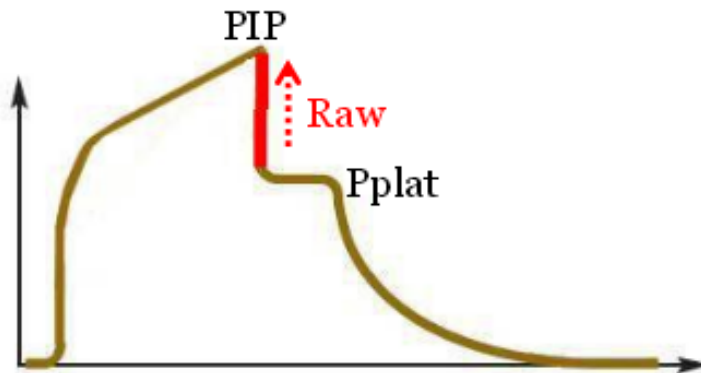


Monitorização

- Discutir obstrução x piora da complacência

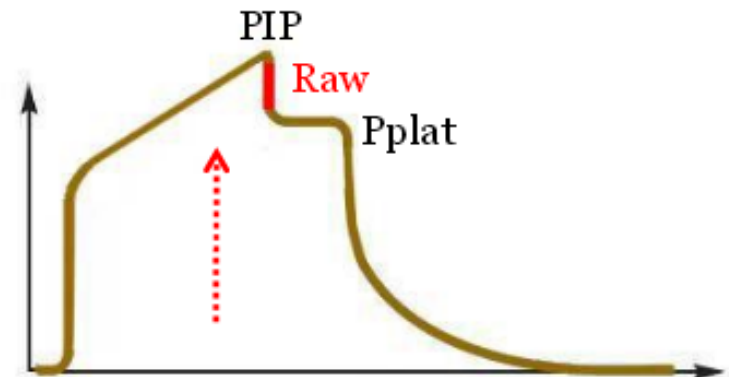
Increased Airway Resistance

A.

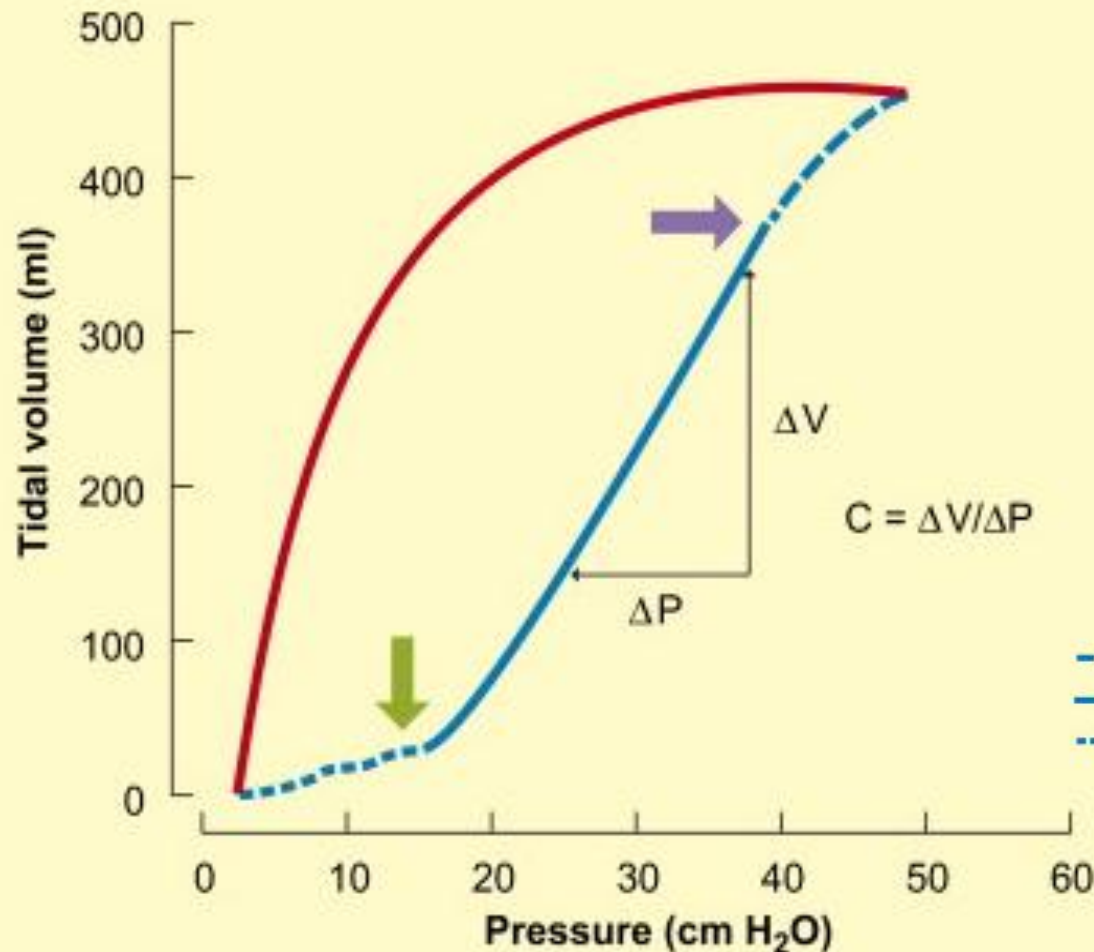


Decreased Compliance

B.



Monitorização



Curva

Pressão
Volume

- Zone of overdistension
- Maximal compliance
- Zone of under recruitment
- Upper reflection point
- Lower reflection point

Respiratory monitoring during mechanical ventilation

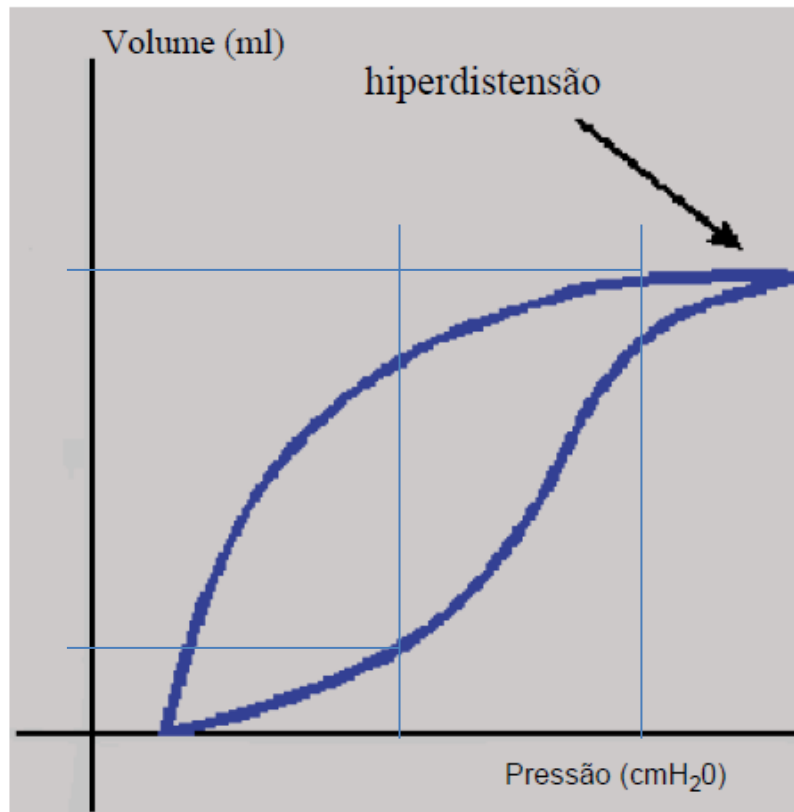
Robinder G Khemani, Robert D Bart, and Christopher JL Newth
Paediatrics and Child Health, 2007-05-01, Volume 17, Issue 5, Pages 193-201

Monitorização

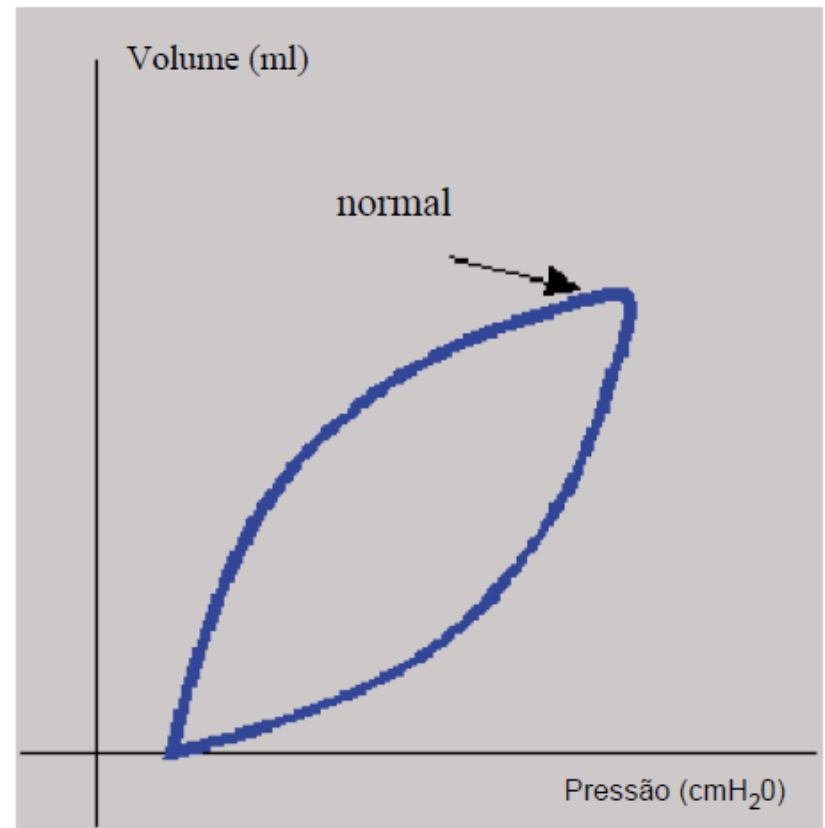
Traçado alterado



Traçado corrigido



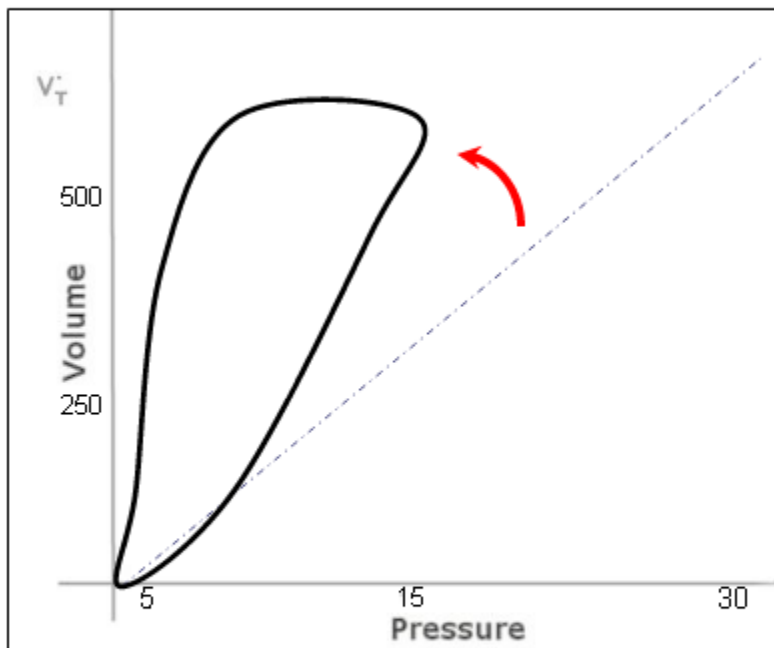
PIP: 26 cmH₂O



PIP: 22 cmH₂O

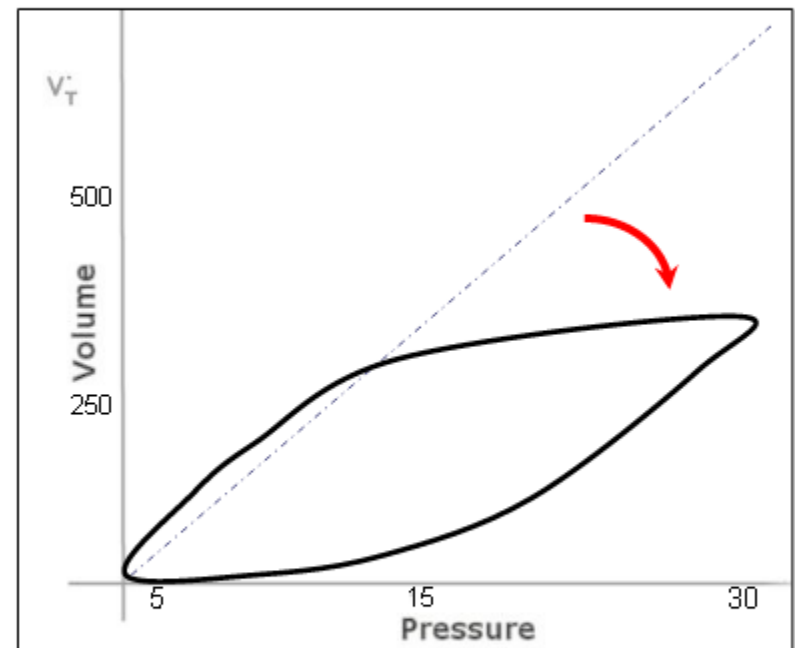
Monitorização

Increased Compliance



Example: Emphysema,
Surfactant Therapy

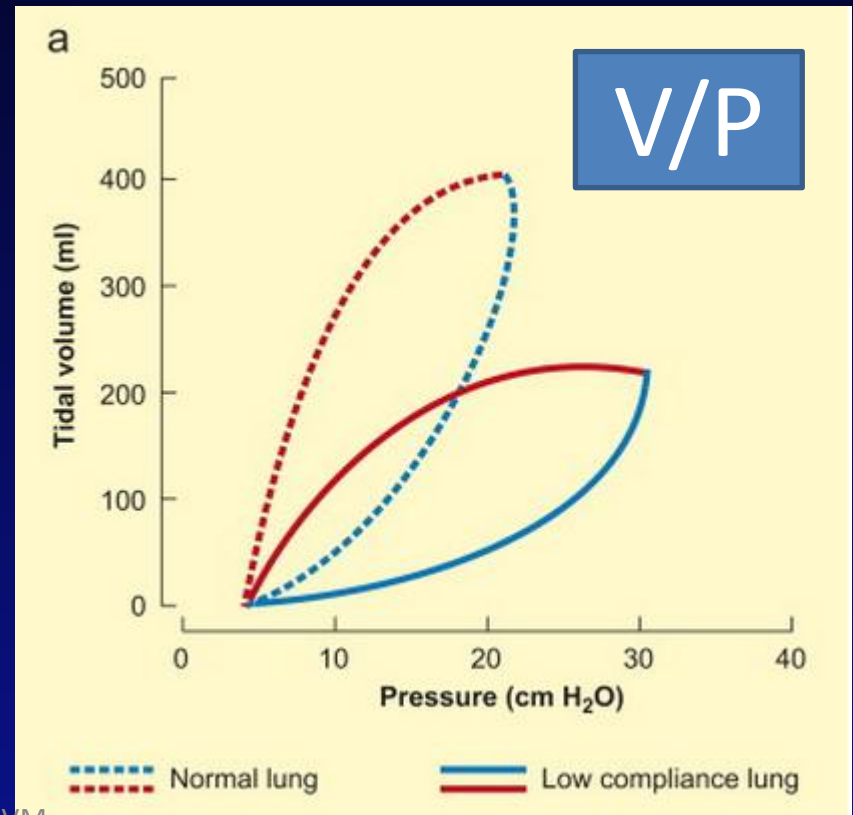
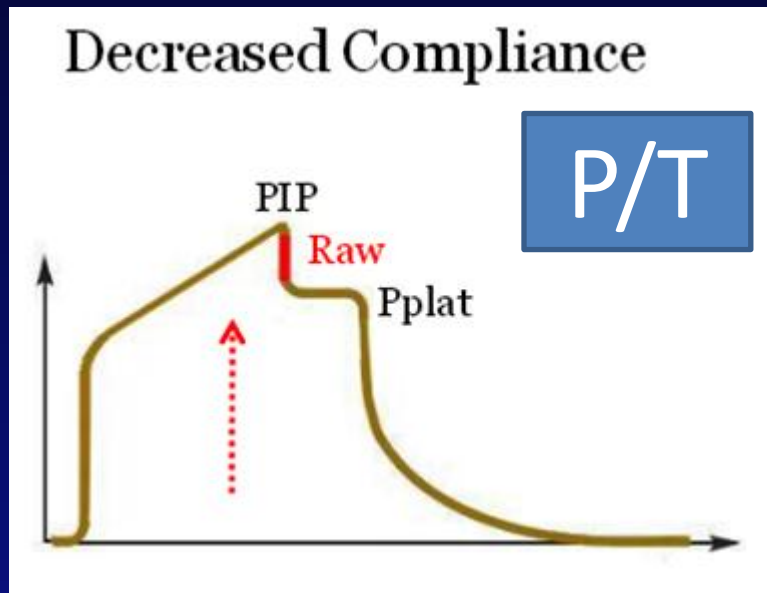
Decreased Compliance



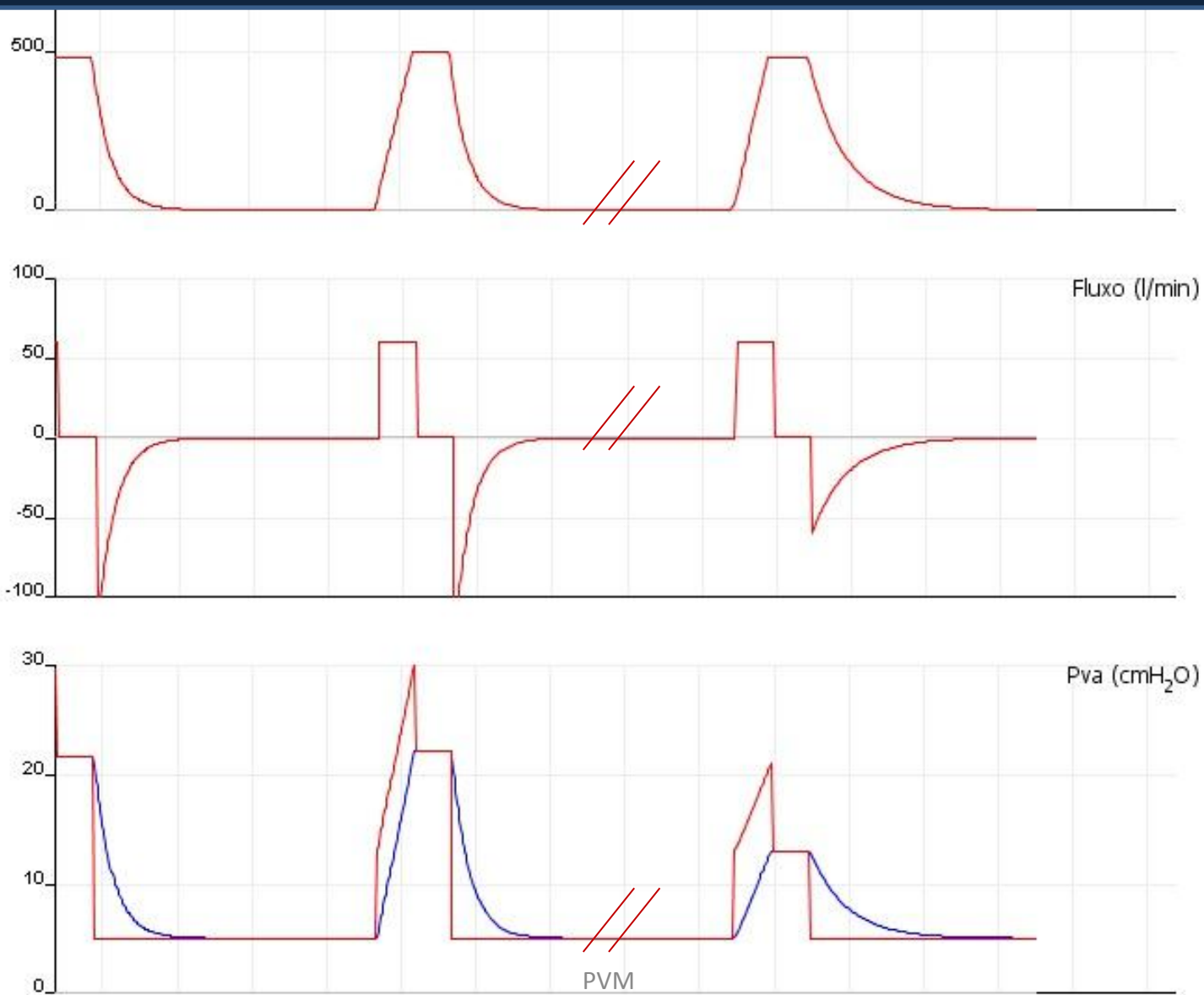
Example: ARDS, CHF,
Atelectasis

Monitorização

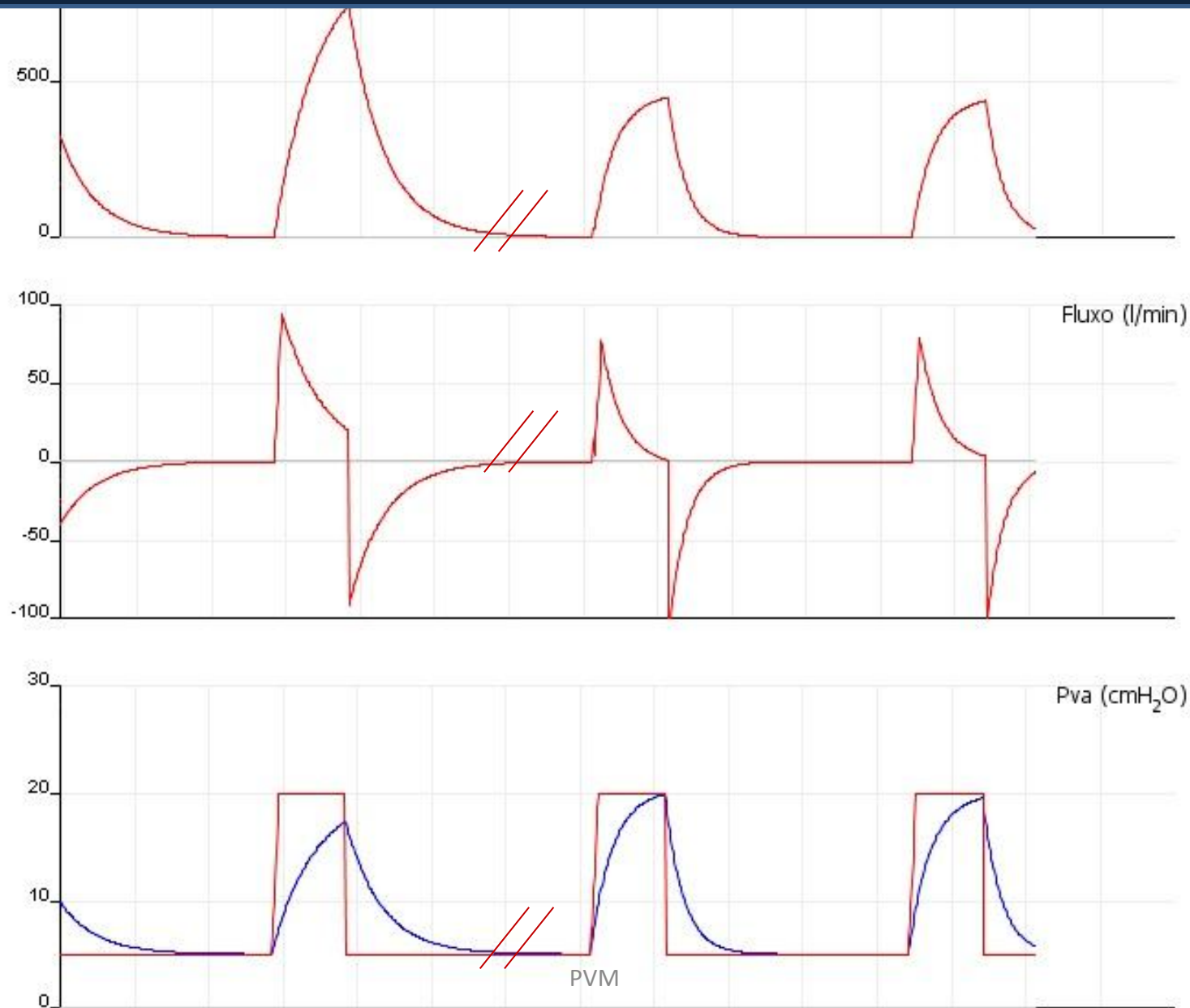
- Atelectasia



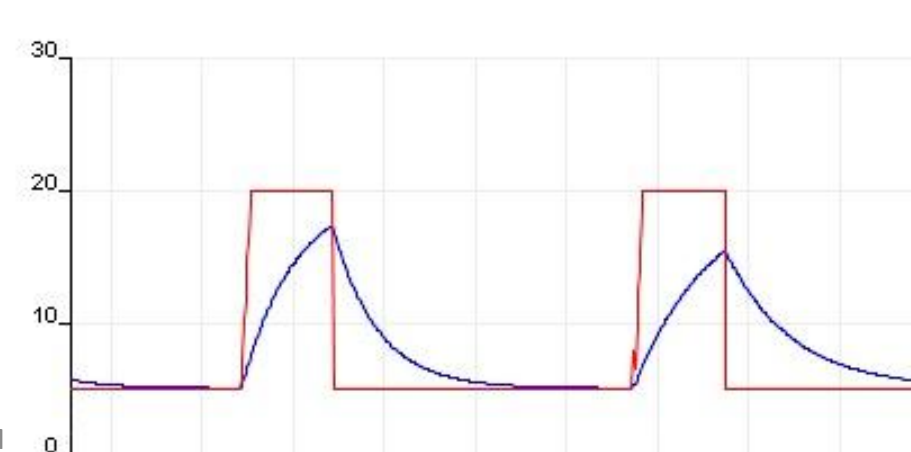
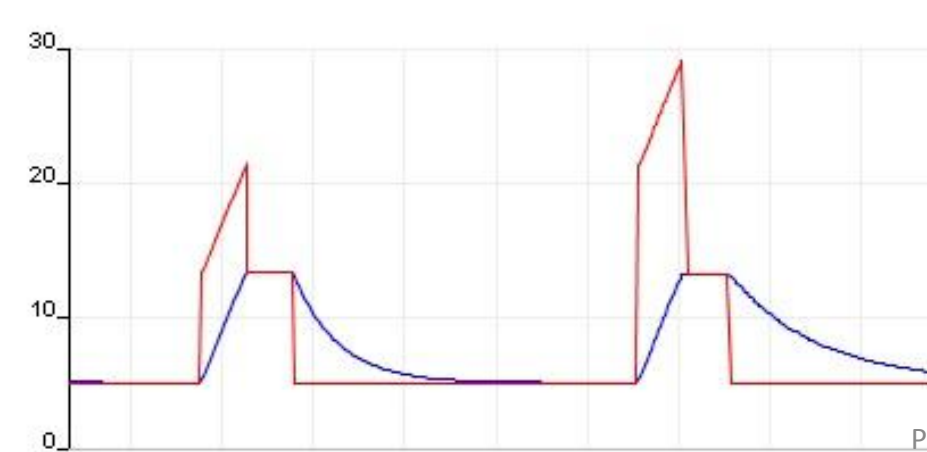
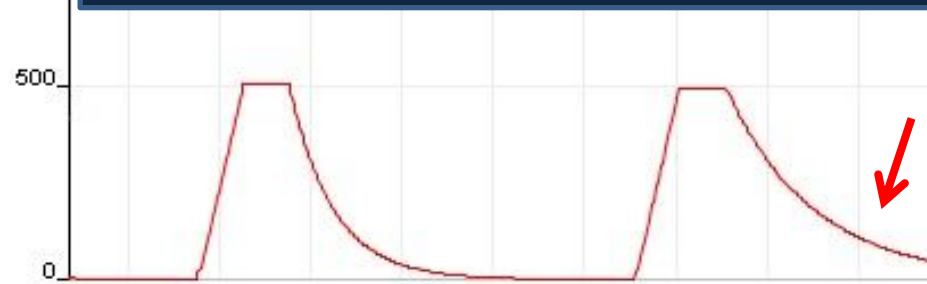
Onda de fluxo quadrada com pausa: ventilação a volume. Observe efeito de melhora da complacência (Ex. recrutamento de atelectasia, toracocentese de alívio no pneumotórax, tto da congestão pulmonar, etc...)



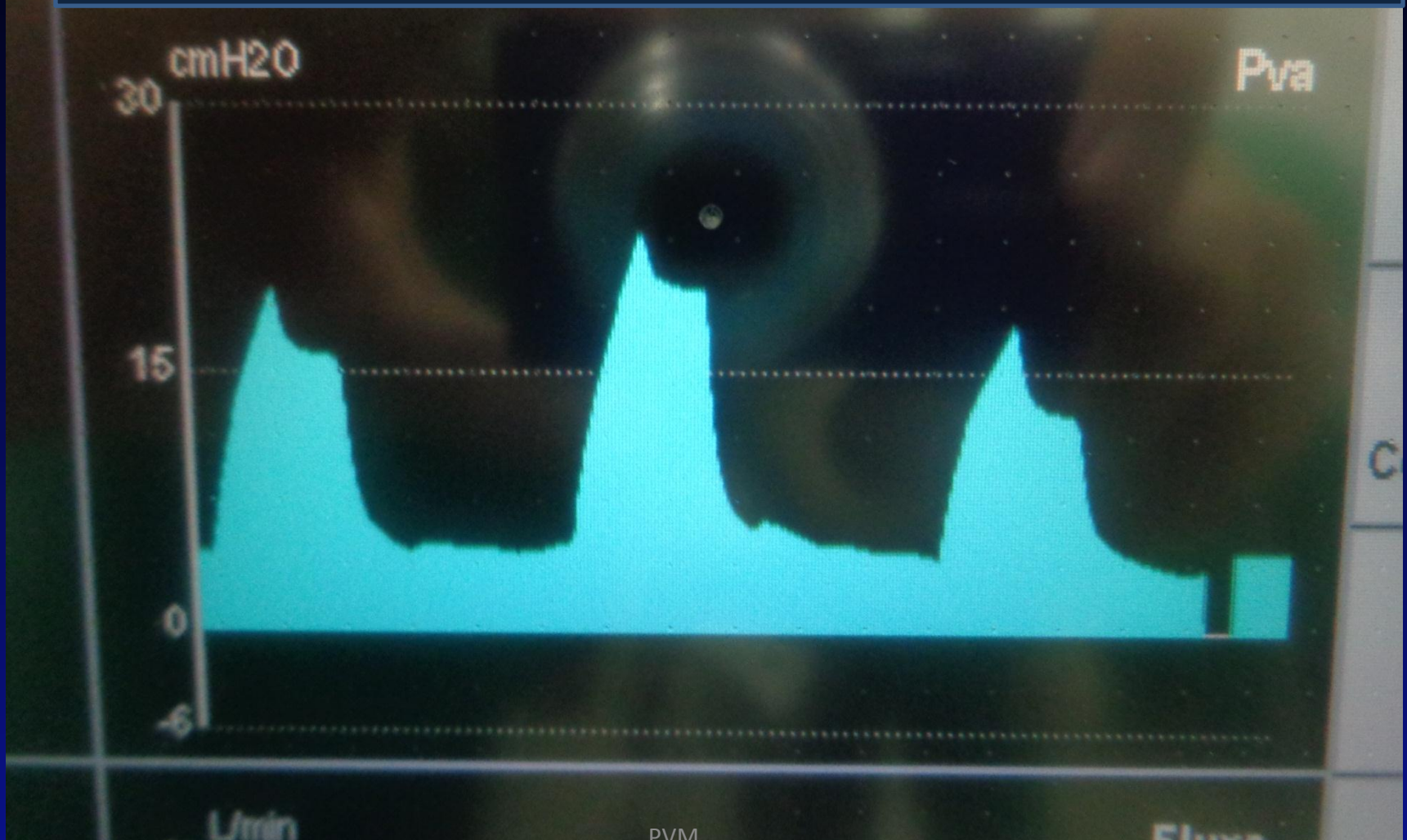
Onda de fluxo descendente: ventilação a pressão. Observe efeito de piora complacência (Ex. atelectasia, pneumotórax, congestão pulmonar, etc...)



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 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

2014-06-09 17:09:51

** Filso muito alto

VM
L/min
4.3

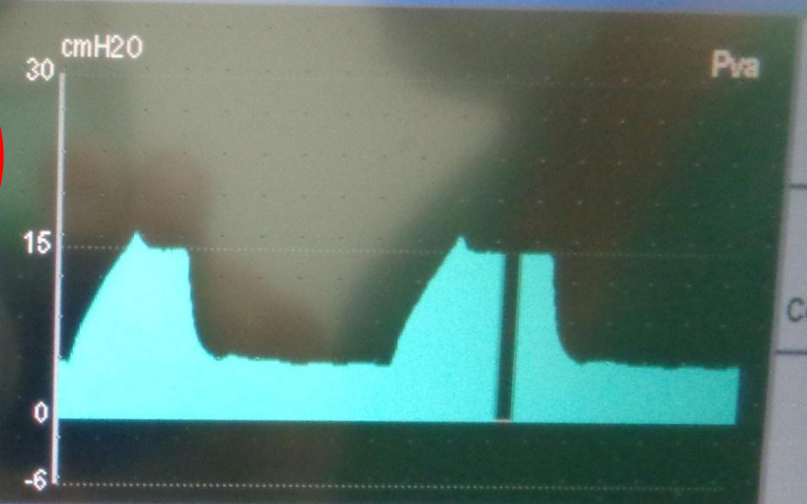
VCe
mL
426

Freq.
bpm
10

Ppico
cmH2O
17

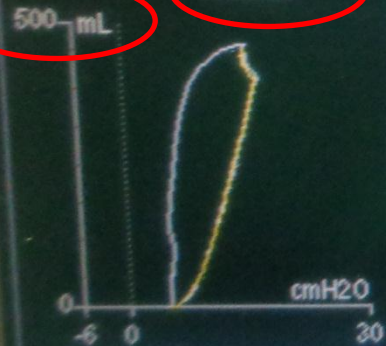
Pplat
cmH2O
15

PEEP
cmH2O
5



Loop P-V

Ref.



Insp Exp

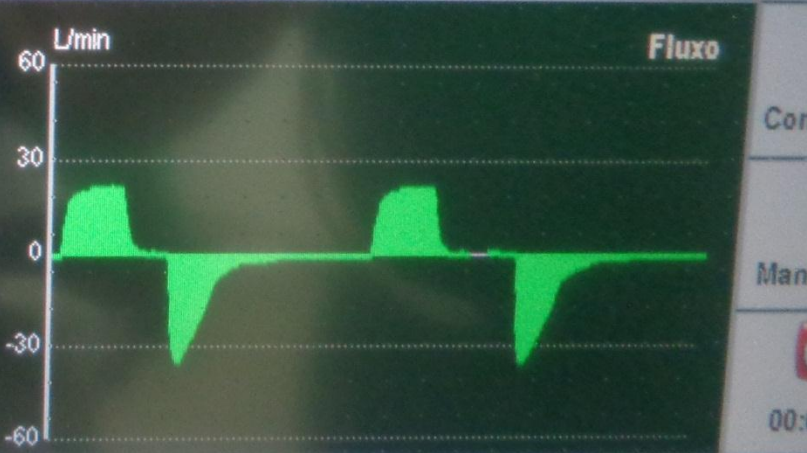
N2O **0** **0** %

Iso **2.4** **1.5** %

CO2 **0** **26** mmHg

O2 **84** %

CAM **1.3**



VC	mL	Freq.	bpm	I:E	TIP:TI	%	Plimit	cmH2O	PEEP	cmH2O
450		10		1:2	40		30		5	

PVIM

VCV

2014-06-05 17:16:38



VM 4.3

VCe 444

Freq. 10

Ppico 21

Pplat 20

PEEP 5



Modo vent

Config alarme



Telas



Conf. usuário



Manutenção

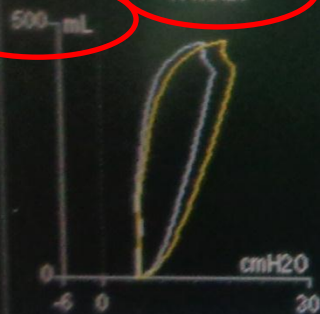


00:00:00

Loop P-V

Ref

17:09:26



Insp Exp

N2O 0 0 %
Iso 1.8 1.3 %
CO2 0 27 mmHg
O2 86 %
CAM 1.1

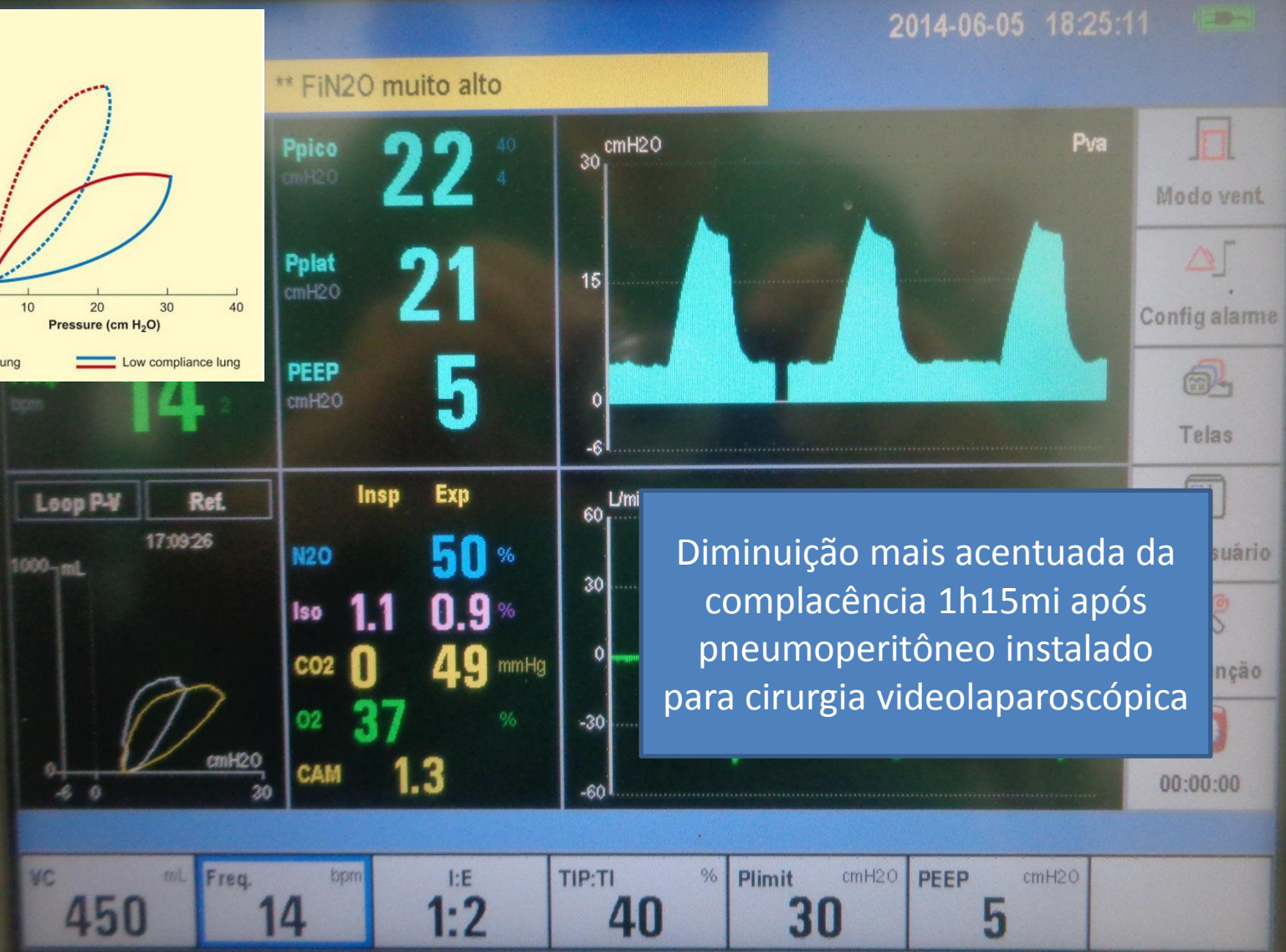
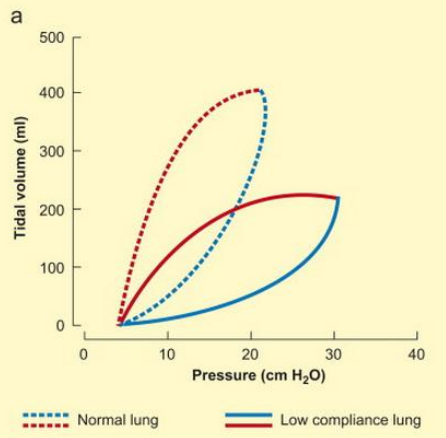
L/min



Diminuição da complacência 7 minutos após pneumoperitônio instalado para cirurgia videolaparoscópica

VC	450 mL	Freq.	10 bpm	I:E	1:2	TIP:TI	40 %	Plimit	30 cmH2O	PEEP	5 cmH2O
----	--------	-------	--------	-----	-----	--------	------	--------	----------	------	---------

PVM

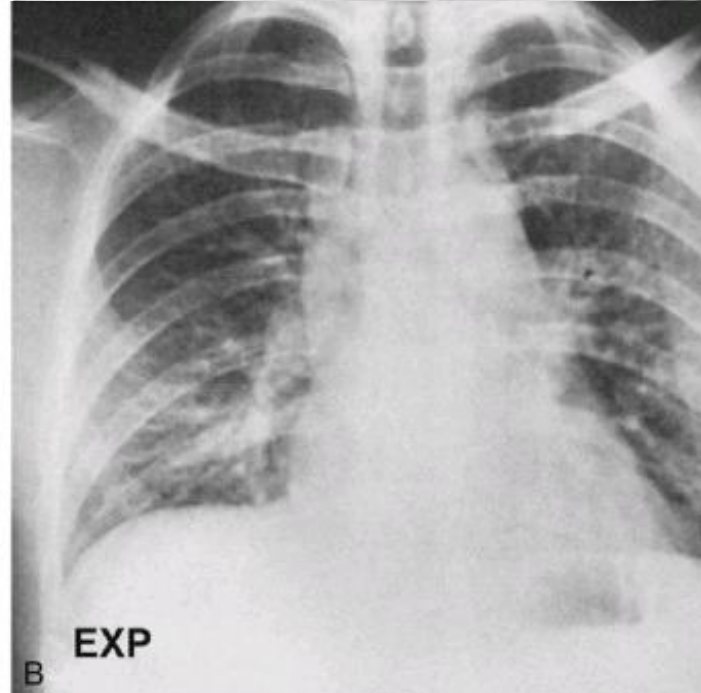
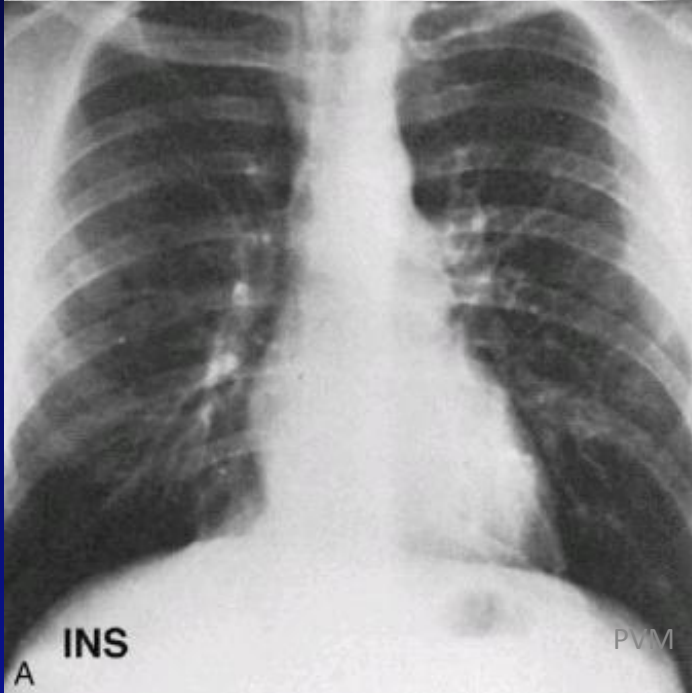
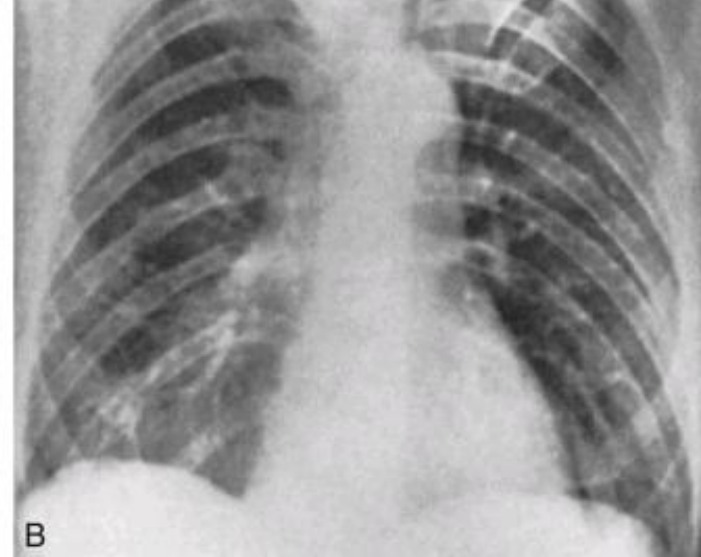
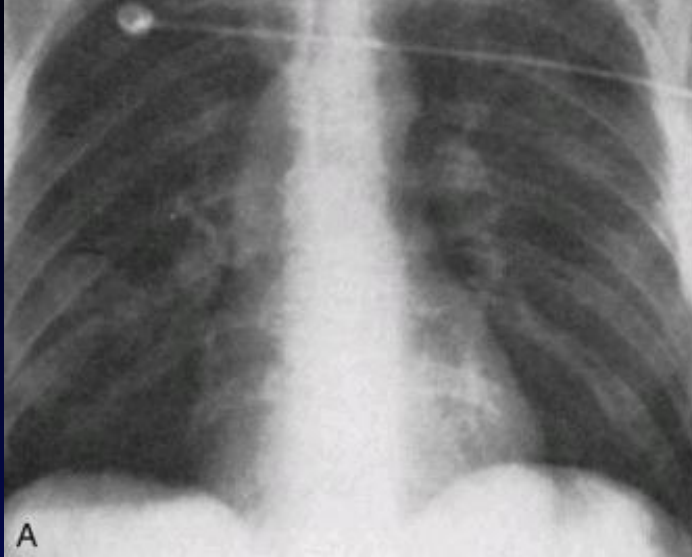


Diminuição mais acentuada da complacência 1h15mi após pneumoperitônio instalado para cirurgia videolaparoscópica

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

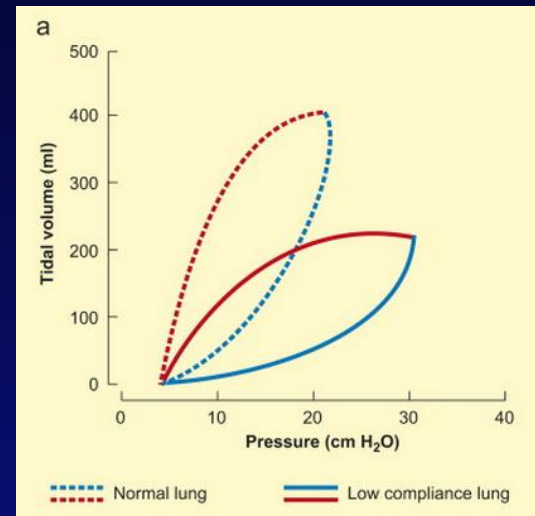
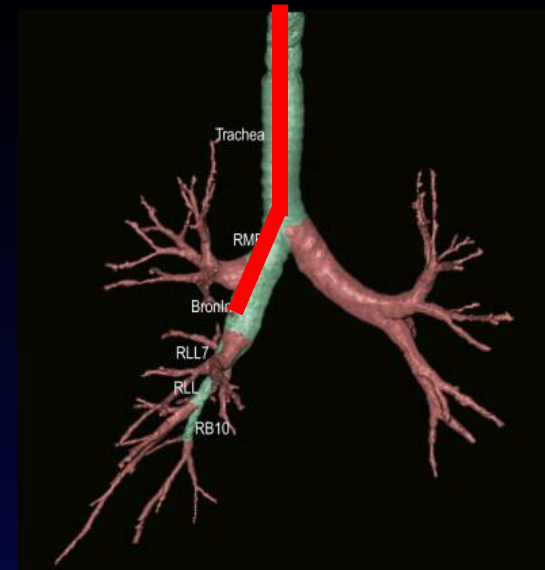
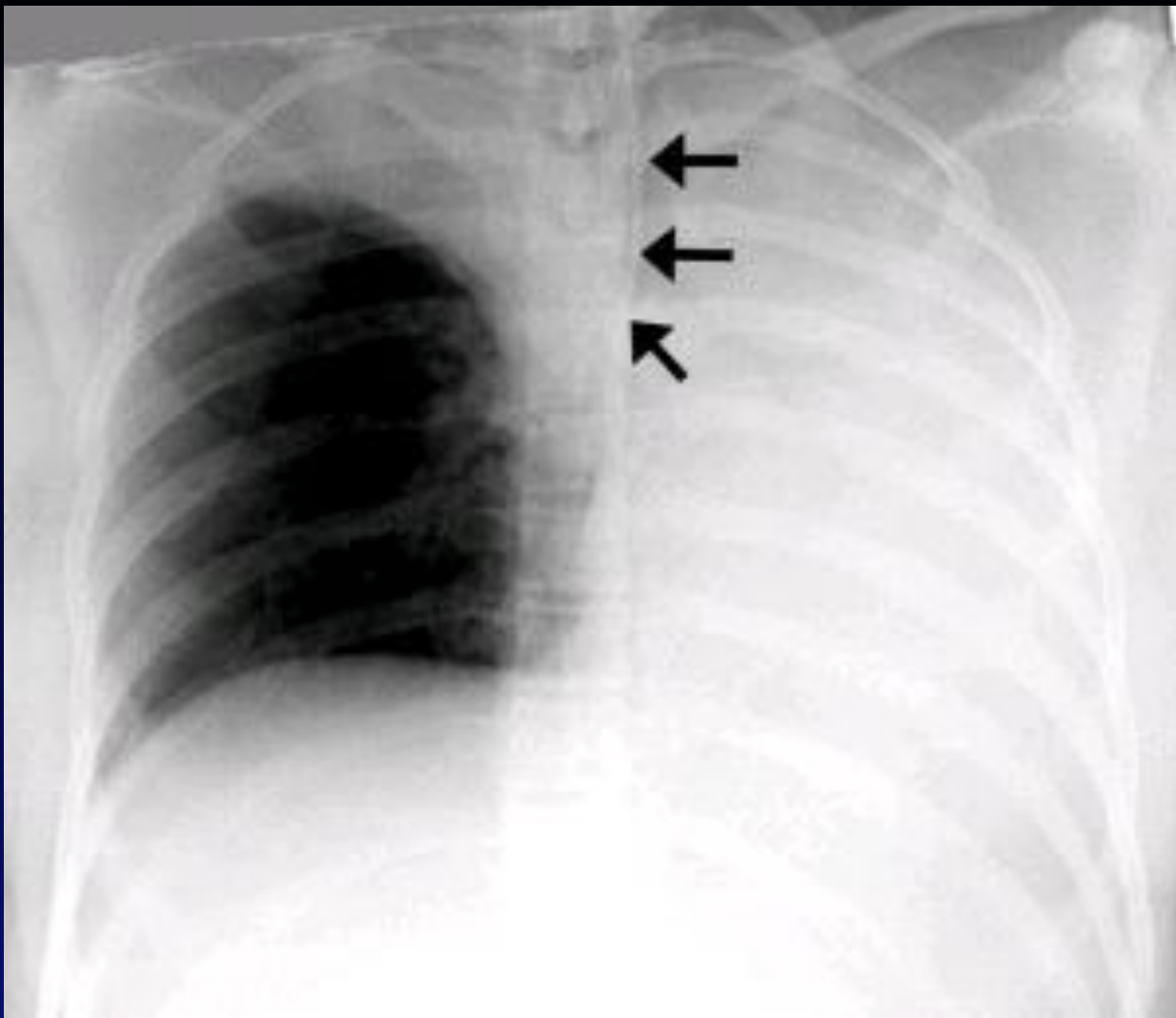
Limitações da radiologia: qualidade do exame (topo – mesmo paciente, aparelhos diferentes), técnica (inferior – mesmo paciente, um ins outro expirado)



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



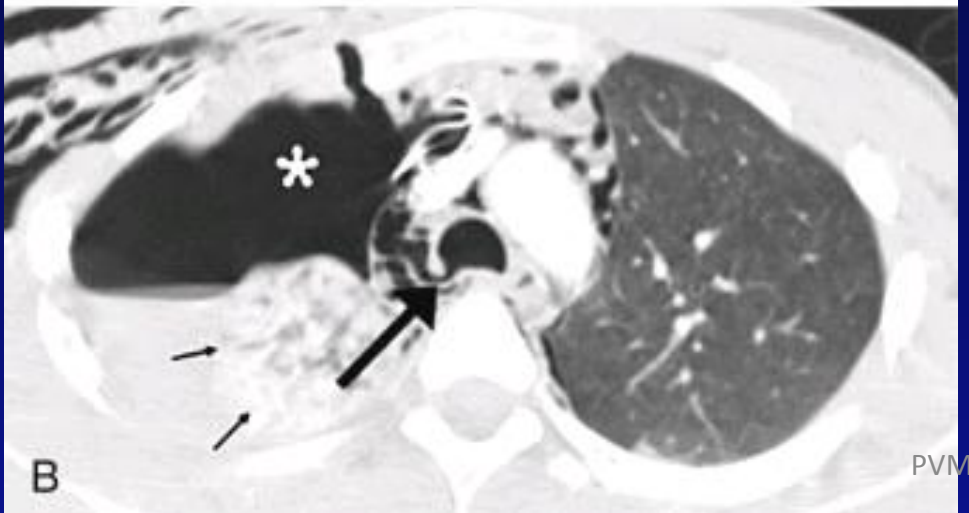
Hemothorax: Supine chest x-ray
with a subtle density difference.

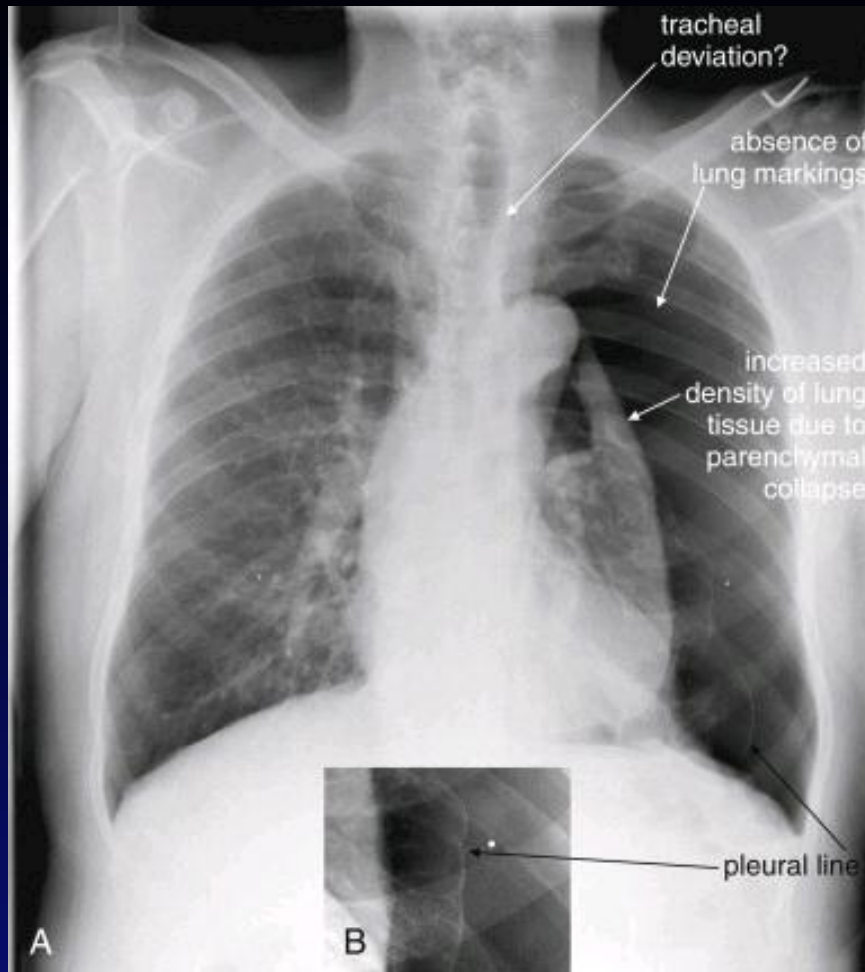


Anteroposterior chest radiograph shows endotracheal tube (*arrows*) extending into bronchus intermedius, with resulting collapse of left lung and right upper lobe from hypoventilation.



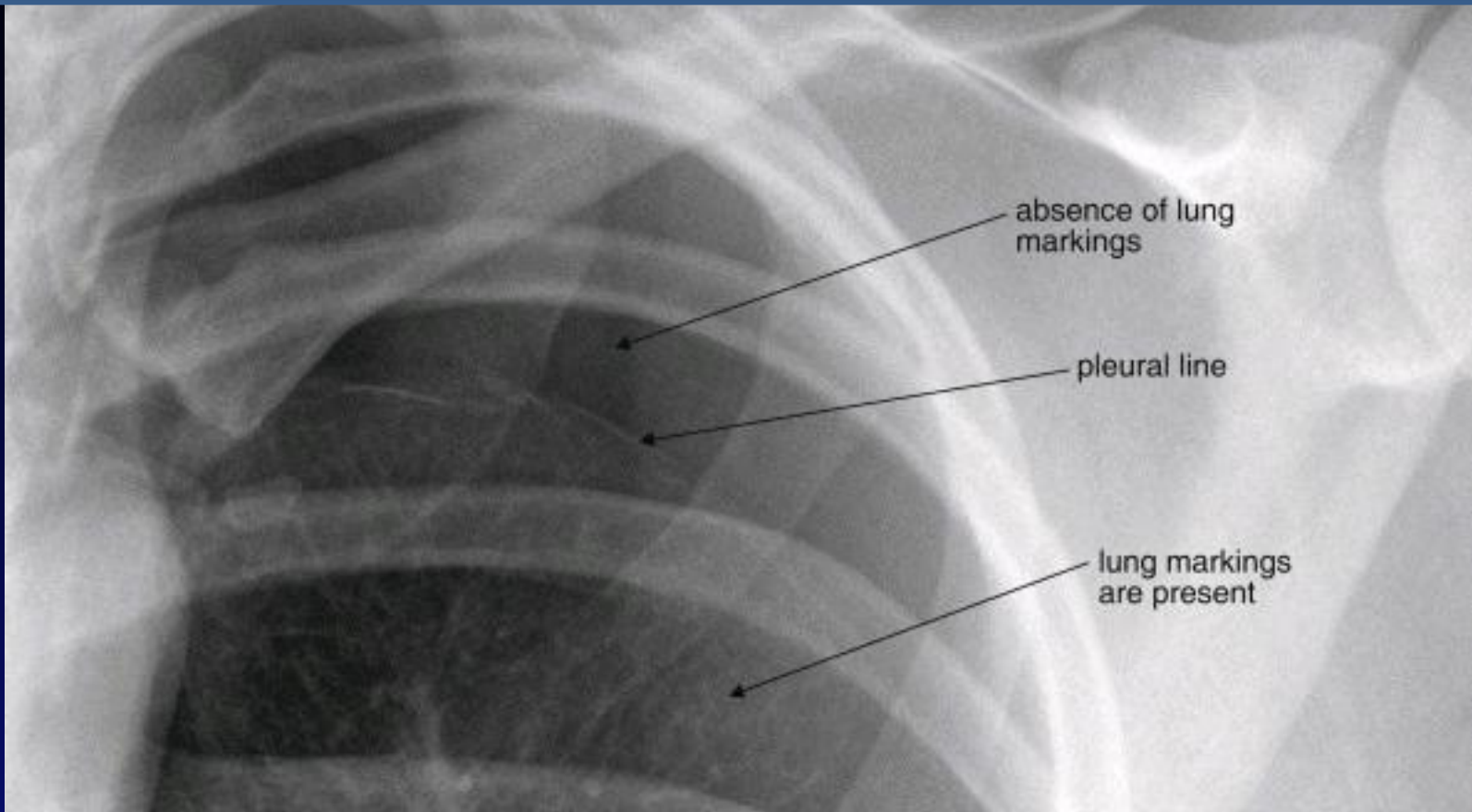
A 22-year-old man was involved in a high-speed motor vehicle crash. A, Anteroposterior chest radiograph shows right pneumothorax, pneumomediastinum, right lung collapse, and subcutaneous emphysema. B, Computed tomography shows tracheal laceration (*large arrow*), right pneumothorax (*asterisk*), and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



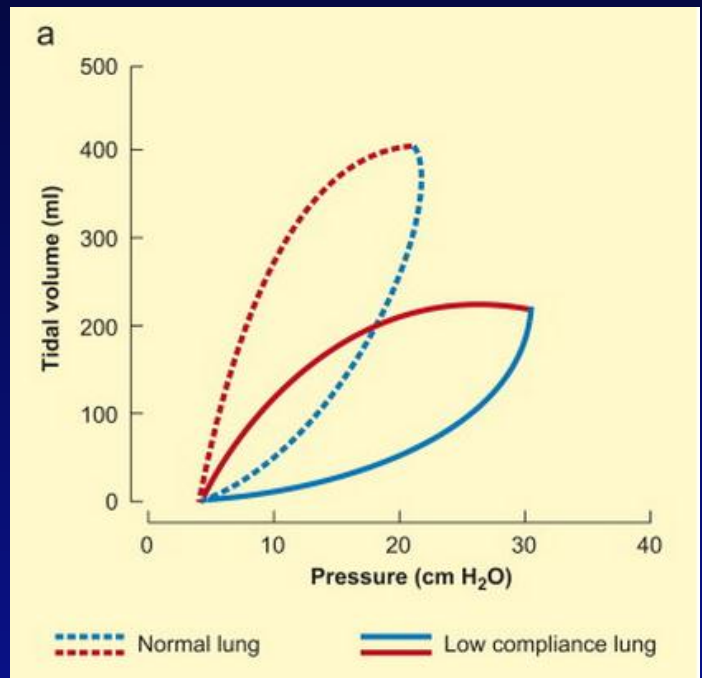
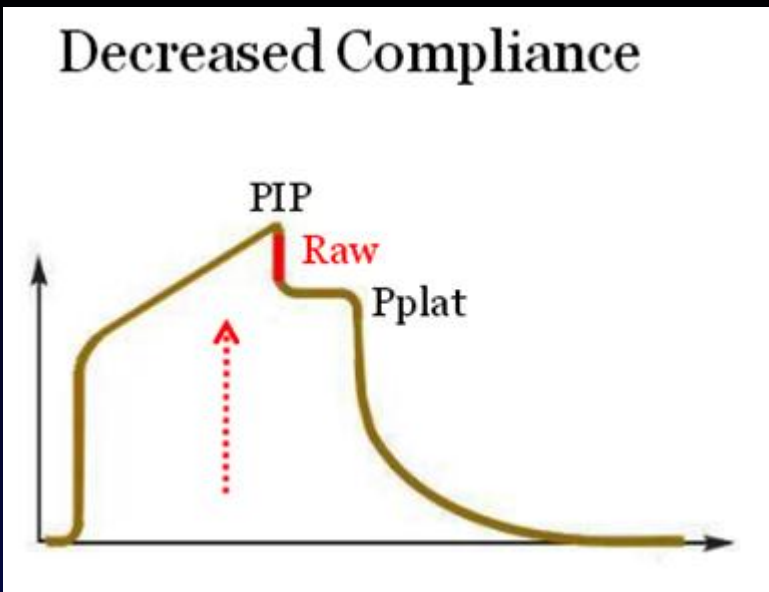
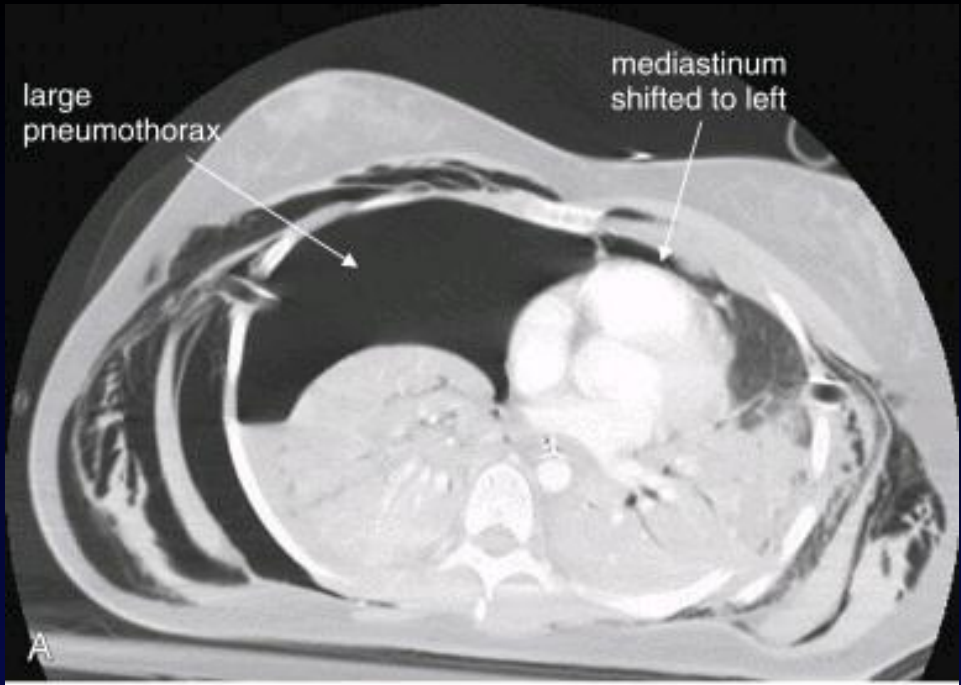


Curvas permitem diagnóstico: piora da complacência após pneumotórax.

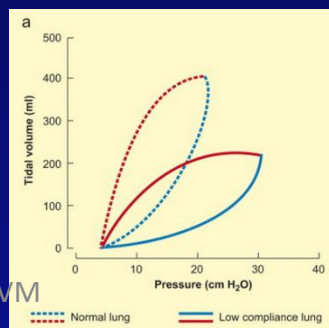
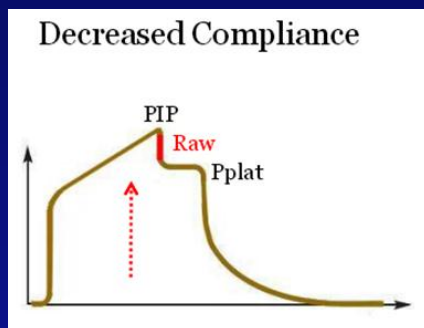
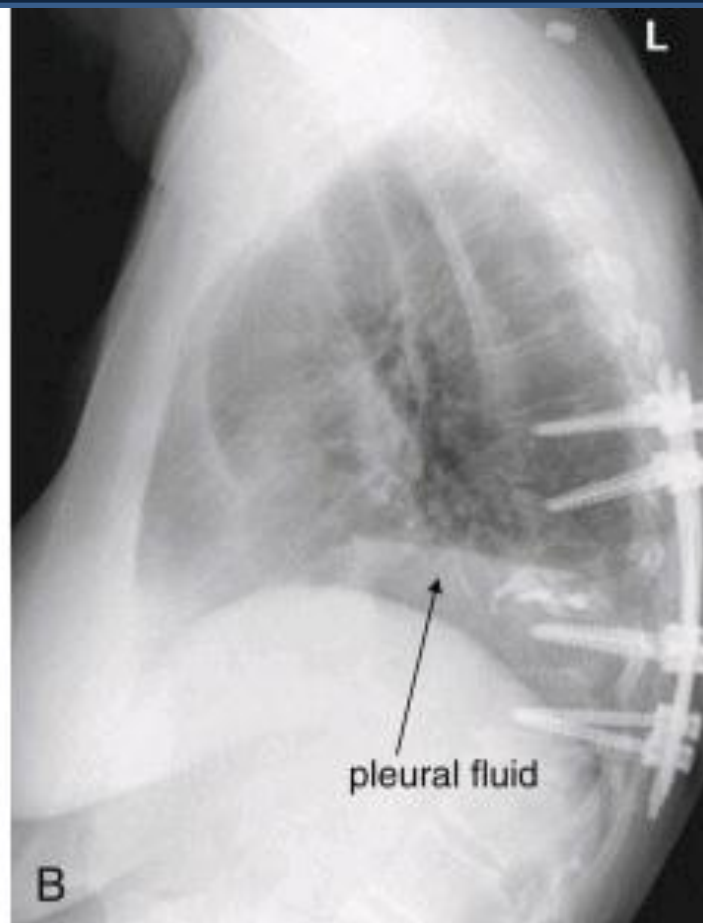
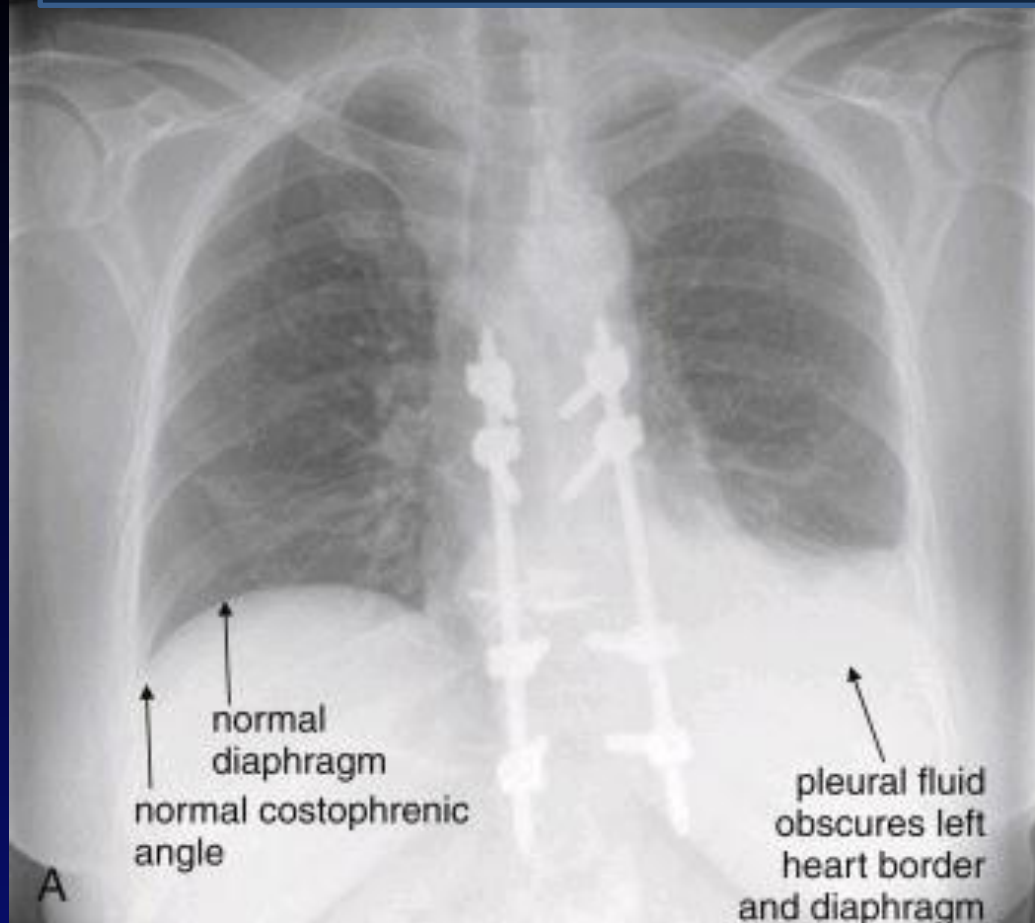
Necessário atenção, principalmente se pneumotórax pequeno!!!!

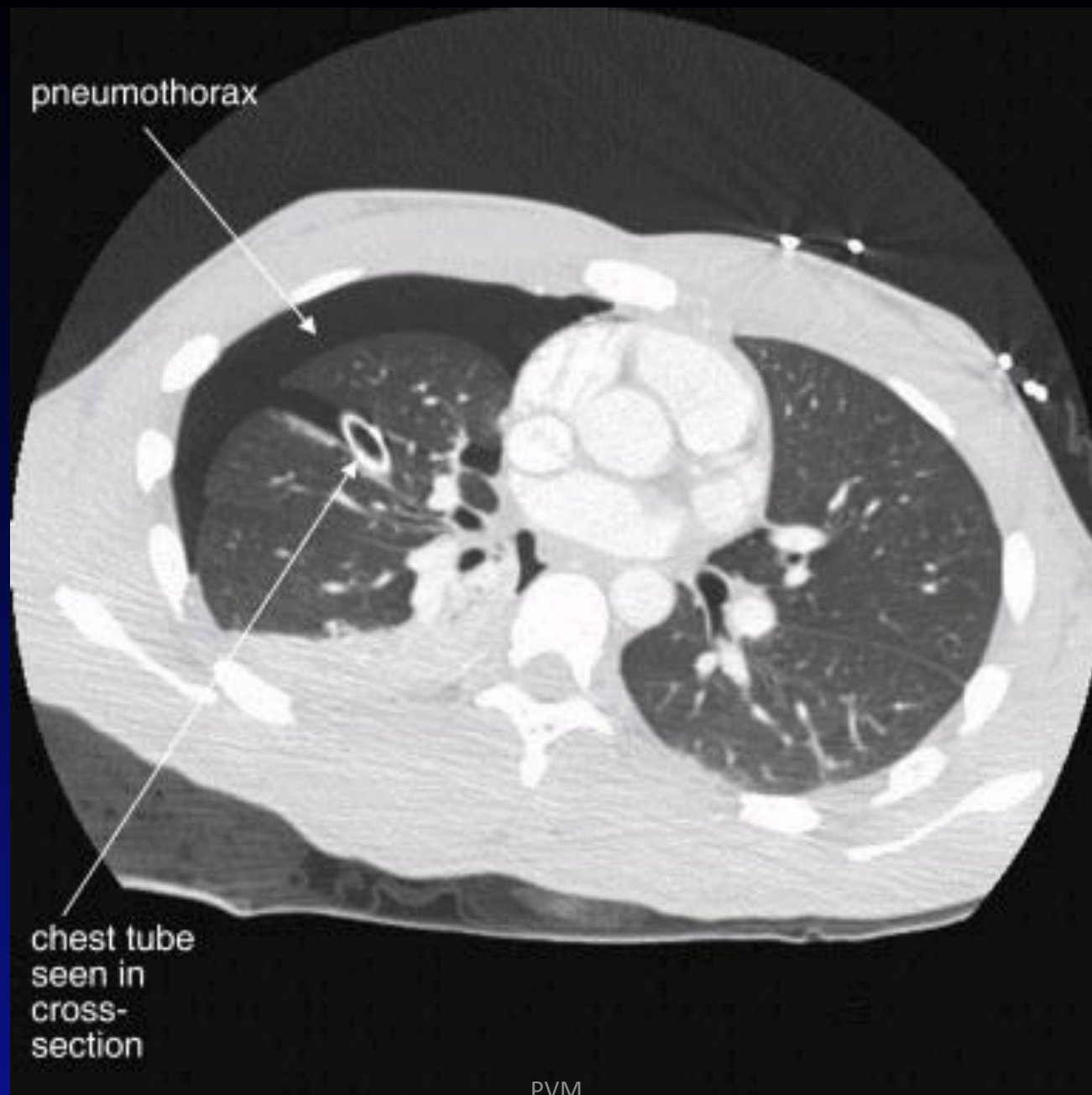


This young male suffered a spontaneous left pneumothorax. The x-ray demonstrates several features typical of pneumothorax and is subtle, though the pneumothorax is relatively large. This pneumothorax appears to be restricted to the left apical region on this upright chest x-ray

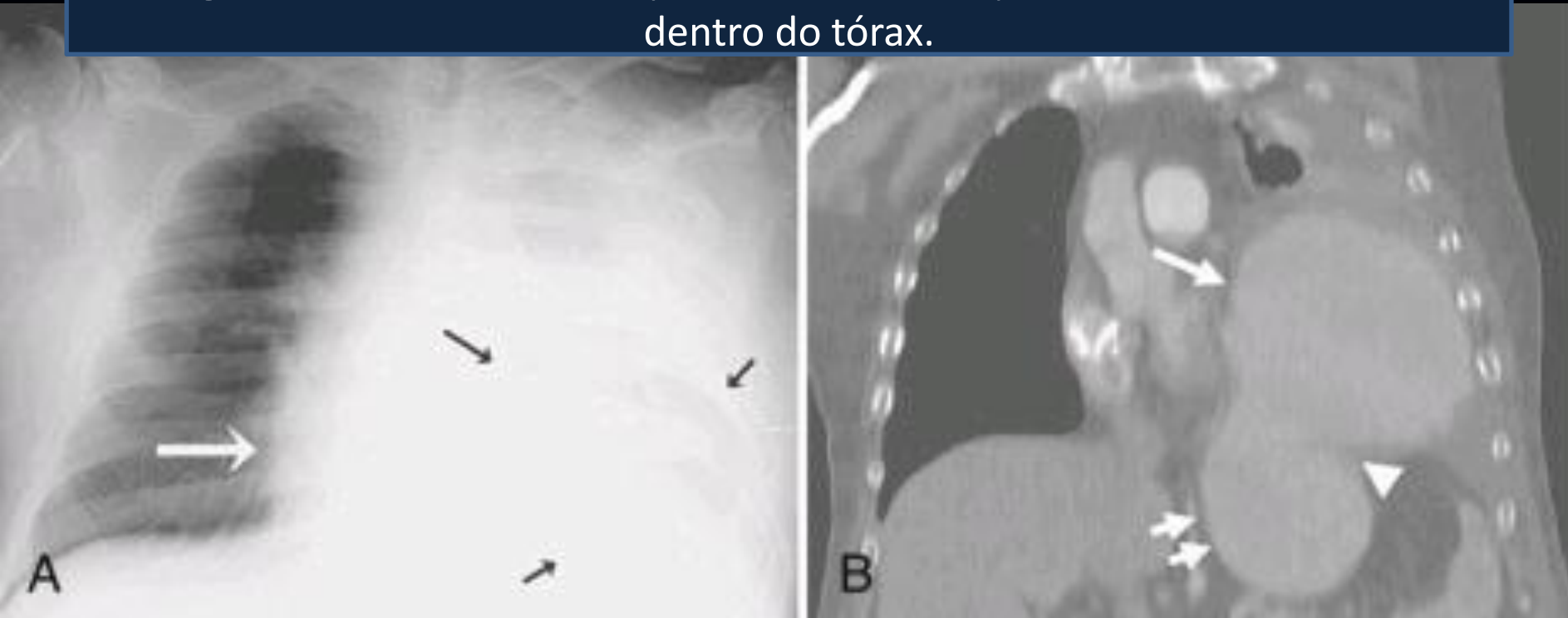


Curvas permitem diagnóstico: piora da complacência após derrame pleural



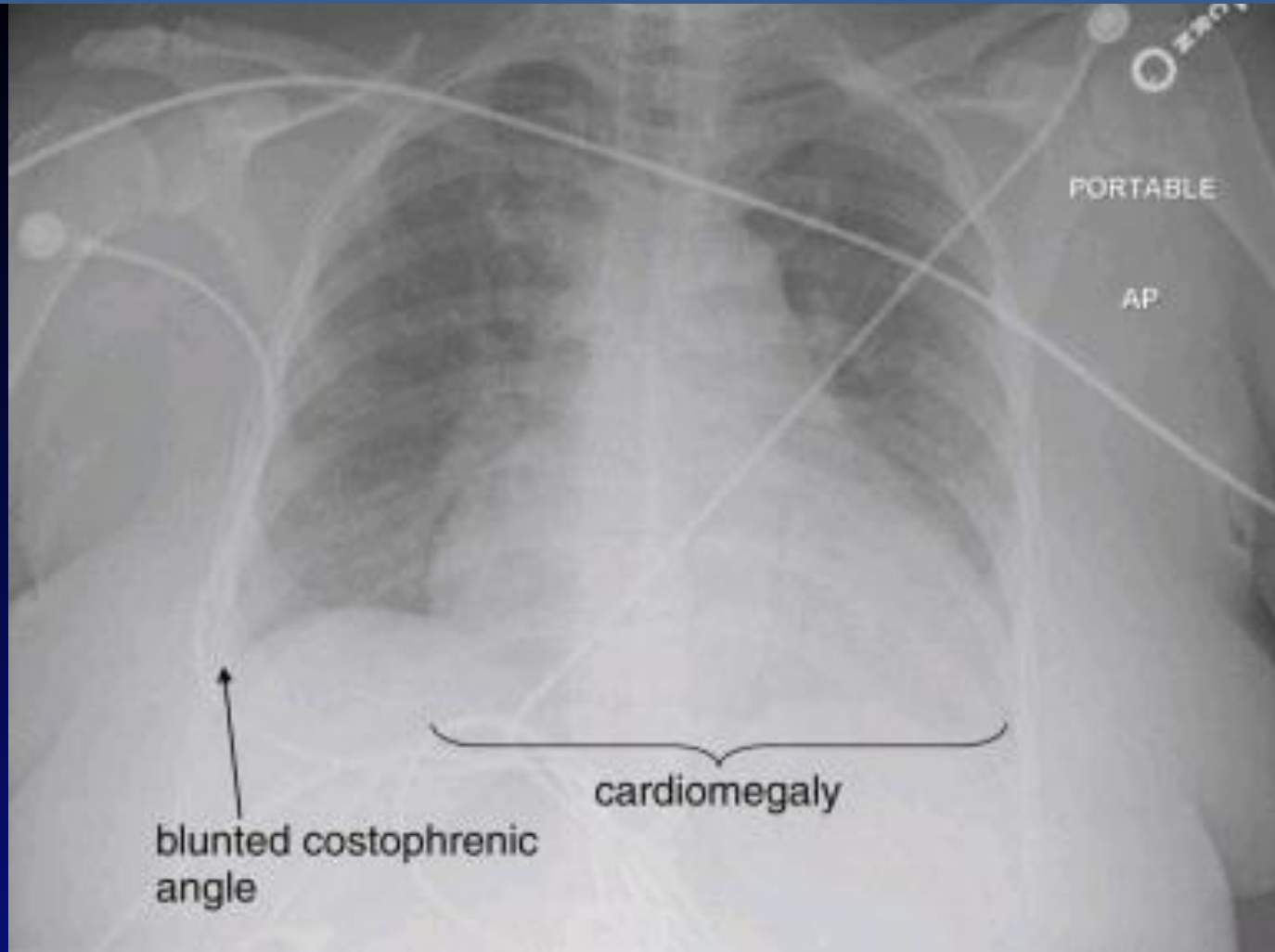


Diagnóstico diferencial: complacência reduzida por conteúdo abdominal dentro do tórax.



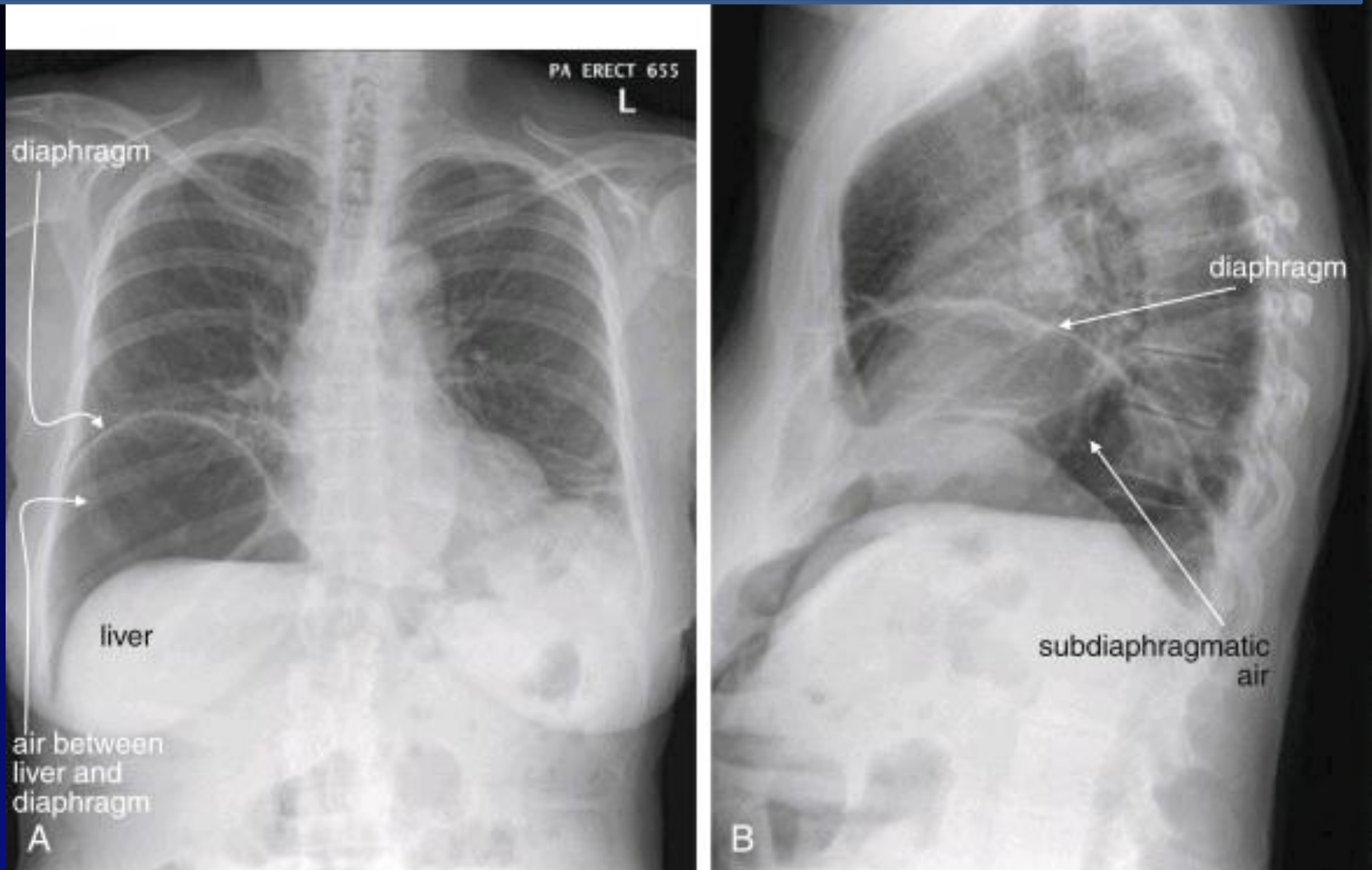
A 48-year-old man involved in a motor vehicle crash sustained a diaphragmatic injury. A, Bedside chest radiograph shows diffuse opacity in left hemithorax and rightward mediastinal displacement (*white arrow*). A round lucency representing the gastric bubble is present within opacified left hemithorax (*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



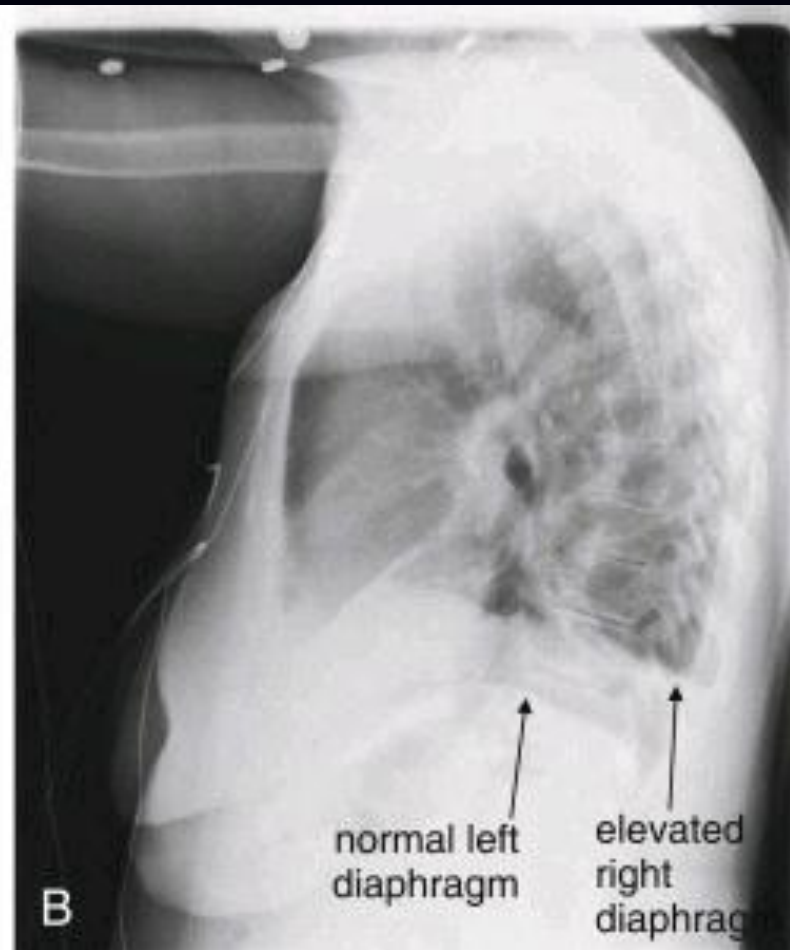
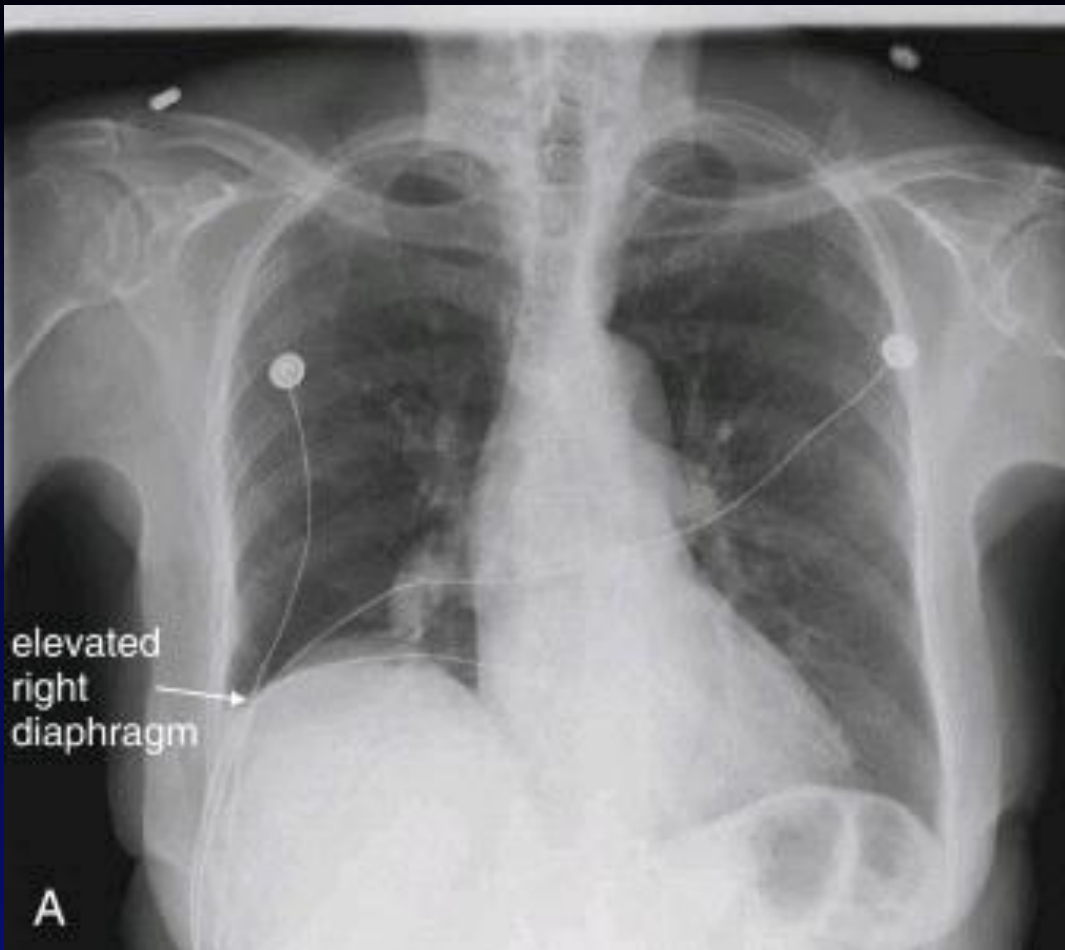
Congestive heart failure, postpartum: Ejection fraction of less than 15%, no pericardial effusion.

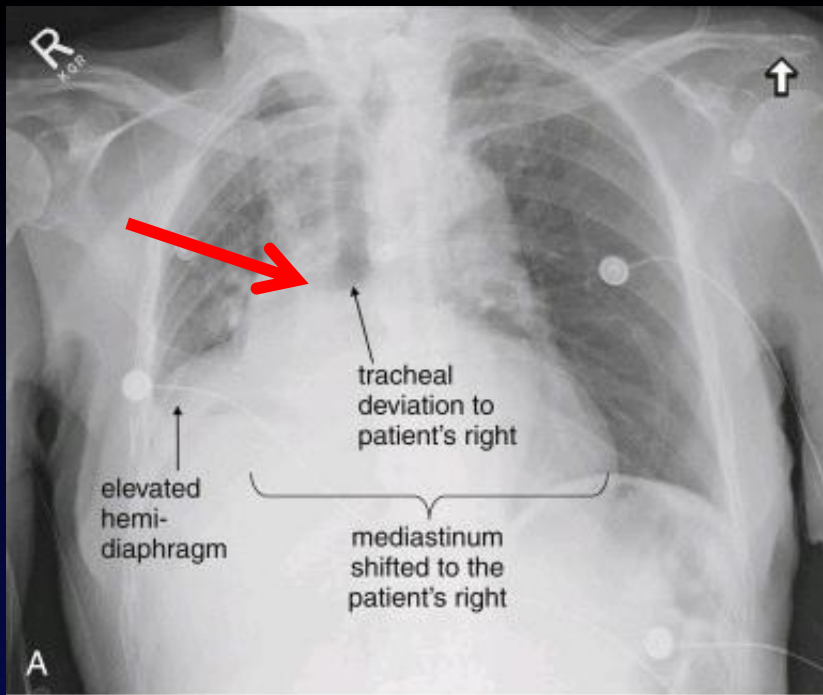
Diagnóstico diferencial: complacência reduzida por pneumoperitônio. Pode ser uma complicação do CPAP nasal, ou úlcera péptica, como no RX abaixo



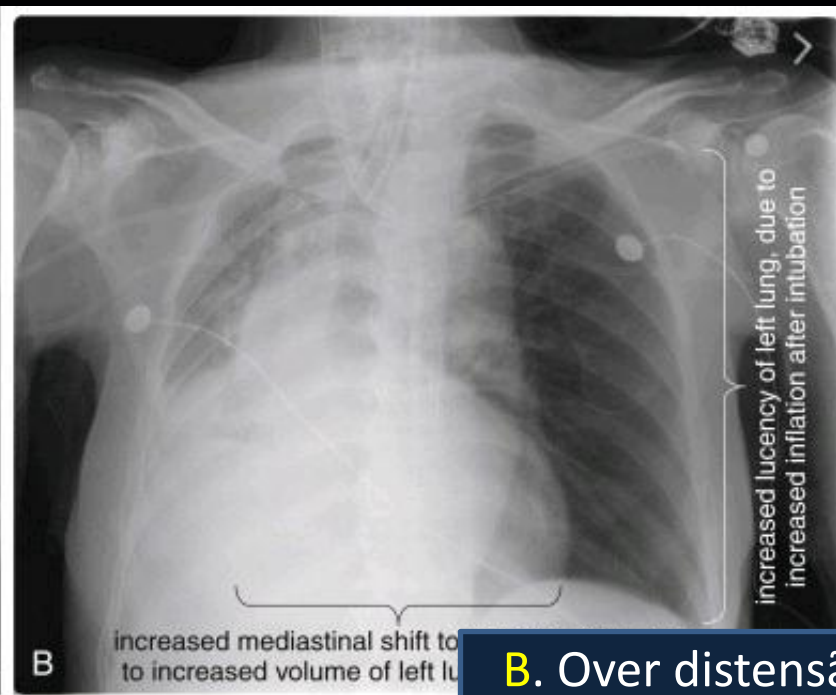
This patient was found to have a perforated gastric ulcer at laparotomy.

Diagnóstico diferencial: complacência reduzida por atelectaísa

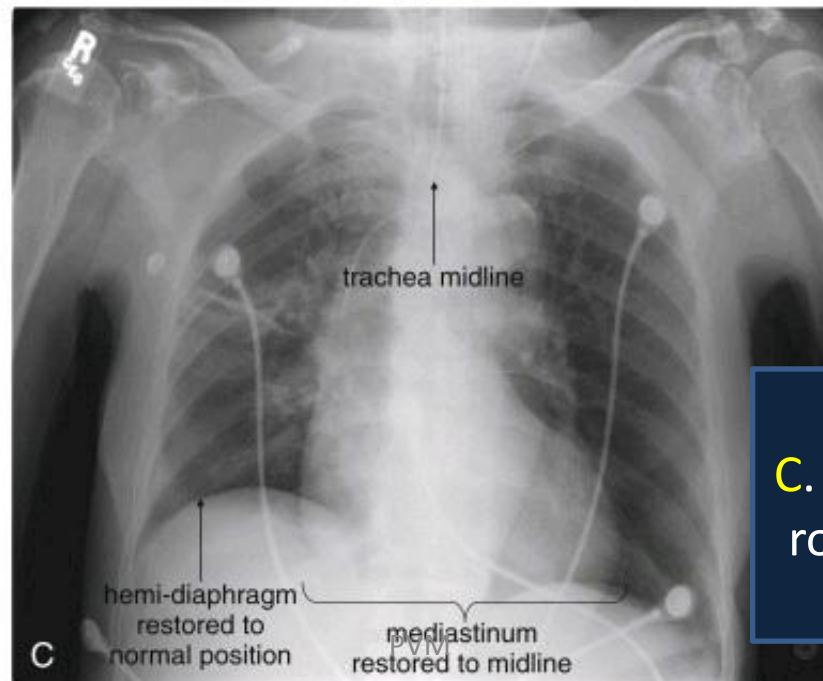




A. Atelectasia por
 rolha em paciente
 asmático. Ver sinal
 de “stop bronquico”
 seta vermelha



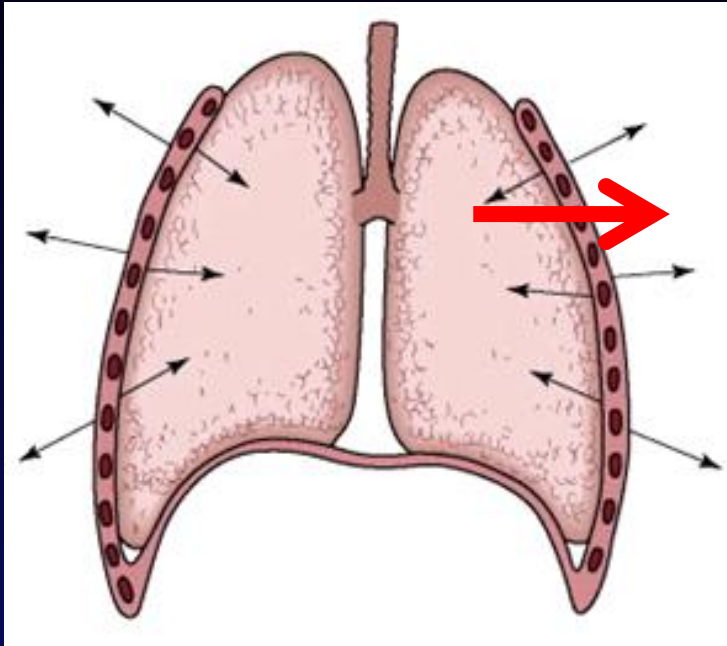
B. Over distensão a
 esquerda e piora da
 atelectasia a direita
 após intubação e
 instalação de VM,
 com piora da hipóxia



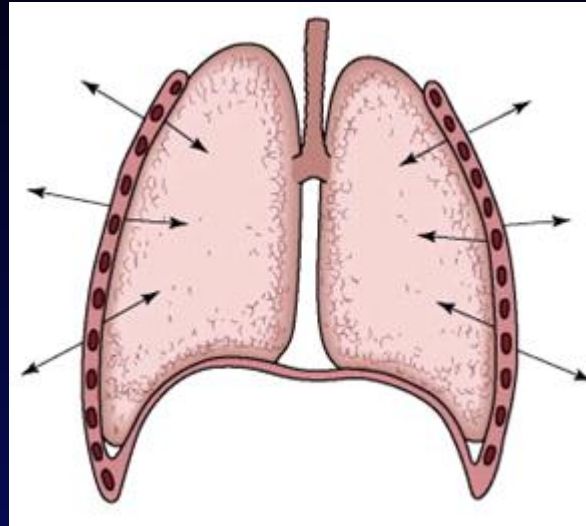
C. Melhora após remover
 rolha com broncoscopia

VM PROTERTORA

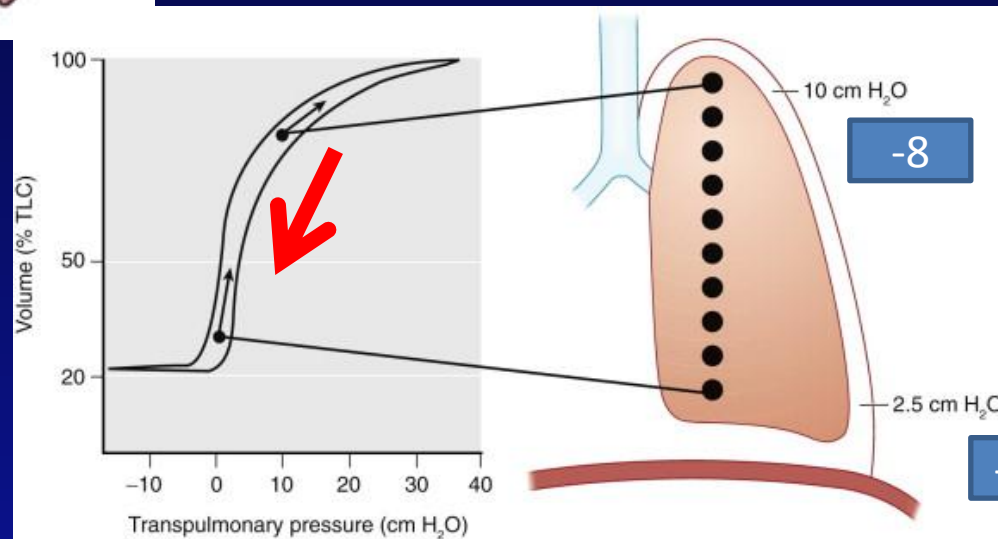
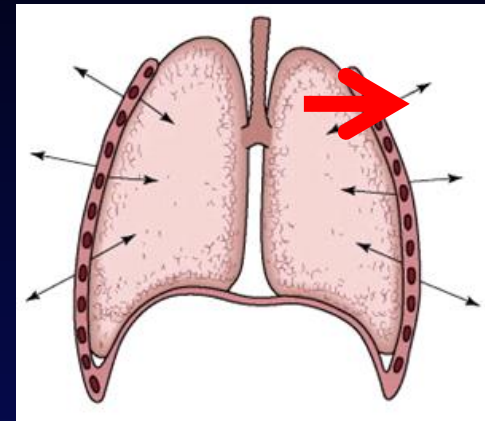
CRF



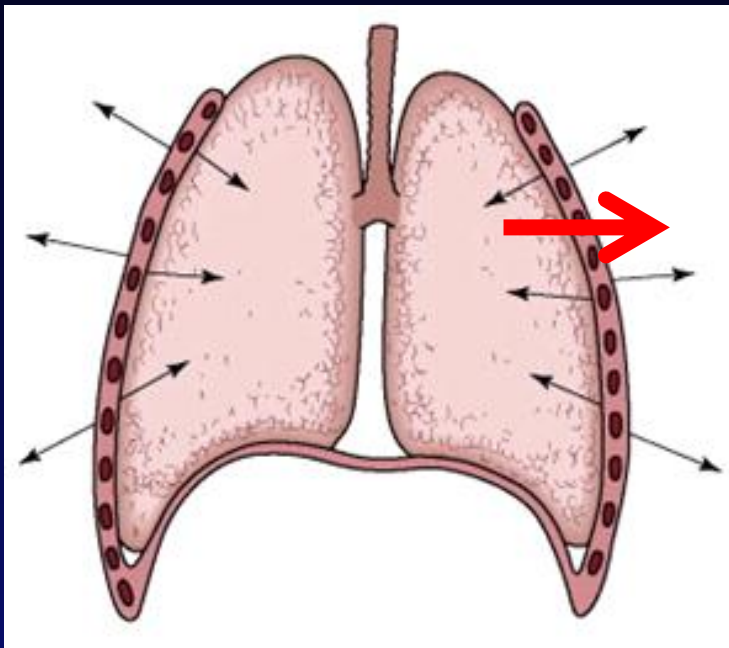
Volume de
Fechamento



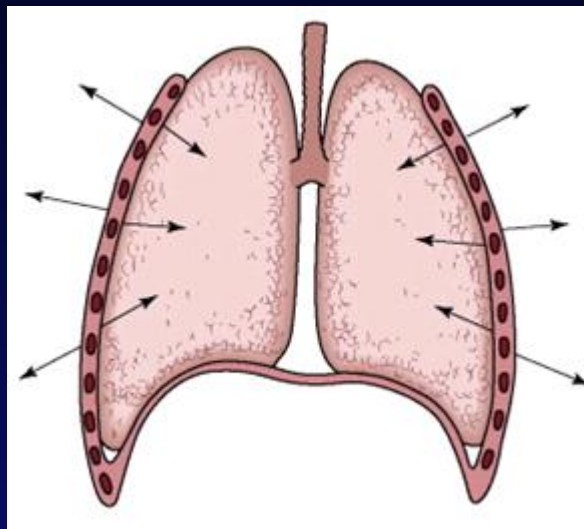
CRF



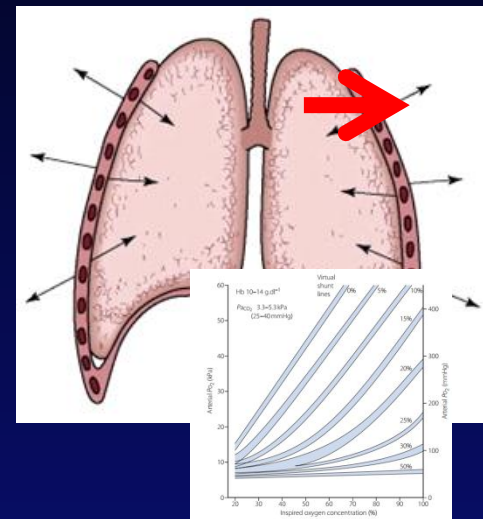
CRF



VF



CRF



CRF > VF
Desejável

PVM

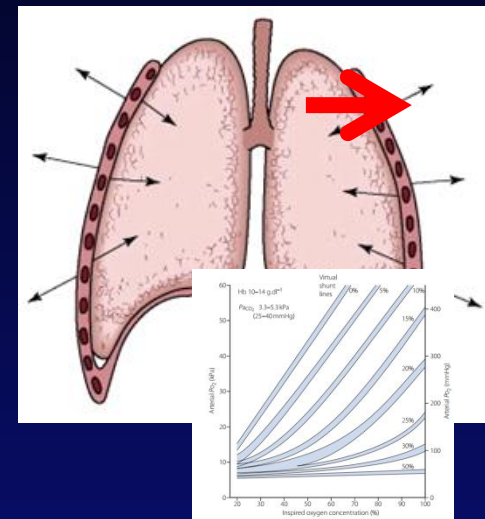
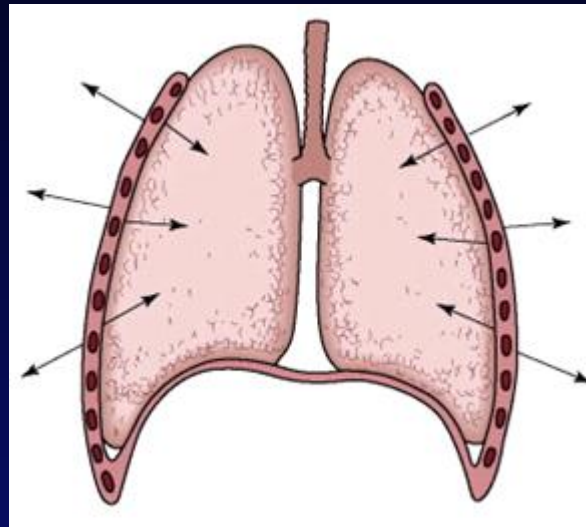
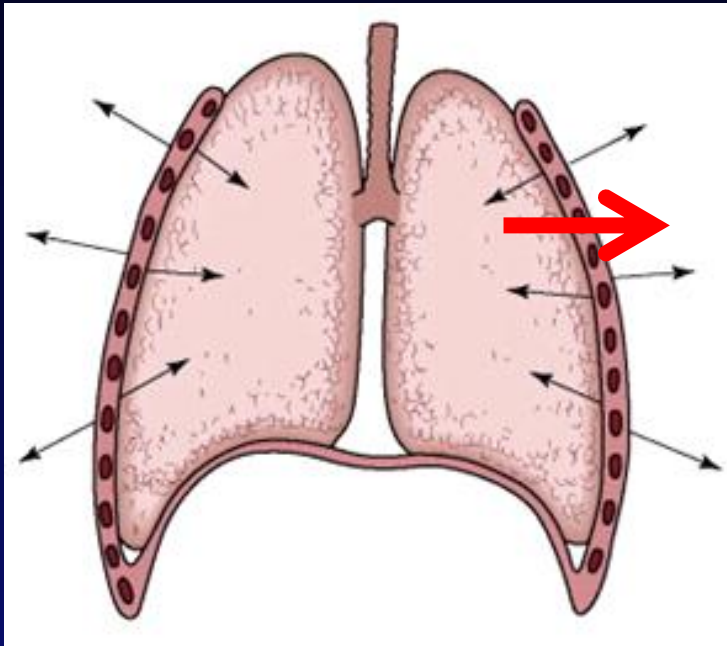
VF > CRF
Atelectasia

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

CRF

VF

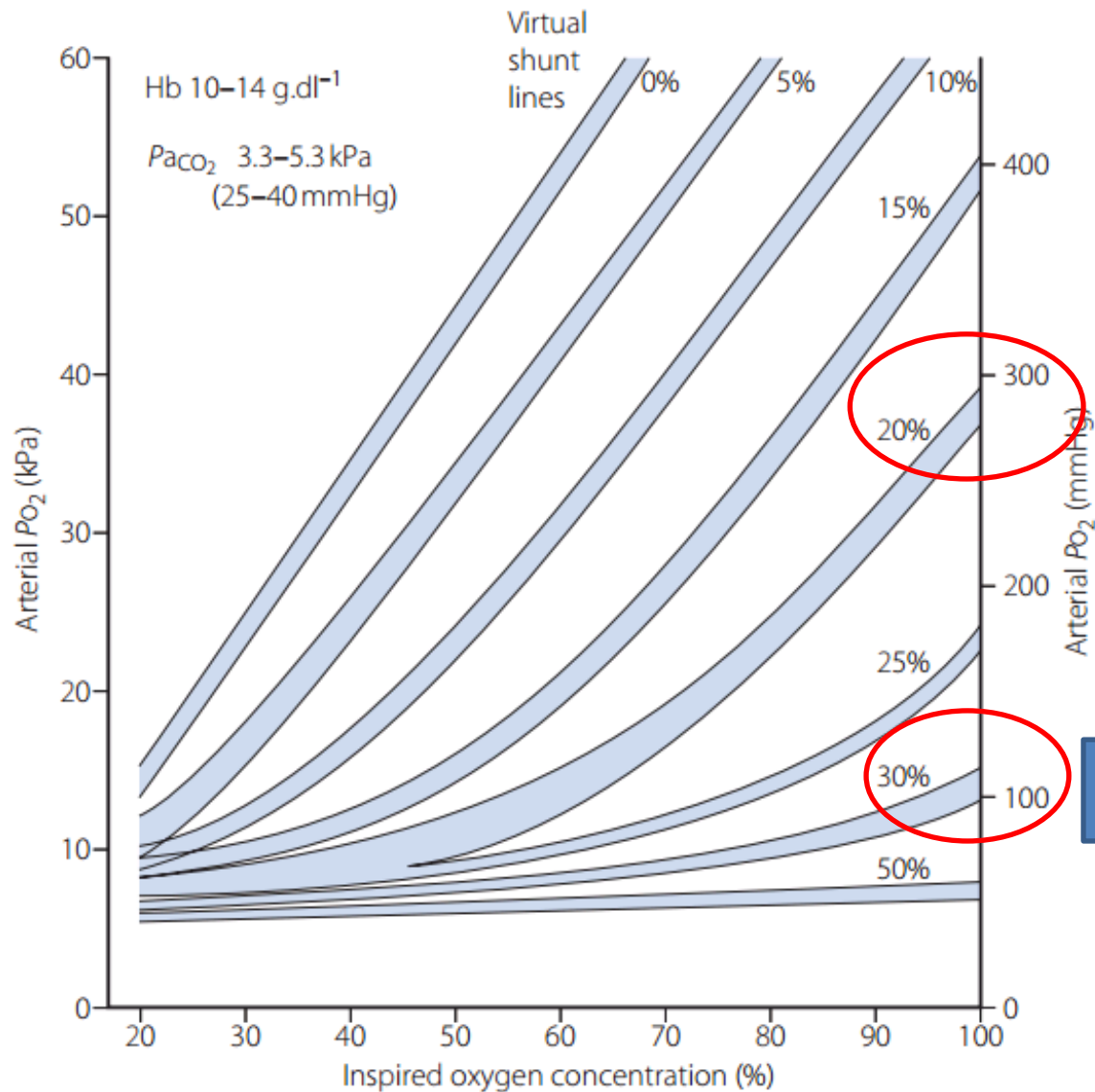
CRF



Desejável

Atelectasia

SHUNT

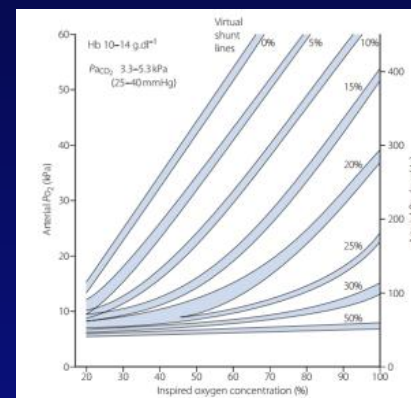


$P/F = 285$

$P/F = 100$

VM Protetora

- Evitar barotrauma
- Evitar volutrauma
- Evitar atelectrauma
- Usar PEEP para estabilizar o alvéolo
- Minimizar FiO2
- $V_t < 6\text{ml/Kg}$
- Pressão plateau $< 25\text{-}30\text{cmH}_2\text{O}$
- Diminuir espaço morto

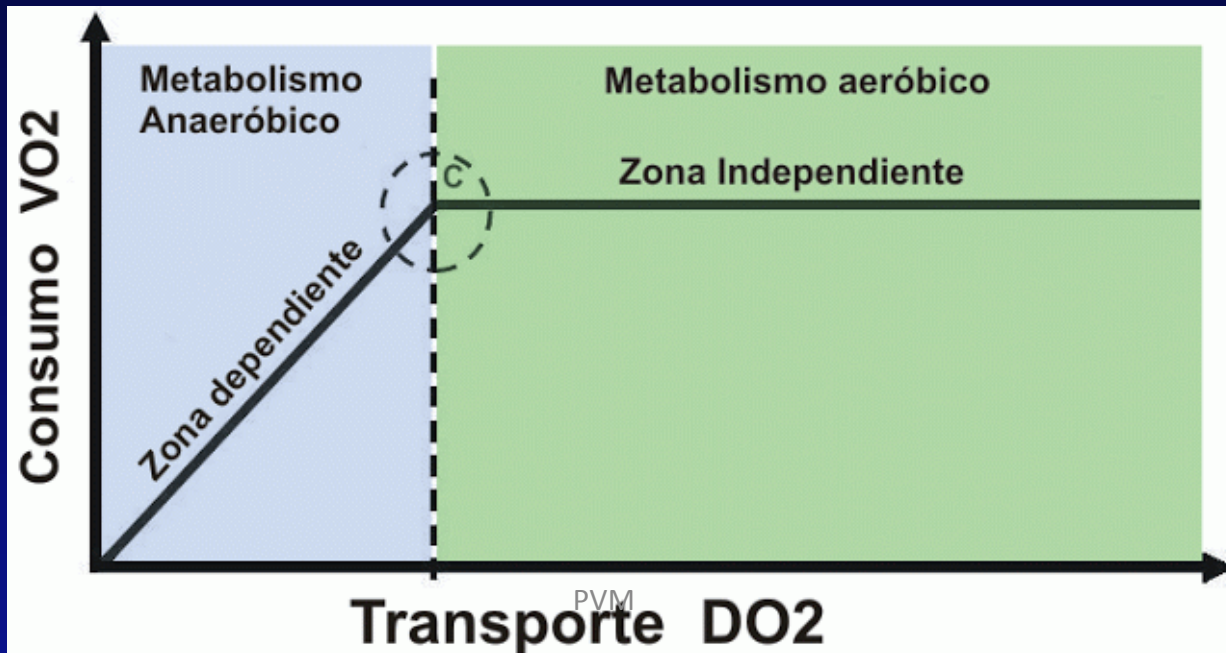


Biotrauma

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

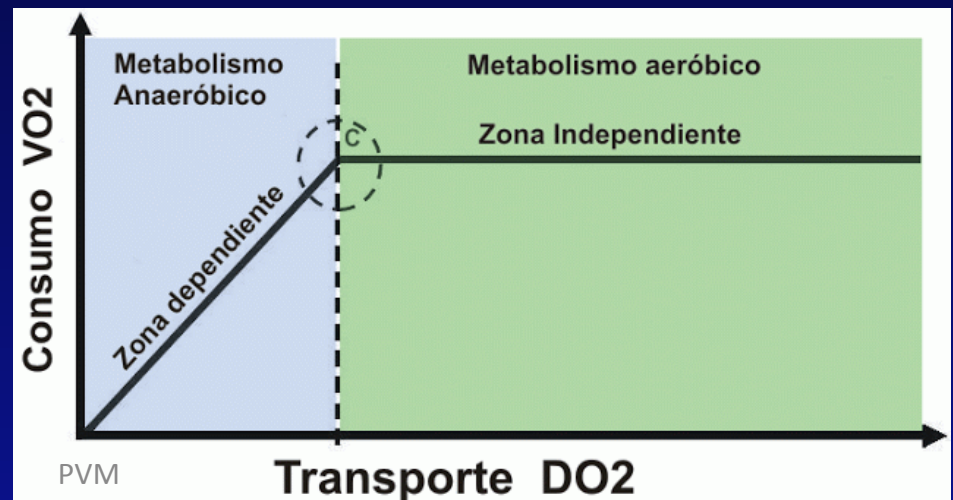
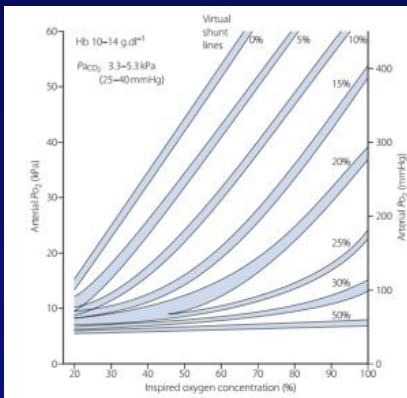
VM Protetora

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

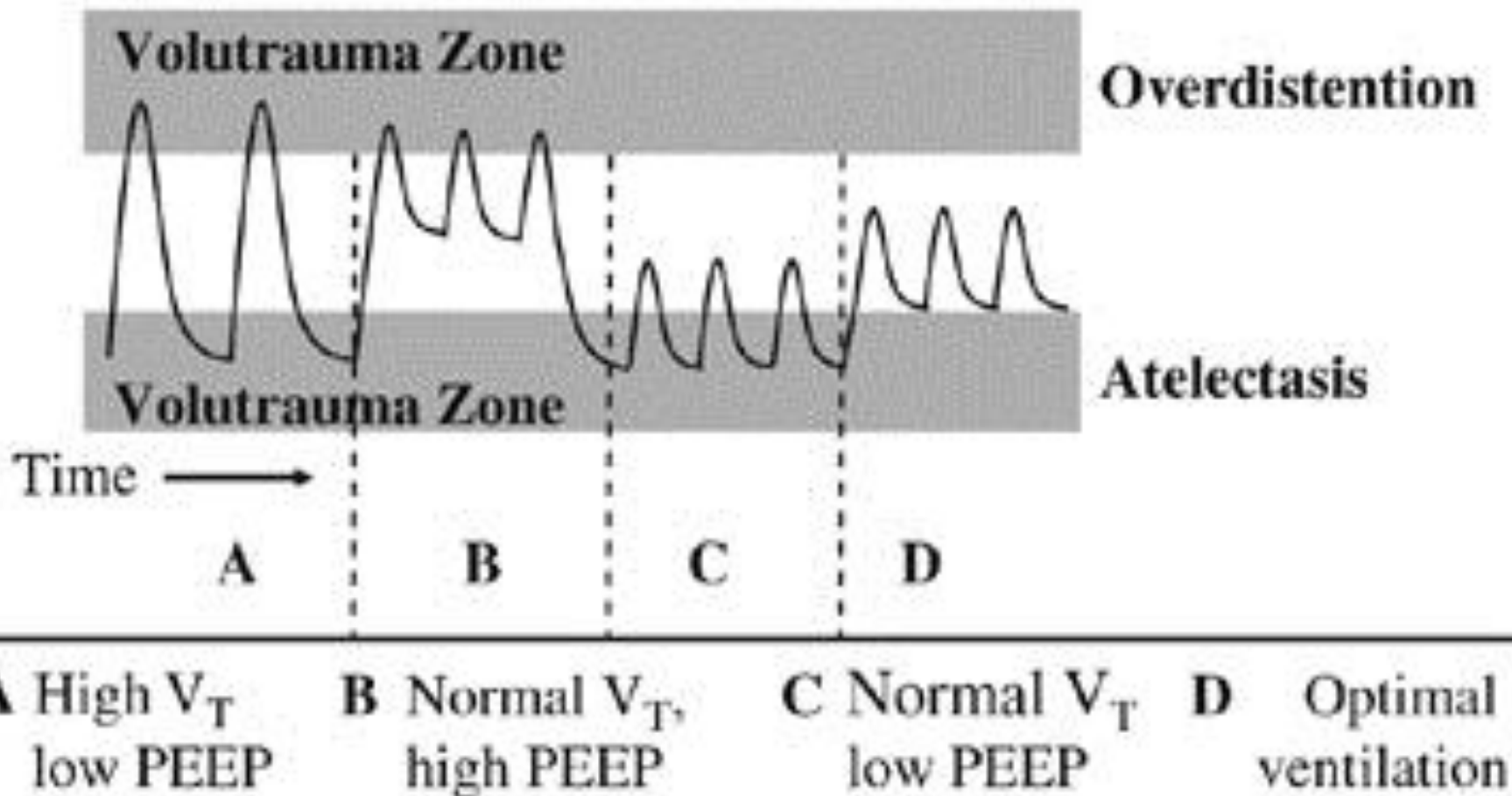


DOSIMETRIA

- $DO_2 = DC \times CaO_2$ ($CaO_2 = Hb \times 1,34 \times StO_2$)
 - Biotrauma: aumento pós-carga VD, diminui DC
 - Biotrauma: SARA: diminui CaO_2
 - Suporte insuficiente: aumenta trabalho respiratório; não melhora a hipoxemia.



WHICH VOLUMES CAUSE LUNG INJURY?



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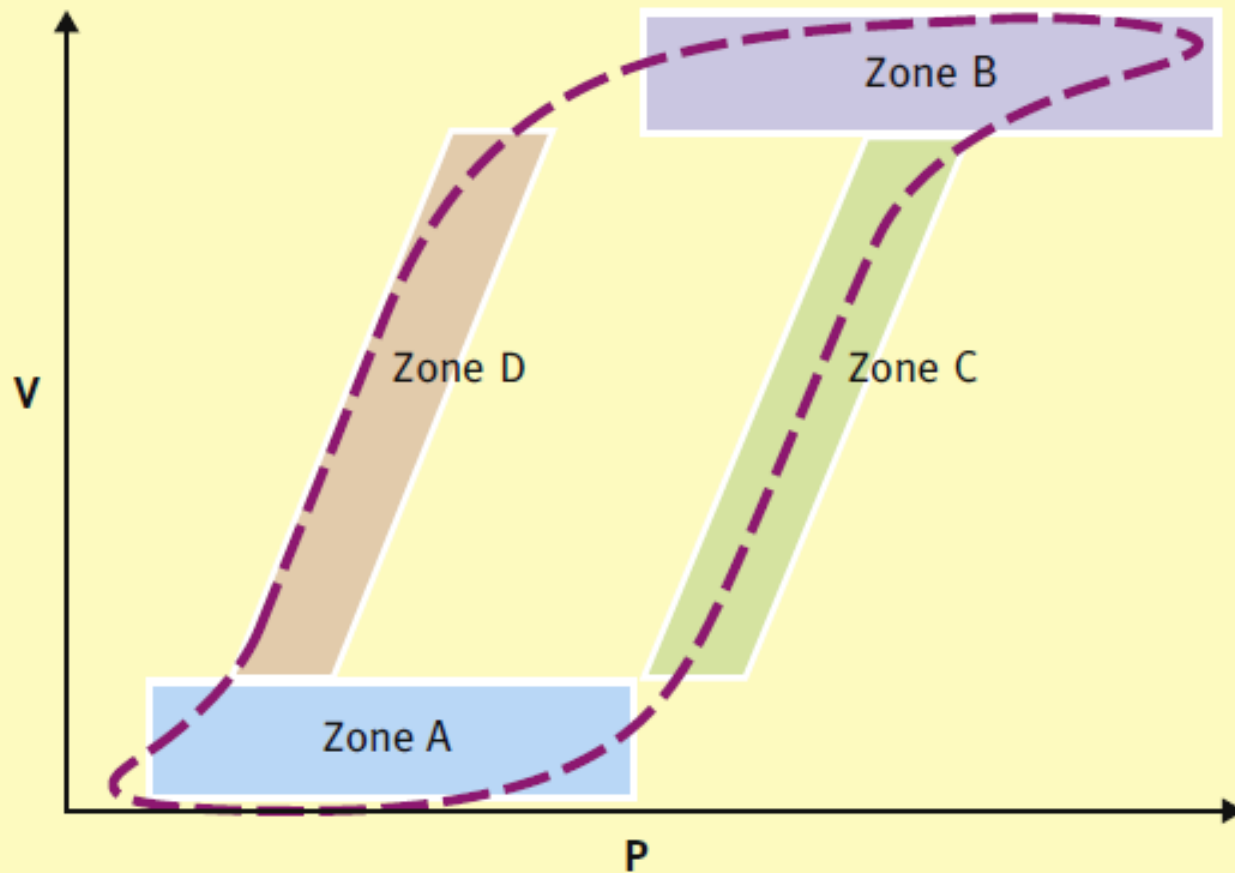


Figure 2 Strategy to avoid ventilator-induced lung injury — adopted from HFO ventilation model (P = Pressure, V = Volume). Zone A = Under-inflation causing atelectrauma. Zone B = over-inflation causing Volutrauma. Zone C = optimal recruitment inflation. Zone D = optimal expiratory inflation: The goal 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
 - $V_t < 6\text{ml/Kg}$
 - Pressão plateau $< 25\text{-}30\text{ cmH}_2\text{O}$
 - 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*

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*

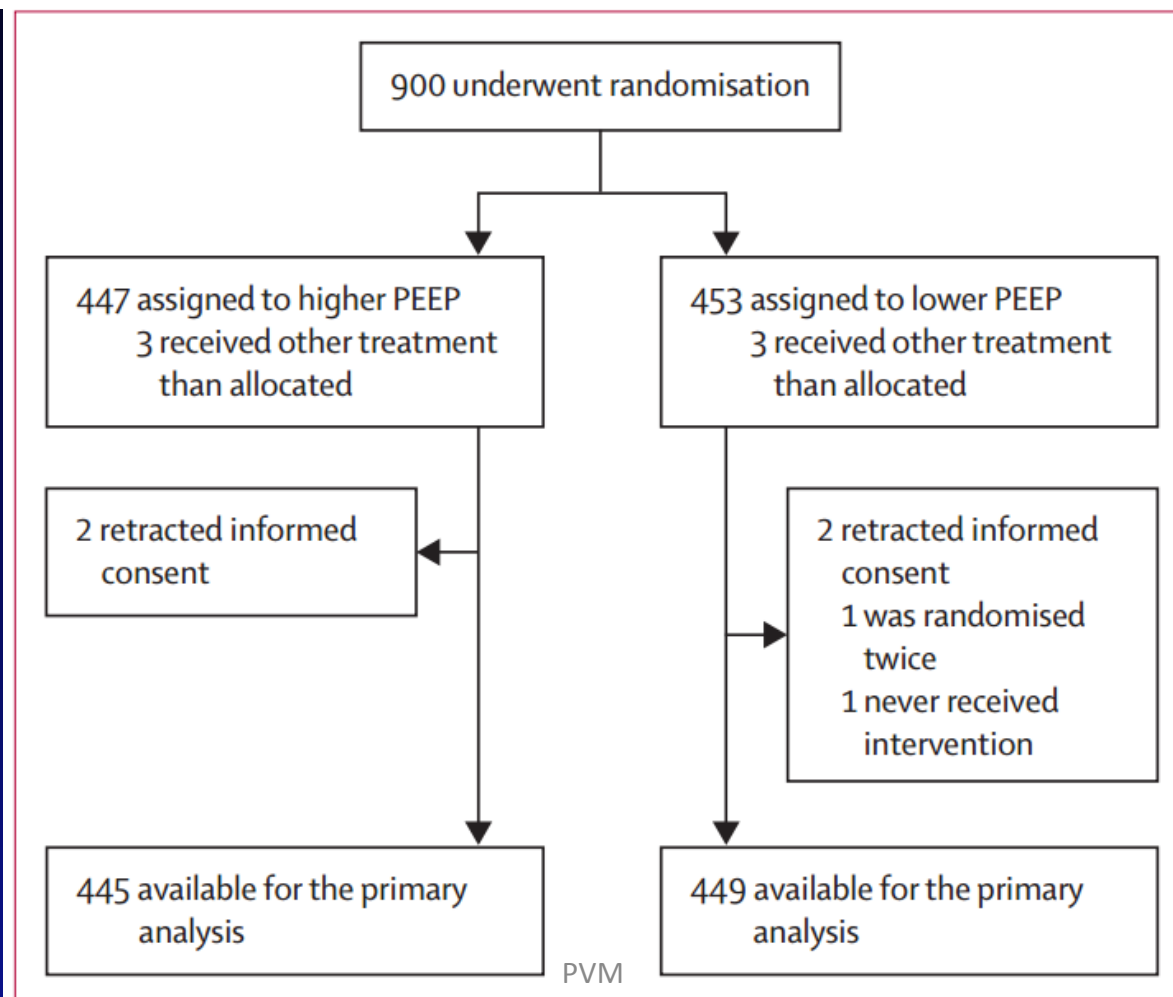
Table 3. Main Outcome Variables.*

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 PVM	11.2±0.4	<0.001

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*



PROVHILO TRIAL

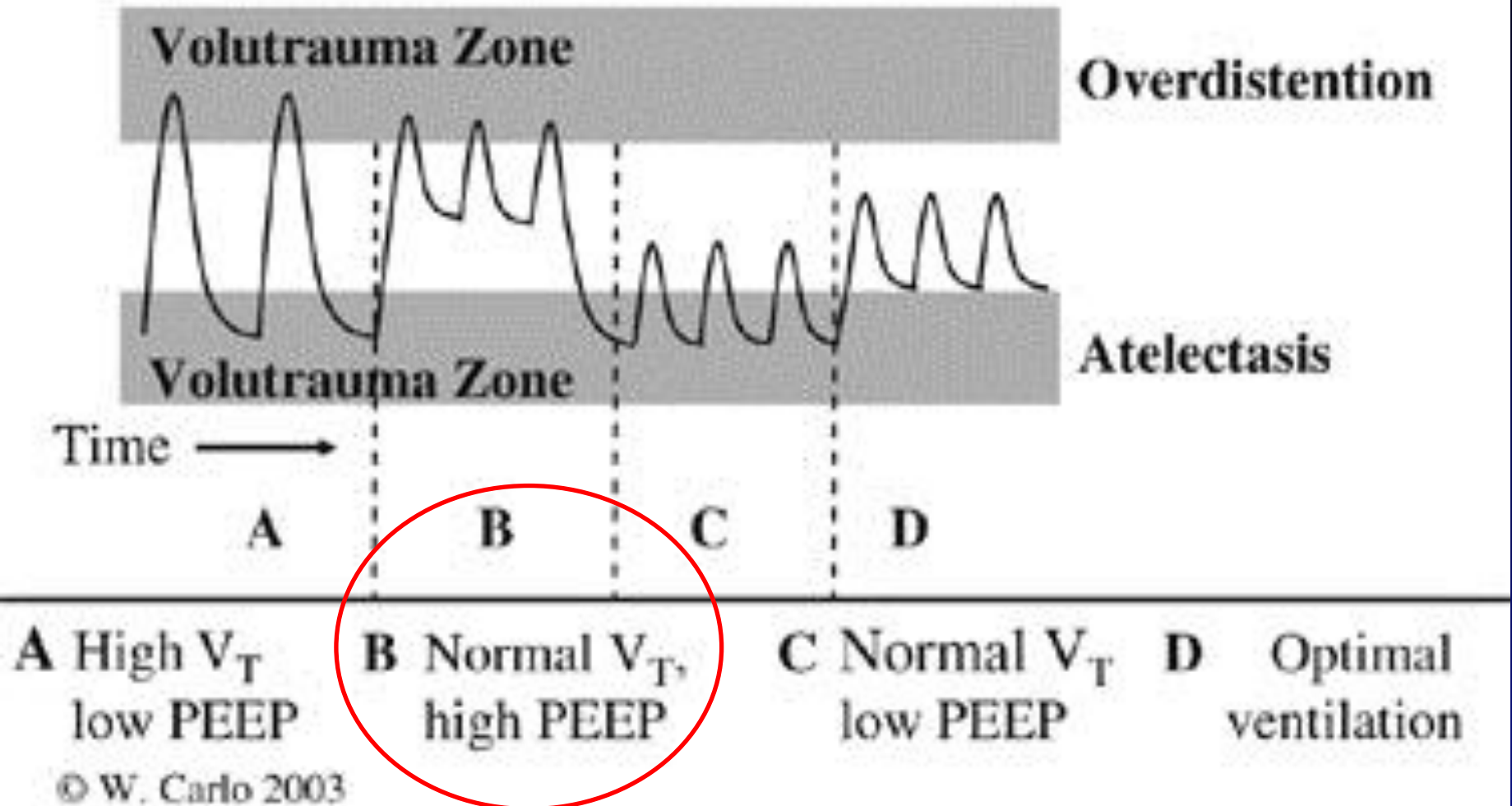
- N pequeno
- Atelectasia persistente no pós-operatório relacionada a FiO2 alta
- Grupo PEEP alto: melhor complacência torácica mas não houve melhor desfecho:
 - Volutrauma nas regiões não dependentes
 - Hemodinâmica

PROVHILO TRIAL

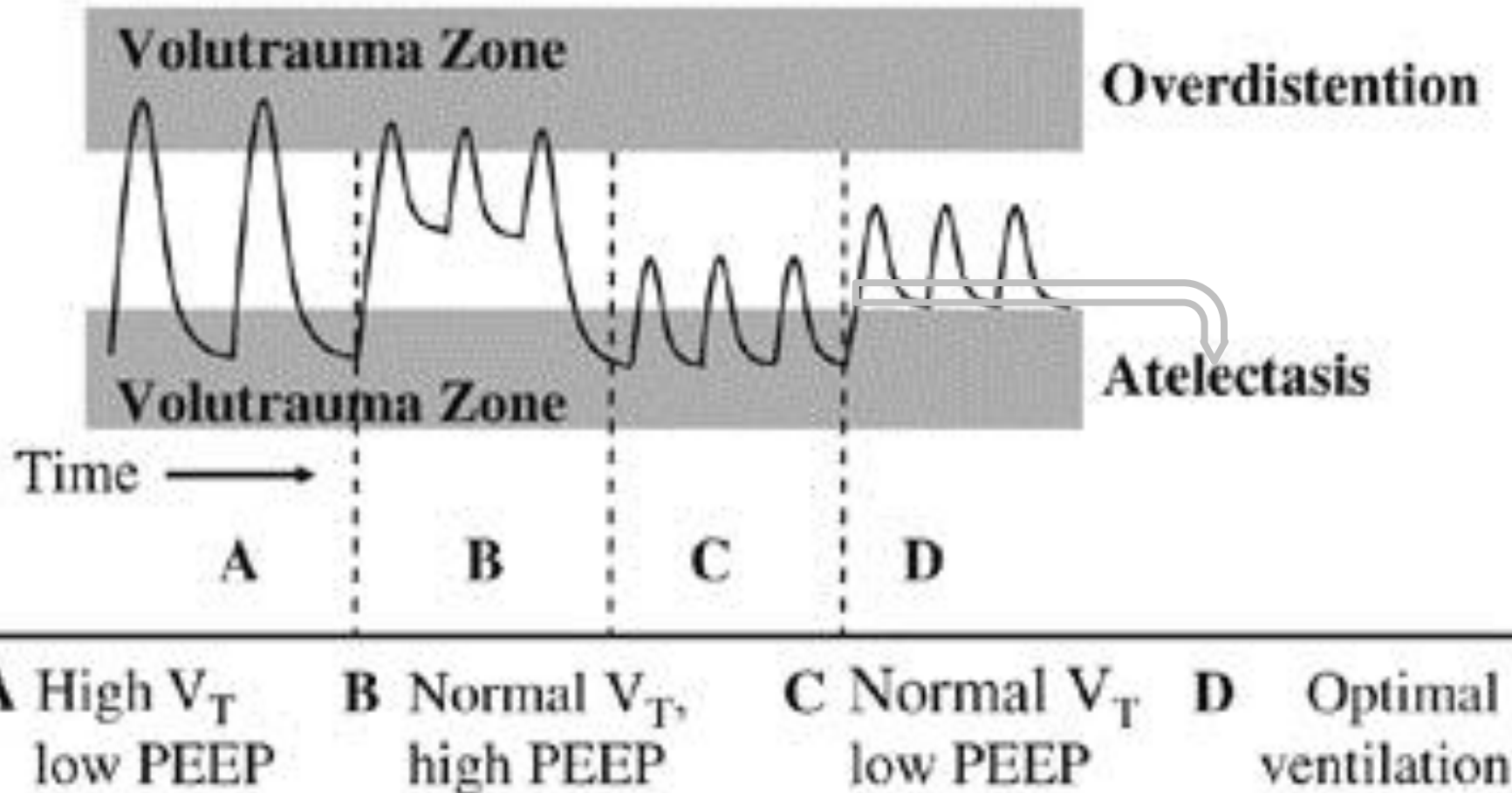
	Higher PEEP group (n=445)	Lower PEEP group (n=449)	Relative risk (95% CI)	p
Intraoperative complications				
Rescue strategy for desaturation	11/442 (2%)	34/445 (8%)	0.34 (0.18–0.67)	0.0008
Hypotension††	205/441 (46%)	162/449 (36%)	1.29 (1.10–1.51)	0.0016
Vasoactive drugs needed	274/444 (62%)	228/445 (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?



WHICH VOLUMES CAUSE LUNG INJURY?



© W. Carlo 2003

PEEP

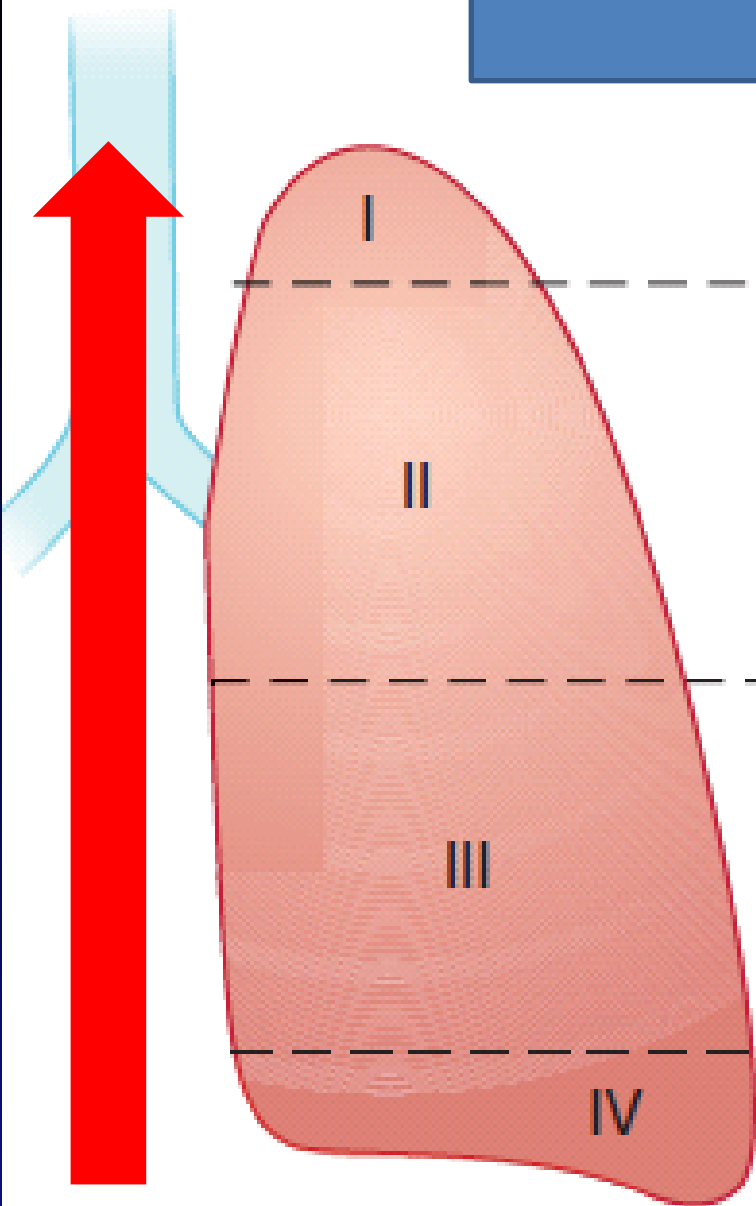
$P_{alv} > P_{pa} > P_{la}$

$P_{pa} > P_{alv} > P_{la}$

$P_{pa} > P_{la} > P_{alv}$

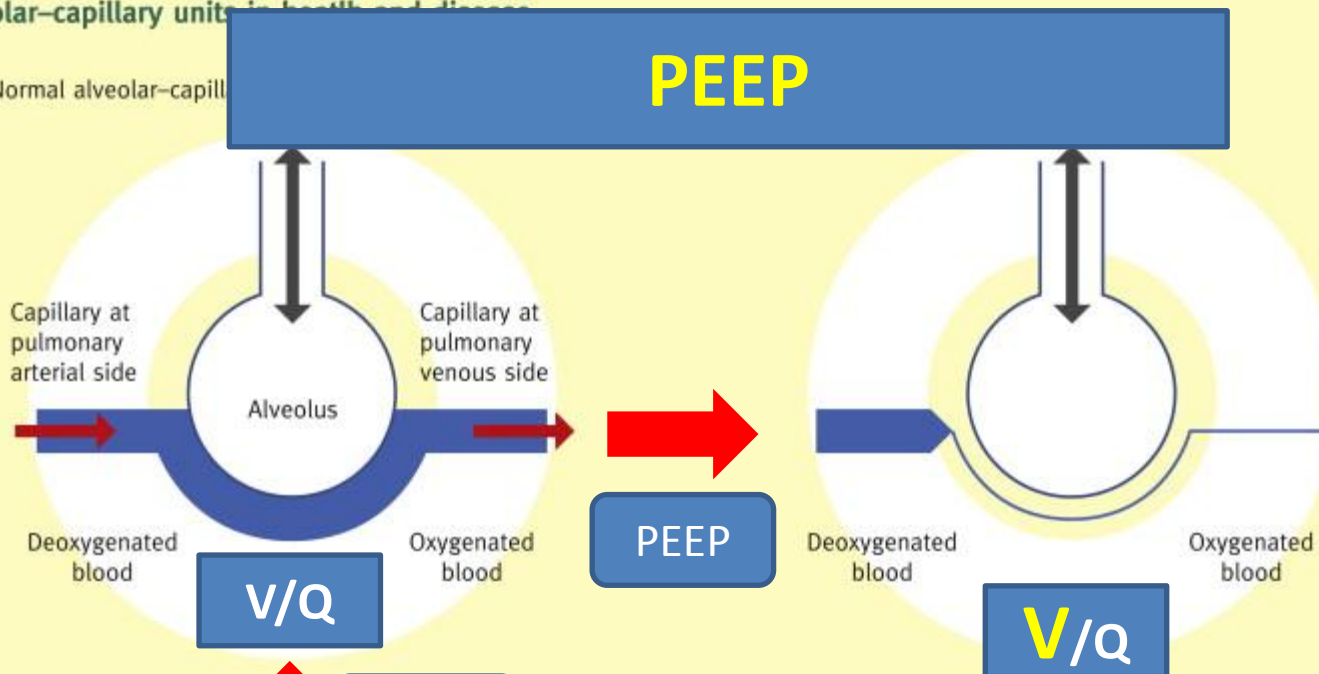
$P_{pa} > P_{la} > P_{alv}$

PVM

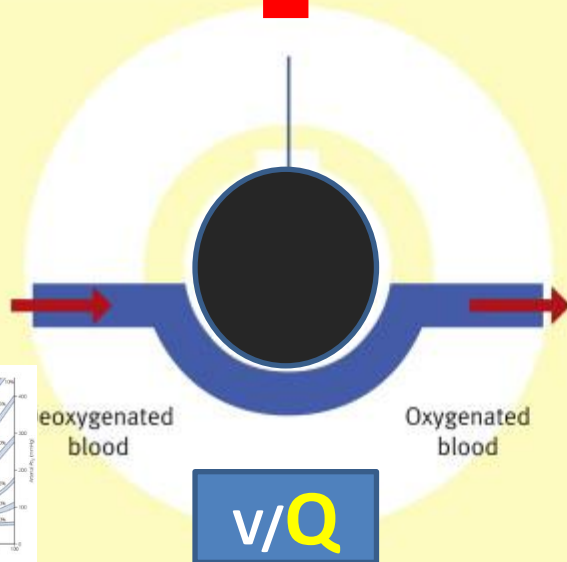


Alveolar-capillary unit in health and disease

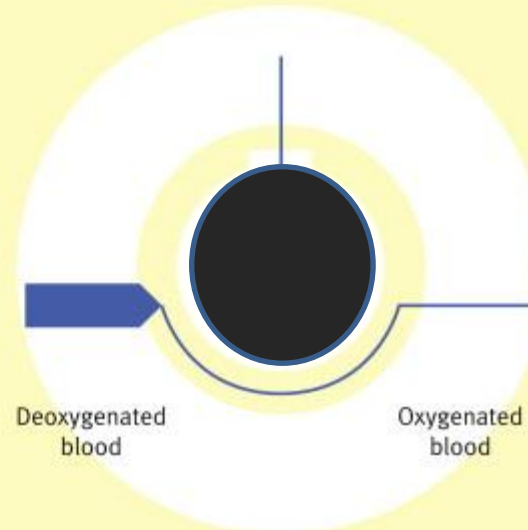
a Normal alveolar-capillary



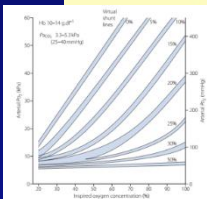
c Reduced ventilation



d Reduced ventilation and perfusion

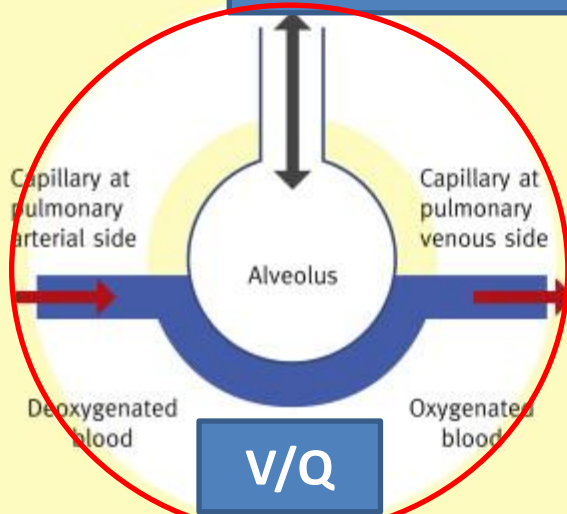


PVM



Alveolar-capillary unit in health and disease

a Normal alveolar-capillary

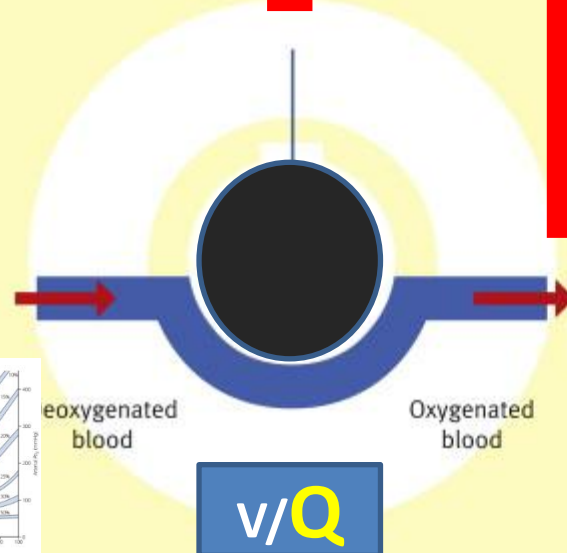


PEEP

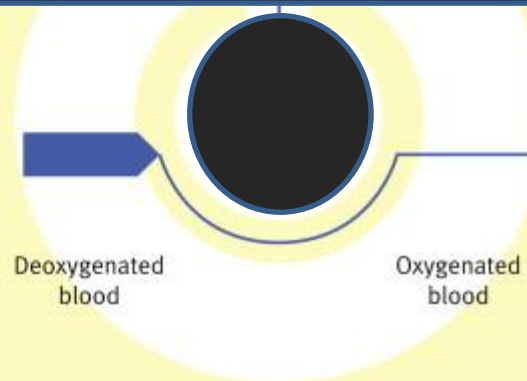
PEEP

PEEP

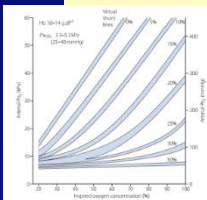
c Reduced ventilation



Aumento da PEEP melhora relação V/Q.
Aumento exagerado leva a aumento do "espaço morto"



PVM



Inflamação

Capillary at pulmonary arterial side

Capillary at pulmonary venous side

Alveolus

Deoxygenated
blood

Oxygenated
blood

Biotrauma e inflamação: inundação do alvéolo e vasoconstricção pulmonar hipóxica

blood

blood

- d Reduced ventilation and perfusion**

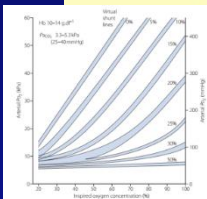
deoxygenated
blood

Oxygenated
blood

~~Deoxygenated blood~~

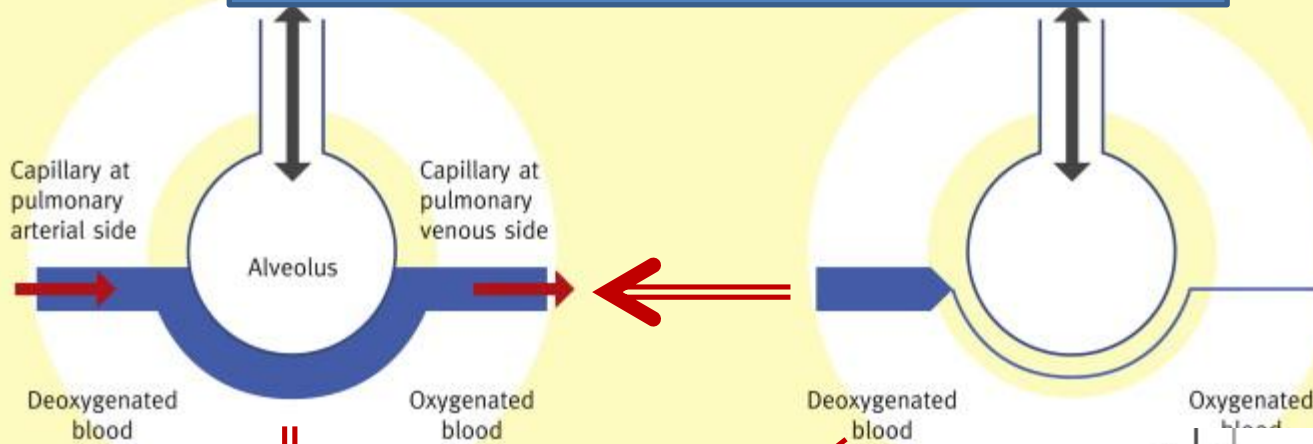
Oxygenated blood

PVM

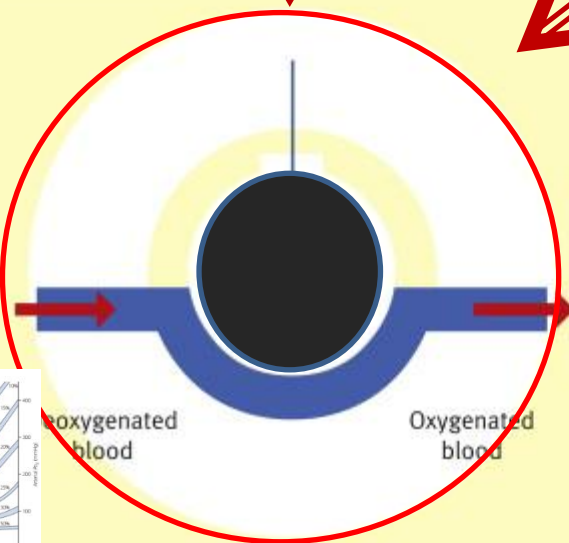


Reposição Volêmica

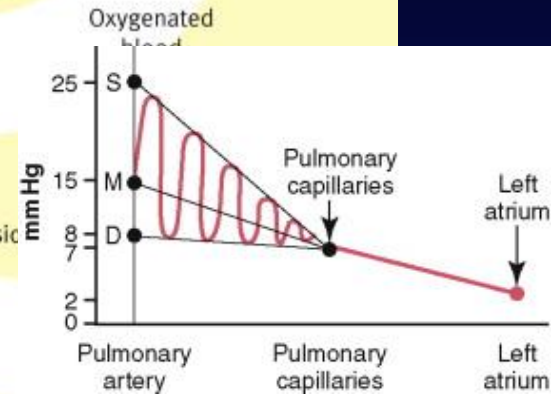
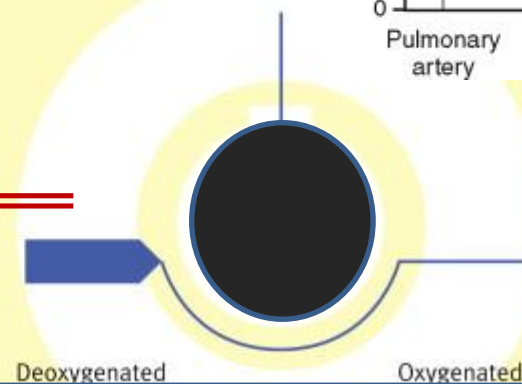
a Normal alveolar-capillary



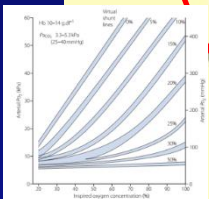
c Reduced ventilation



d Reduced ventilation and perfusion

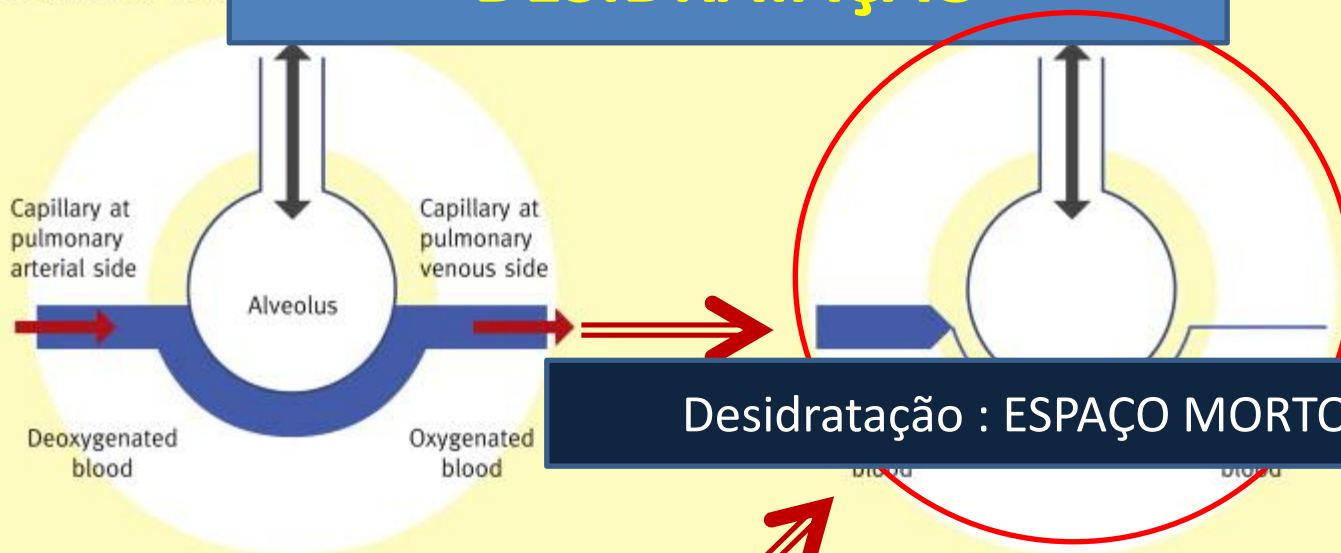


Reposição volêmica exagerada: shunt.

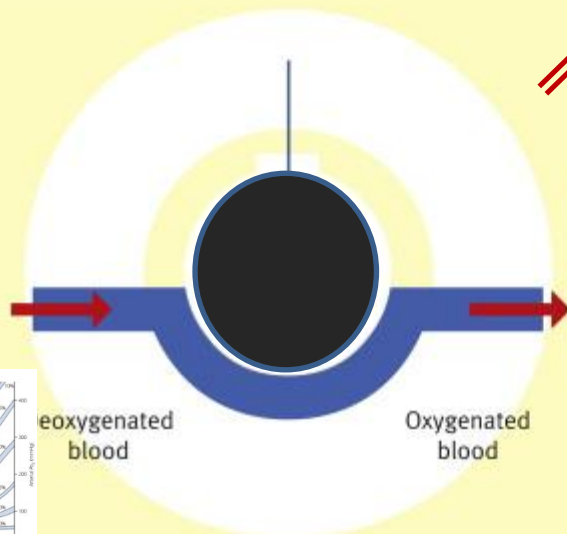


DESIDRATAÇÃO

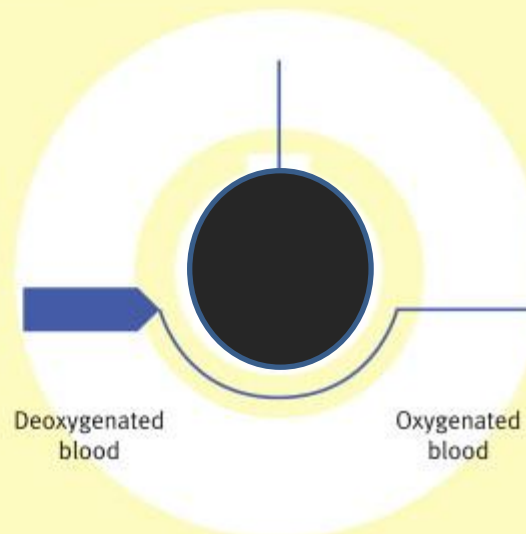
a Normal alveolar-capillary



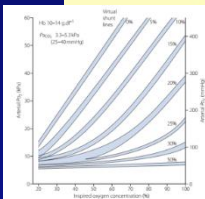
c Reduced ventilation



d Reduced ventilation and perfusion



PVM

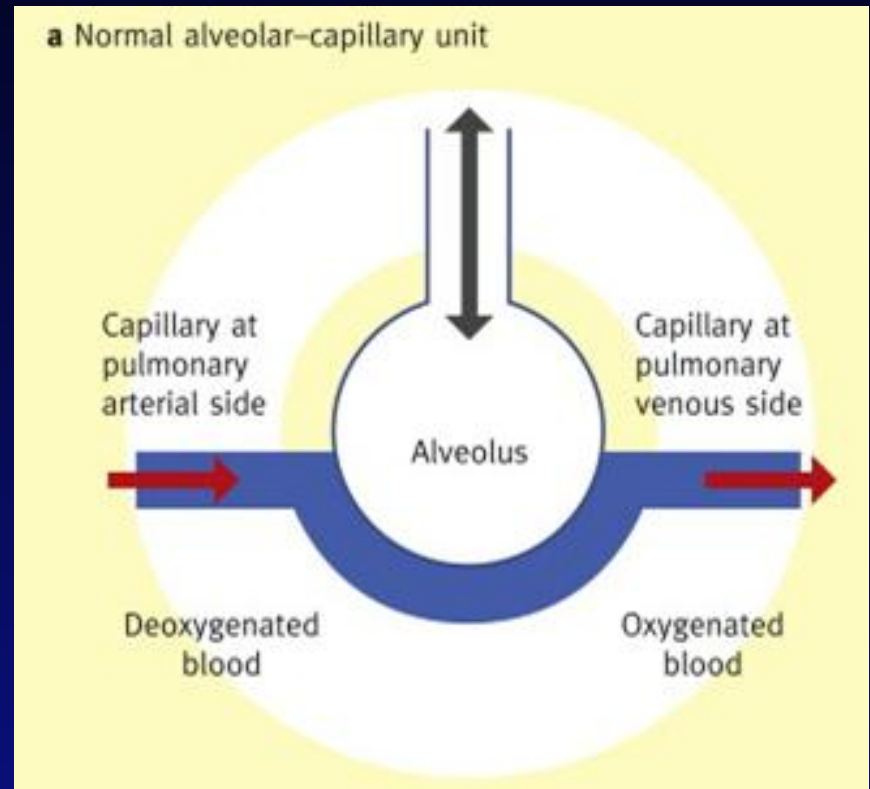


DOSIMETRIA

- Peep
- Reposição volêmica
- Vasopressores

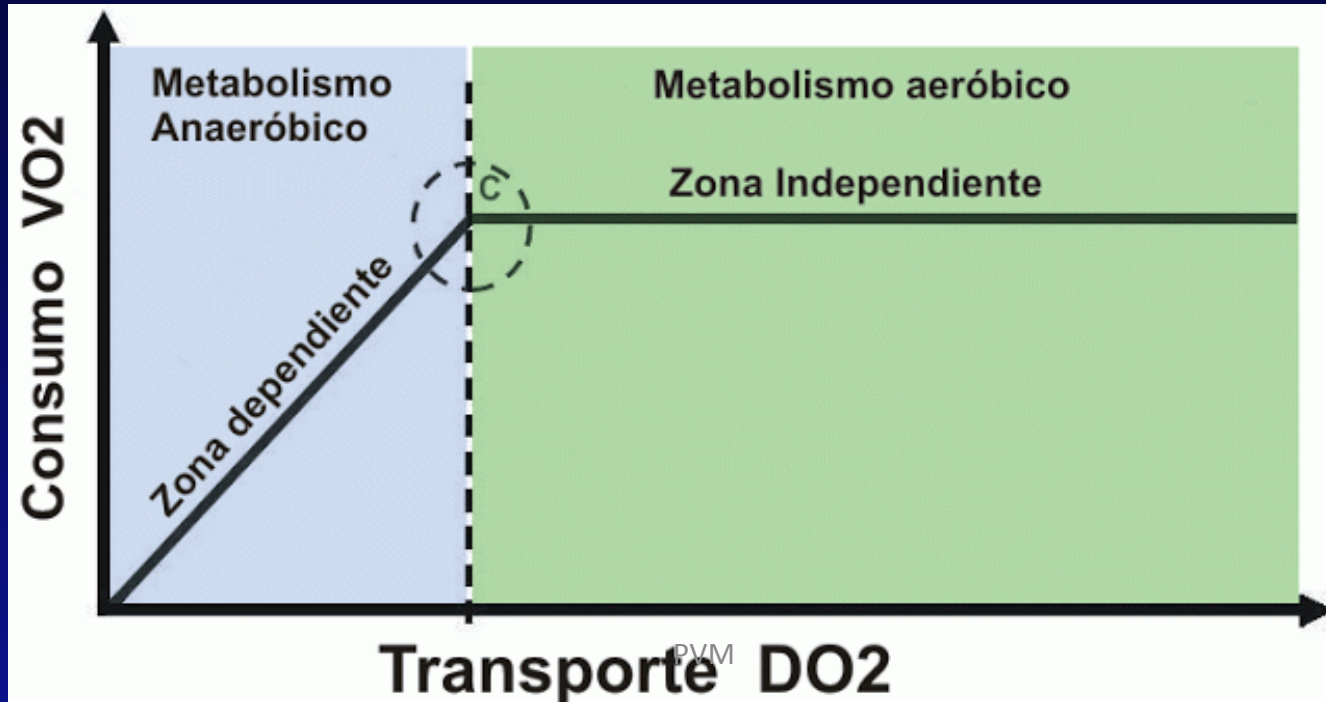
Monitorização adequada

- Hemodinâmica
- Respiratória
- Imagem



DOSIMETRIA

- $DO_2 = DC \times CaO_2$
 - Lactato
 - SvO_2 e $SvcO_2$



DOSIMETRIA

PaO₂/FiO₂

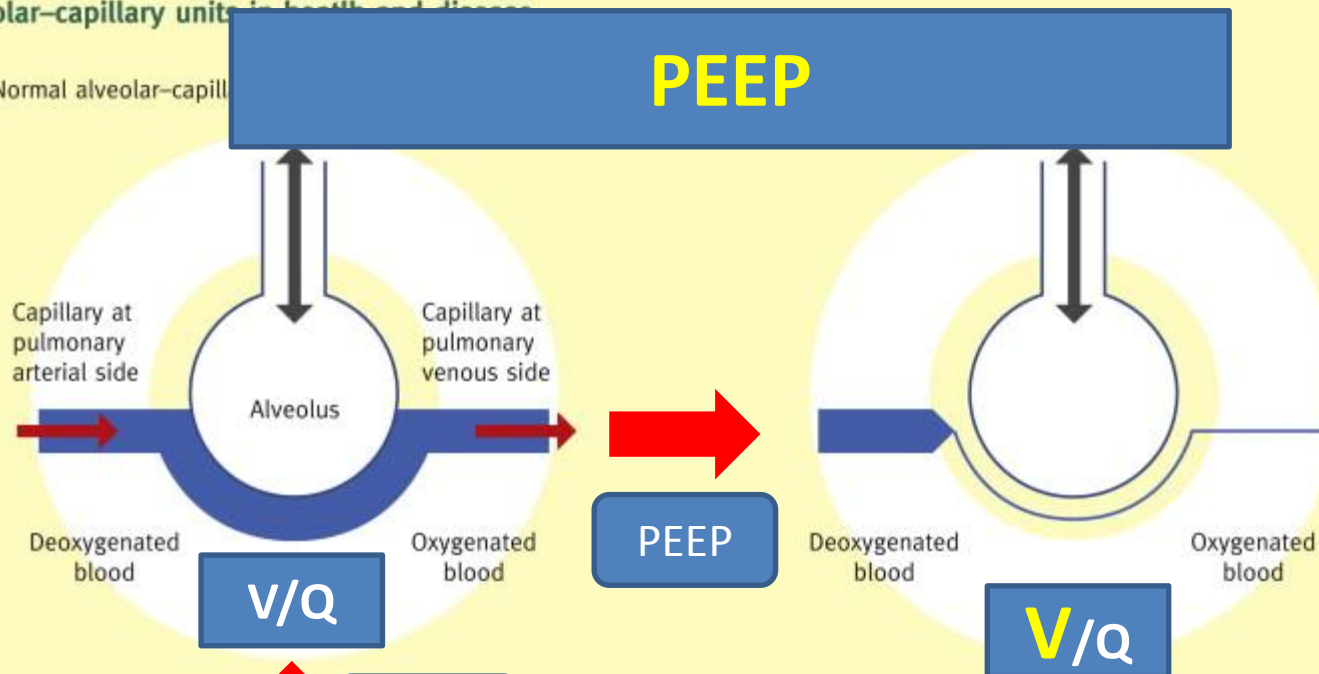
- Recrutamento
- PEEP
- Armadilhas:
 - PEEP muito alto: aumenta espaço morto fisiológico
 - Reposição volêmica excessiva: aumenta shunt

Capnografia

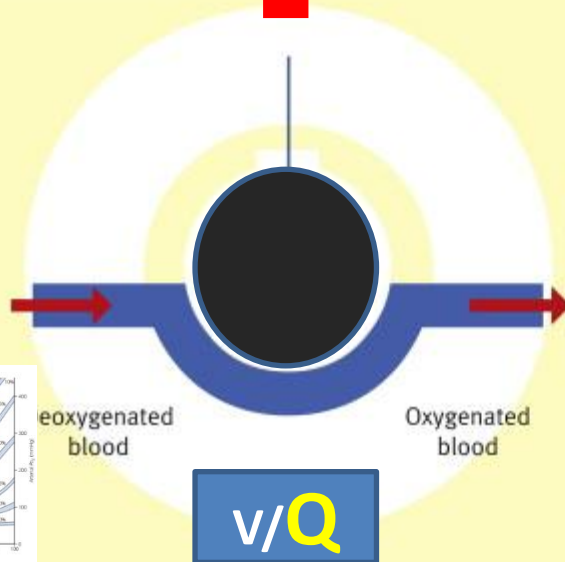
- Gradiente $\text{PaCO}_2\text{-PETCO}_2$
 - Correlação com Vd/Vt
 - PEEP ideal: reduz o gradiente Pa-PET
 - PEEP excessiva: aumenta o gradiente Pa-PET
 - Diminuiu DC
 - Aumenta espaço morto
- Cálculo do espaço morto
 - $\text{VD/VT} = (\text{PaCO}_2 - \text{PECO}_2) / \text{PaCO}_2$

Alveolar-capillary unit in health and disease

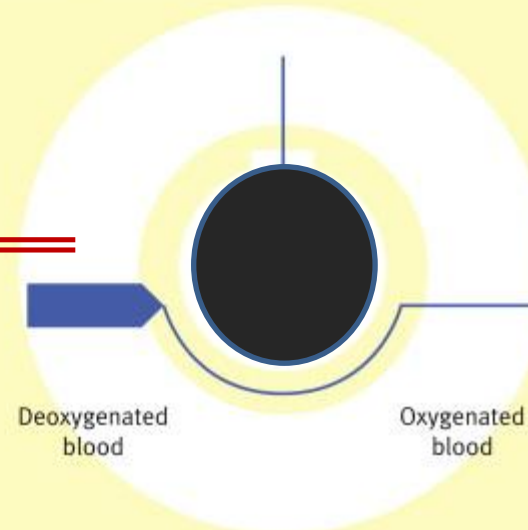
a Normal alveolar-capillary



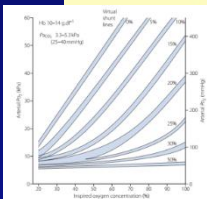
c Reduced ventilation

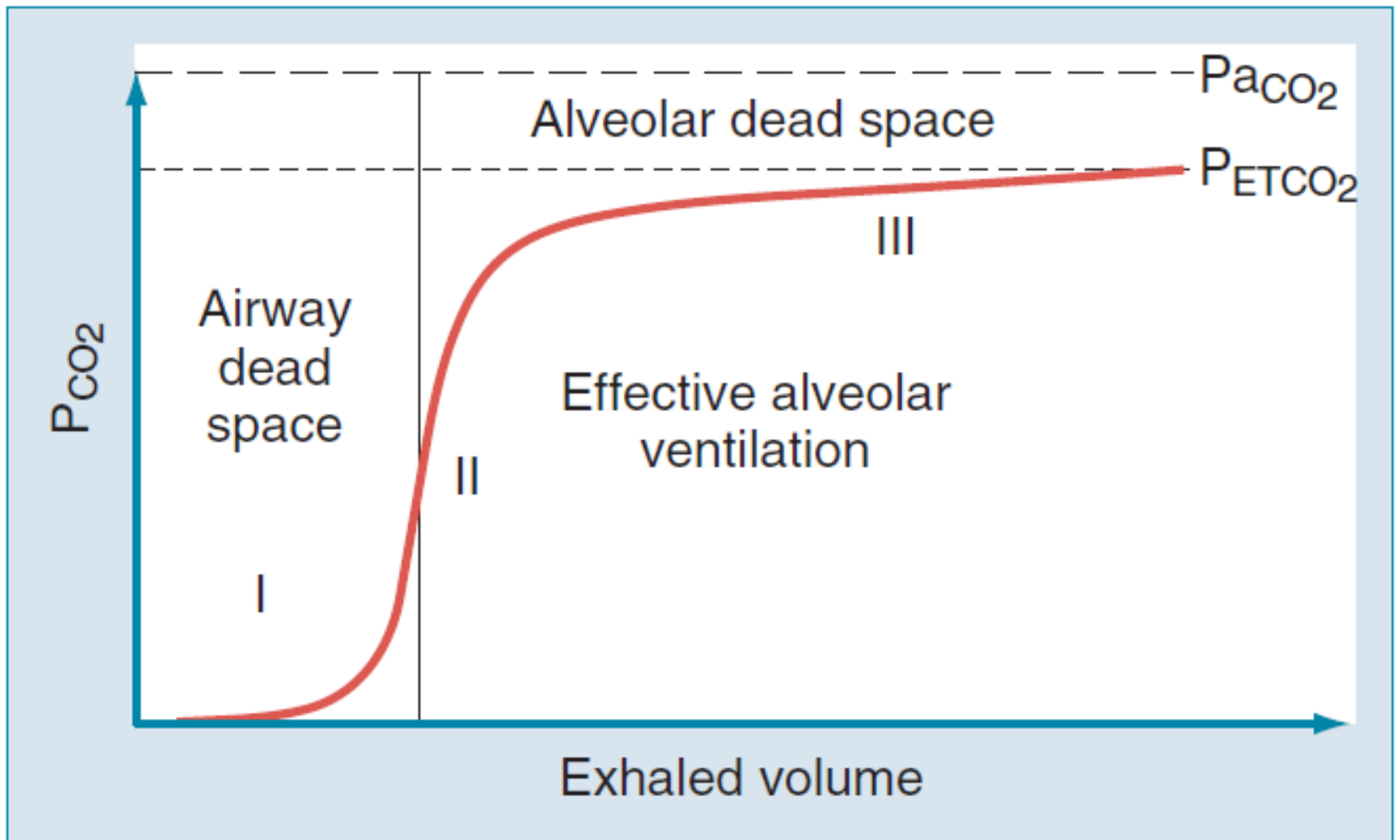


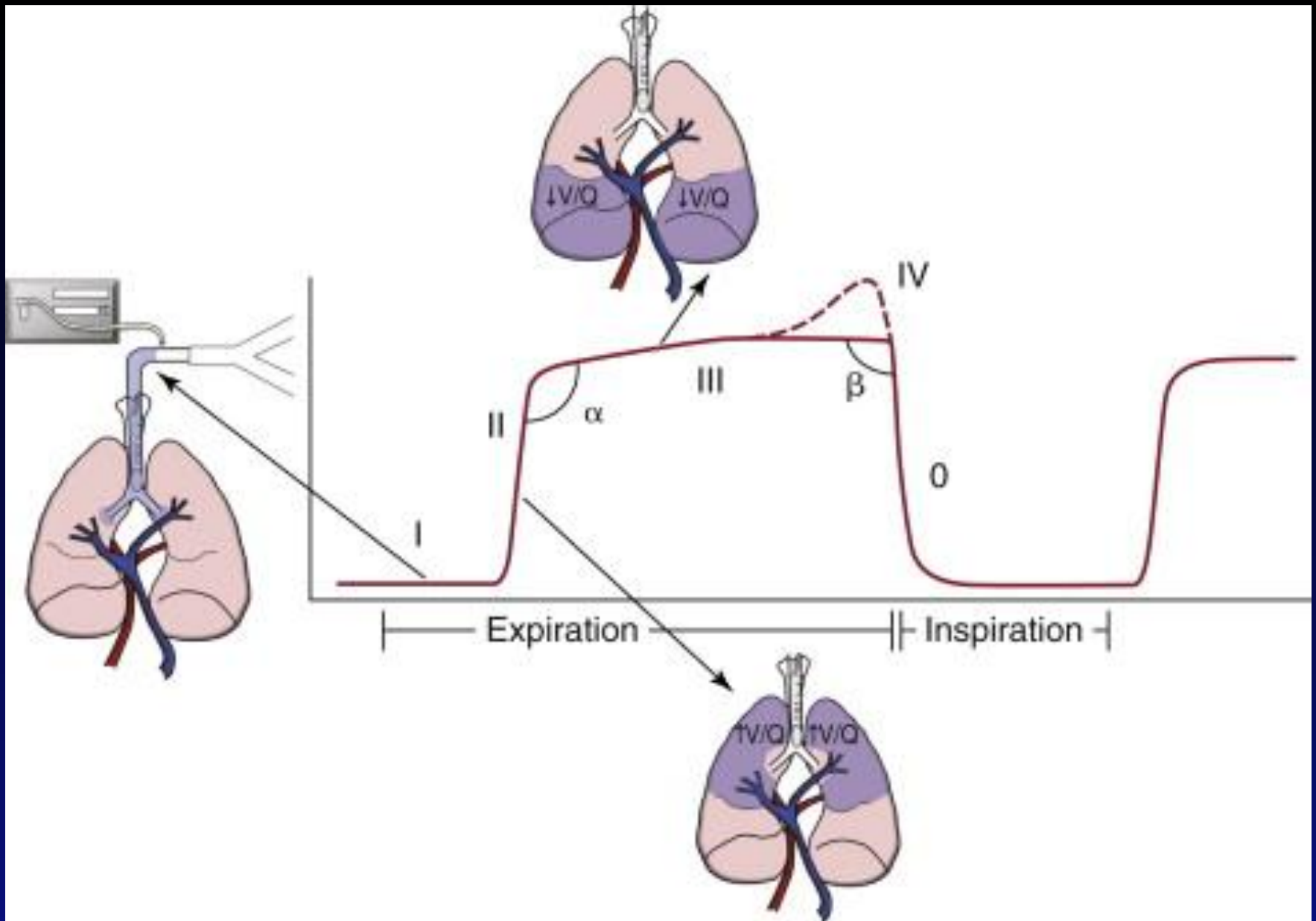
d Reduced ventilation and perfusion



PVM





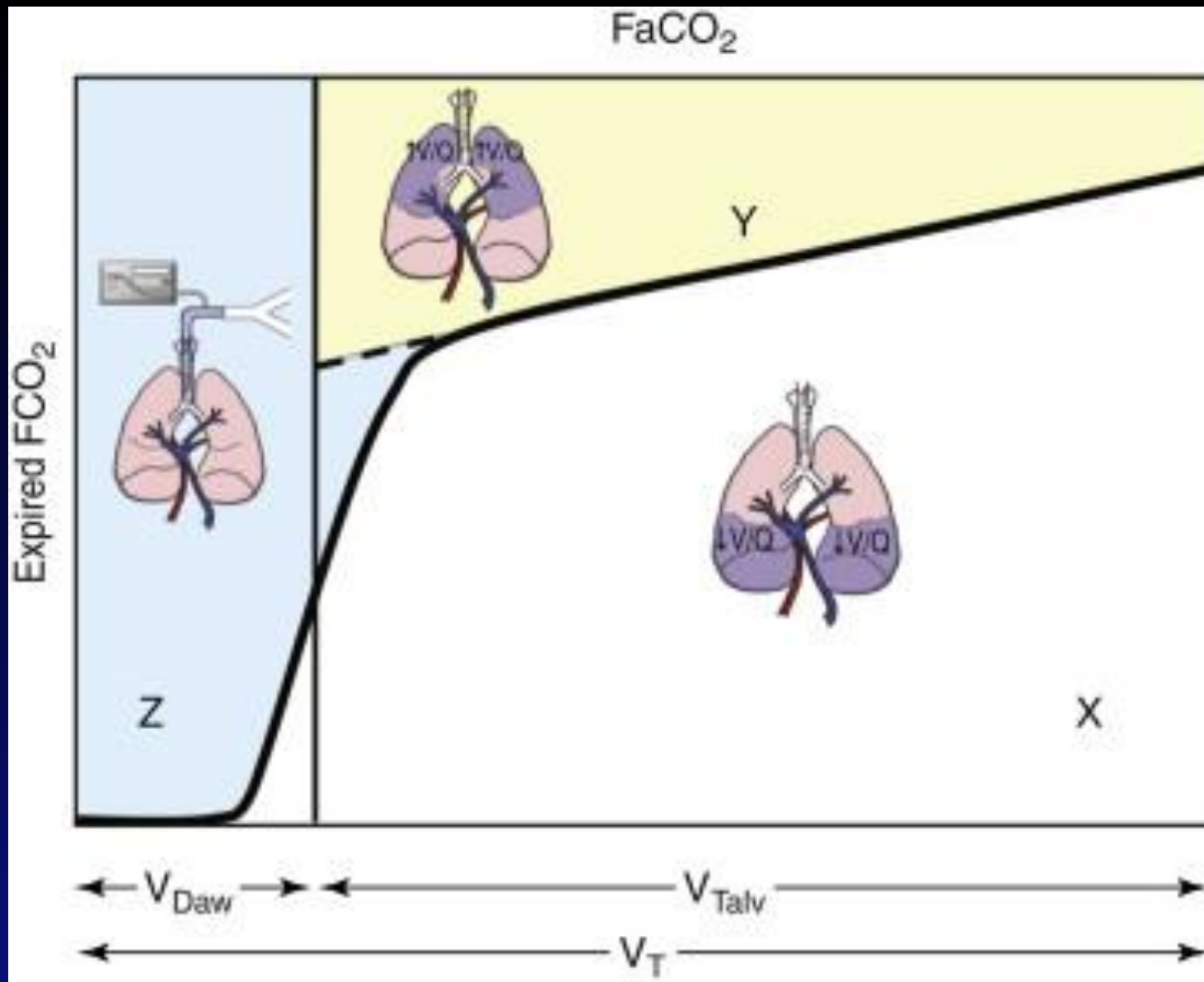


Anesthesia Equipment: Principles and Applications , Second Edition

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

Chapter 10, 249-255

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EM-alveolar:

$$\frac{Y}{X + Y}$$

EM-fisiológico:

$$\frac{(Y + Z)}{(X + Y + Z)}$$

A [correction](#) for this article has been published in *Critical Care* 2011, 15:410

Research

Highly accessed

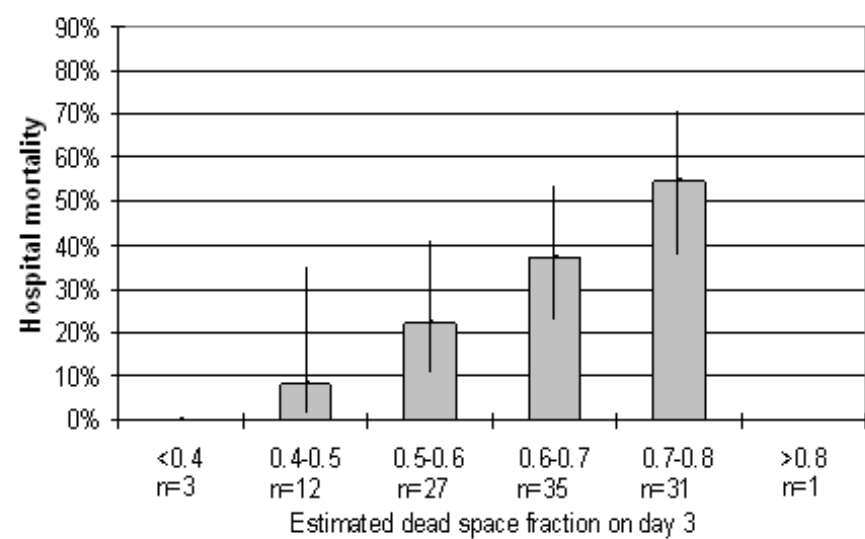
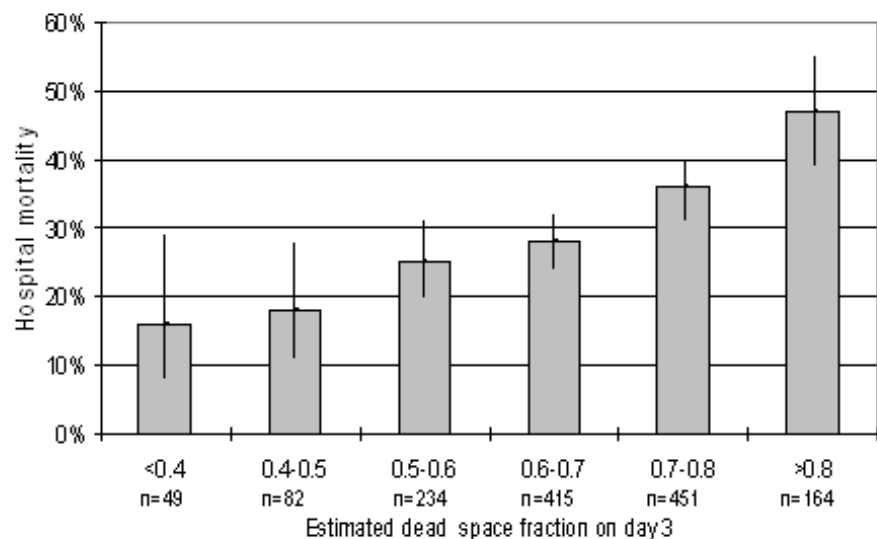
Open Access

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

Hassan Siddiki¹, Marija Kojacic², Guangxi Li², Murat Yilmaz³, Taylor B Thompson⁴, Rolf D Hubmayr² and Ognjen Gajic^{2*}

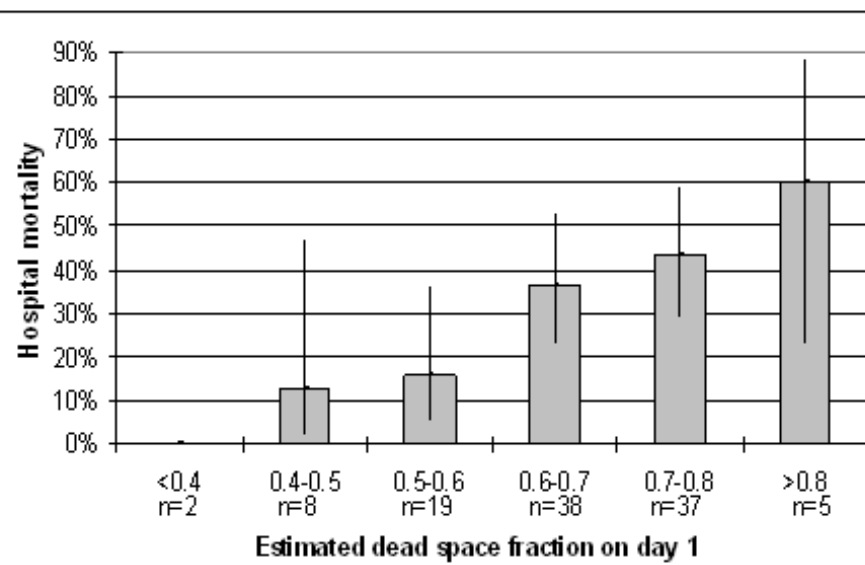
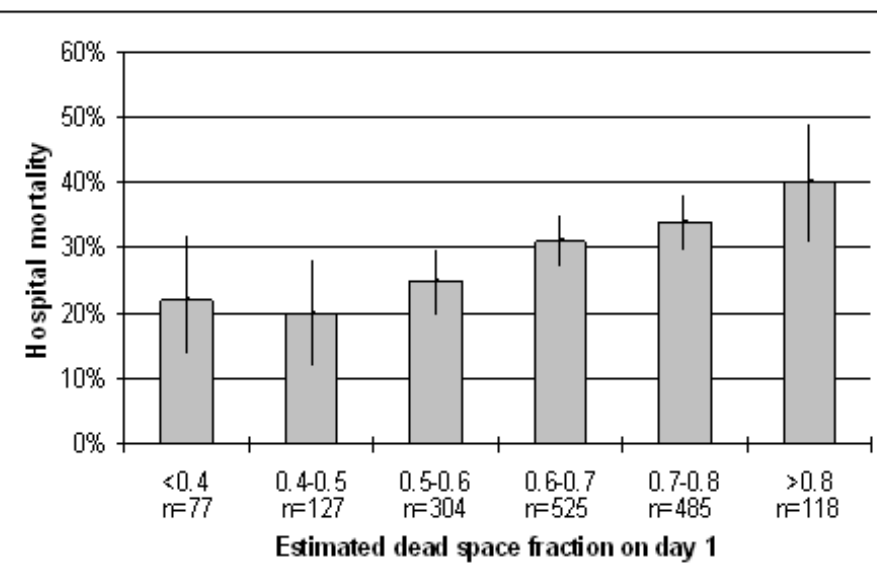
Key messages

- 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.



(a)

(b)



(c)

(d)

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

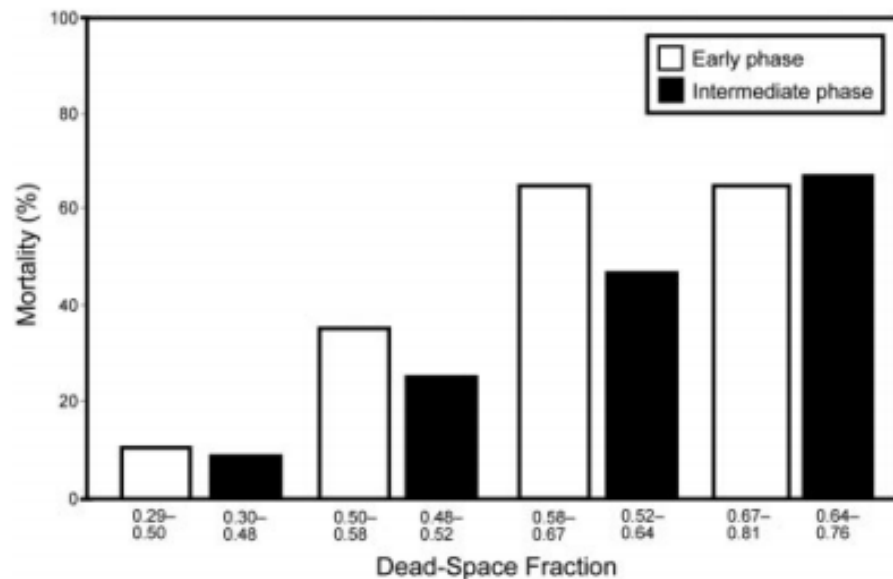


Fig. 1. Mortality according to the quartiles of dead-space fraction in 80 patients with early-phase acute respiratory distress syndrome and 49 patients with intermediate-phase acute respiratory distress syndrome.

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.

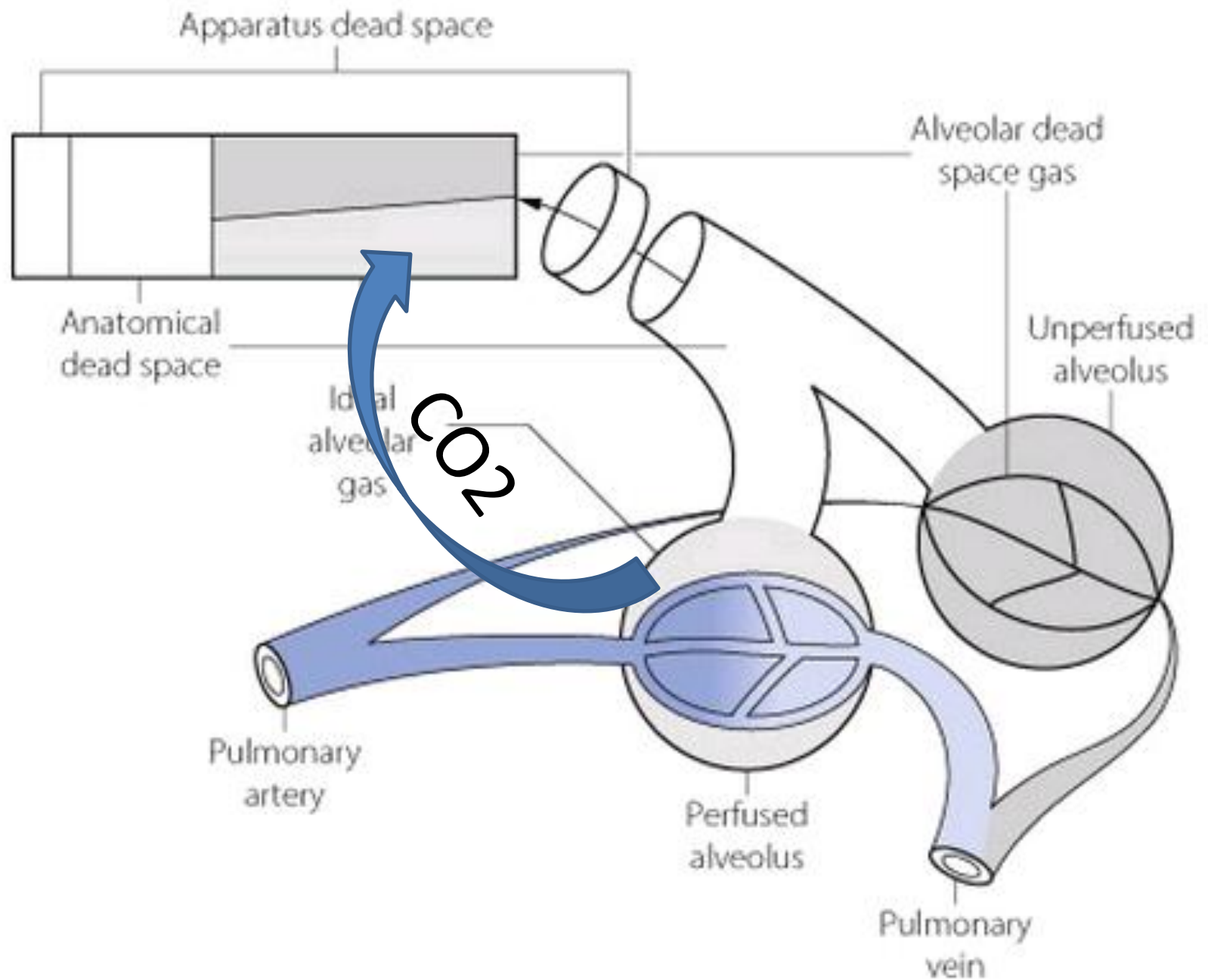
Table 2. Variables Associated With a Greater Risk of Death in the Early Phase of Acute Respiratory Distress Syndrome

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

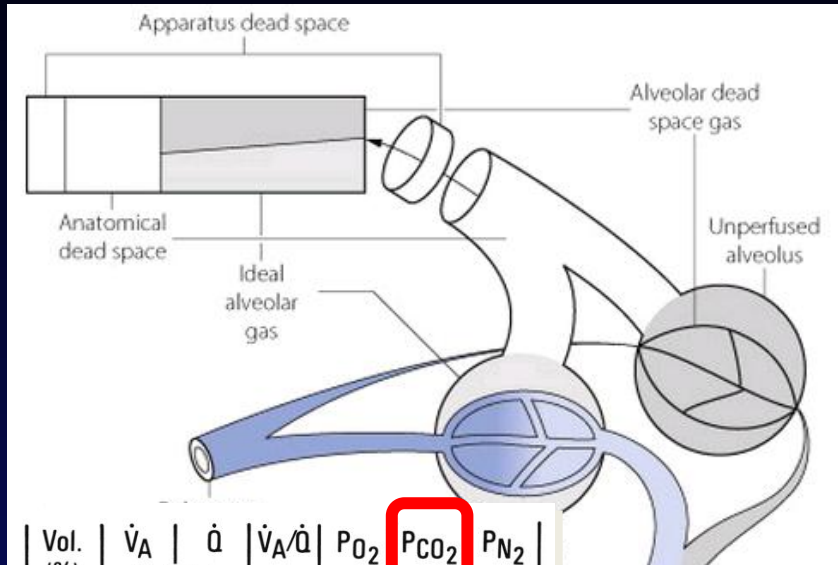
Table 4. Variables Associated With a Greater Risk of Death in the Intermediate Phase of Acute Respiratory Distress Syndrome

	Survivors (<i>n</i> = 31)	Non- survivors (<i>n</i> = 18)	<i>P</i>
Age (mean $\pm$ SD y)	46 $\pm$ 17	59 $\pm$ 19	.02
SAPS II (mean $\pm$ SD)	39 $\pm$ 15	50 $\pm$ 12	.02
SOFA score (mean $\pm$ SD)	6.7 $\pm$ 3.2	10.5 $\pm$ 2.6	< .001
Use of vasopressors (<i>n</i> , %)	11 (36)	12 (67)	.04
Use of activated protein C (<i>n</i> , %)	4 (13)	0 (0)	.28
Lung injury score (mean $\pm$ SD)	2.5 $\pm$ 0.6	2.8 $\pm$ 0.7	.14
PEEP (mean $\pm$ SD cm H ₂ O)	8.5 $\pm$ 3.8	9.7 $\pm$ 4.0	.33
Tidal volume (mean $\pm$ SD mL/kg IBW)	7.6 $\pm$ 1.5	7.3 $\pm$ 1.5	.32
Minute volume (mean $\pm$ SD L/min)	11.7 $\pm$ 2.8	11.4 $\pm$ 3.1	.69
Plateau pressure (mean $\pm$ SD cm H ₂ O)	25.4 $\pm$ 4.4	27.7 $\pm$ 6.2	.24
Quasistatic respiratory compliance (mean $\pm$ SD mL/cm H ₂ O)	31.8 $\pm$ 9.7	27.6 $\pm$ 14.2	.24
pH (mean $\pm$ SD)	7.45 $\pm$ 0.06	7.38 $\pm$ 0.09	.003
P _a CO ₂ (mean $\pm$ SD mm Hg)	39 $\pm$ 10	47 $\pm$ 10	.008
P _a O ₂ /F _I O ₂ (mean $\pm$ SD mm Hg)	205 $\pm$ 76	169 $\pm$ 77	.13
Dead-space fraction (mean $\pm$ SD)	0.50 $\pm$ 0.10	0.62 $\pm$ 0.09	< .001
CO ₂ production (mean $\pm$ SD mL/min/kg of body weight)	3.6 $\pm$ 0.8	3.2 $\pm$ 1.0	.14

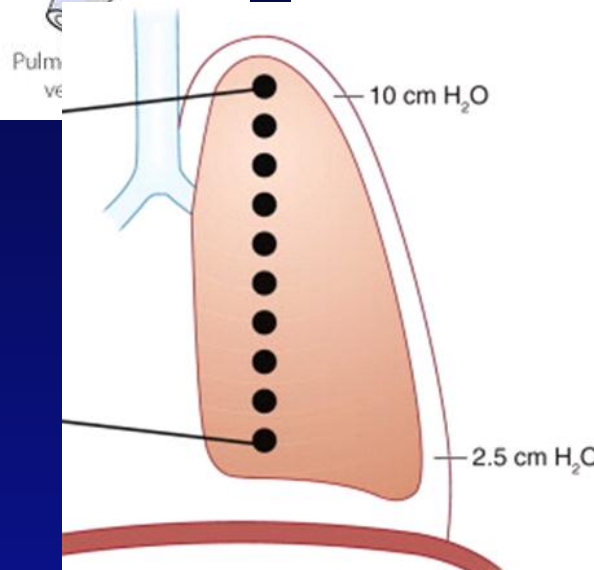
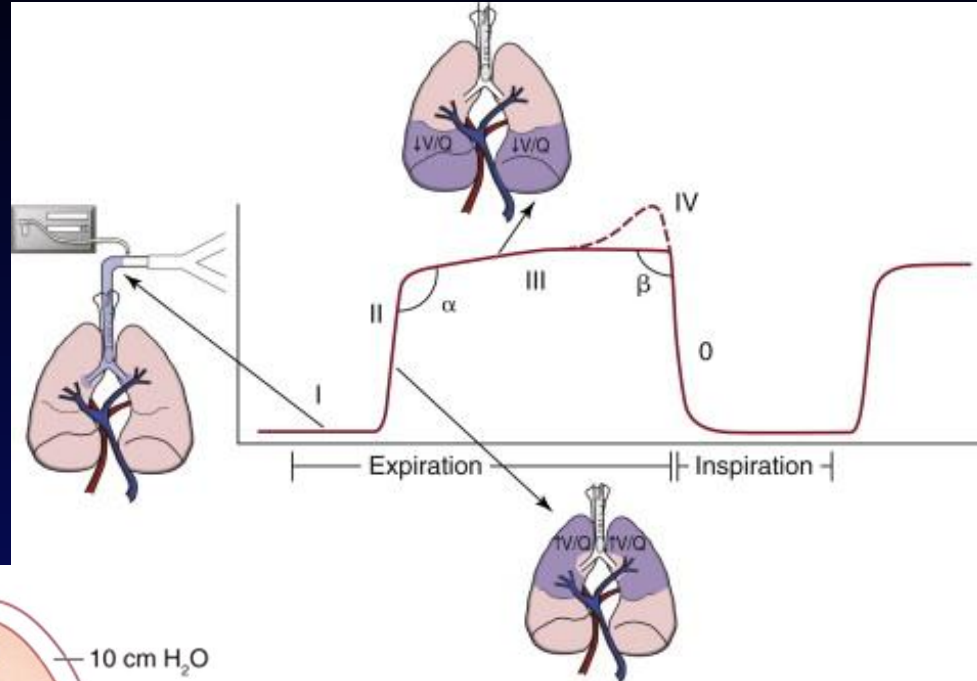
PVM



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.

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

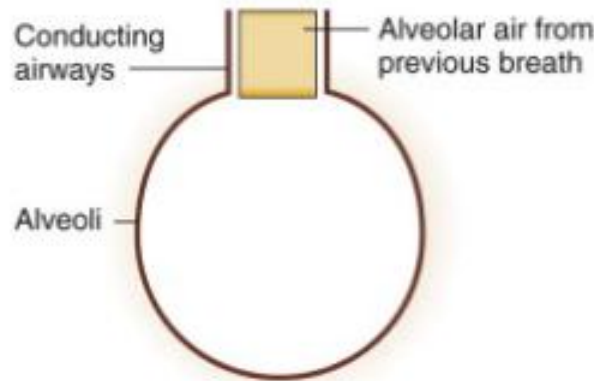
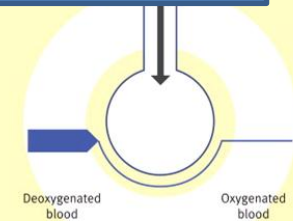
EM fisiológico=

Tidal volume
= 500 mL

Anatomic
dead space

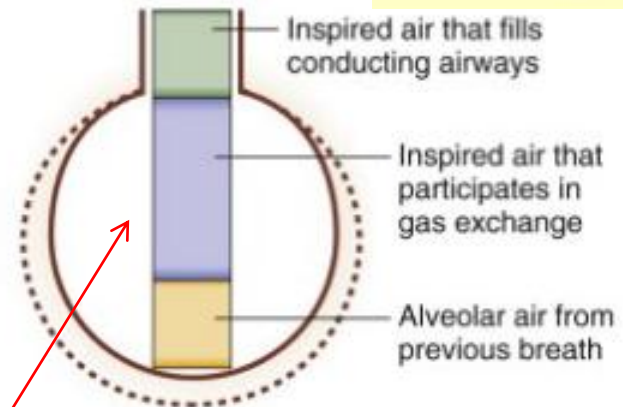
+

EM alveolar



End-expiration

Inspire one V_T



End-inspiration

Physiology, Fifth Edition

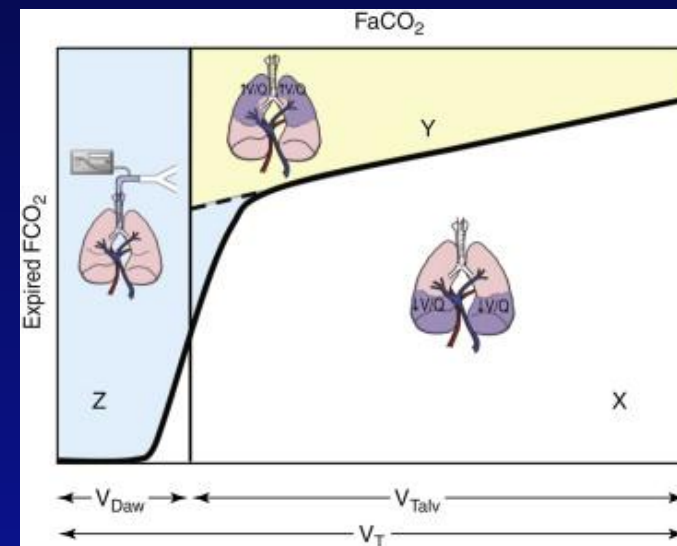
Linda S. Costanzo

$$V_d/V_t = (P_a\text{CO}_2 - P_e\text{CO}_2)/P_a\text{CO}_2$$

$$V_d/v_T = 0,6 \Rightarrow V_d = 0,6 \times V_t \Rightarrow V_d = 360\text{ml} \times 0,6 = 216$$

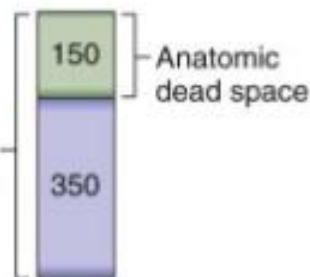
$$V_t \text{ alveolar} = 360 - 216 = 144\text{ml.}$$

PVM

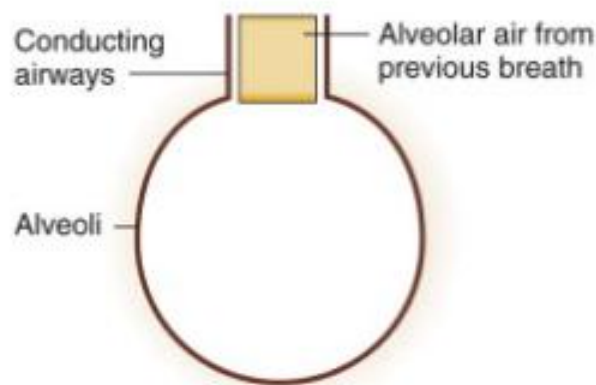
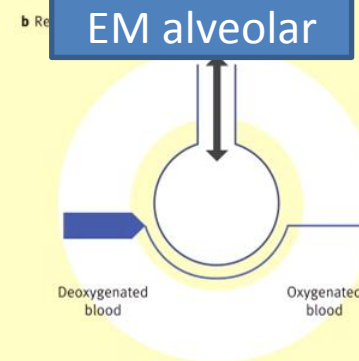


EM fisiológico=

Tidal volume
= 500 mL

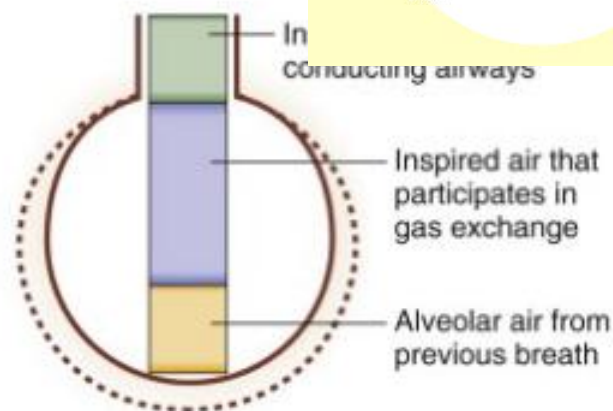


+



End-expiration

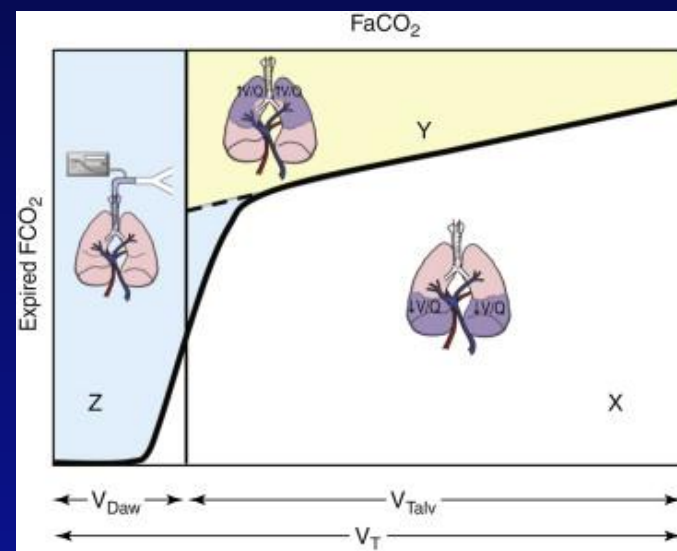
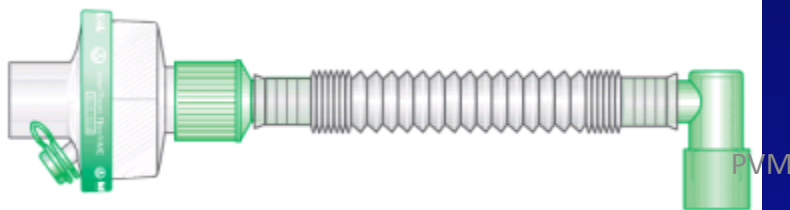
Inspire one V_T

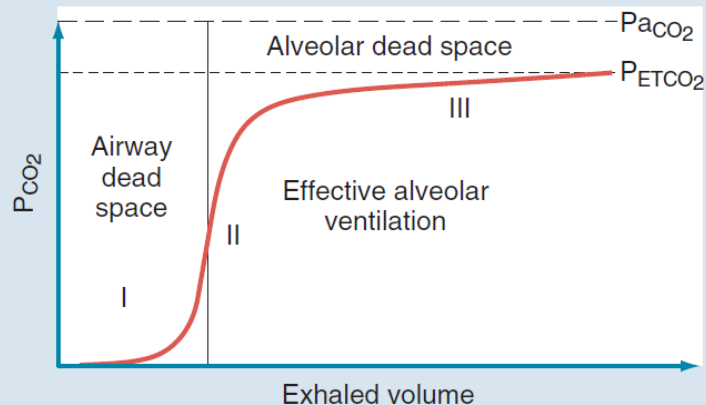
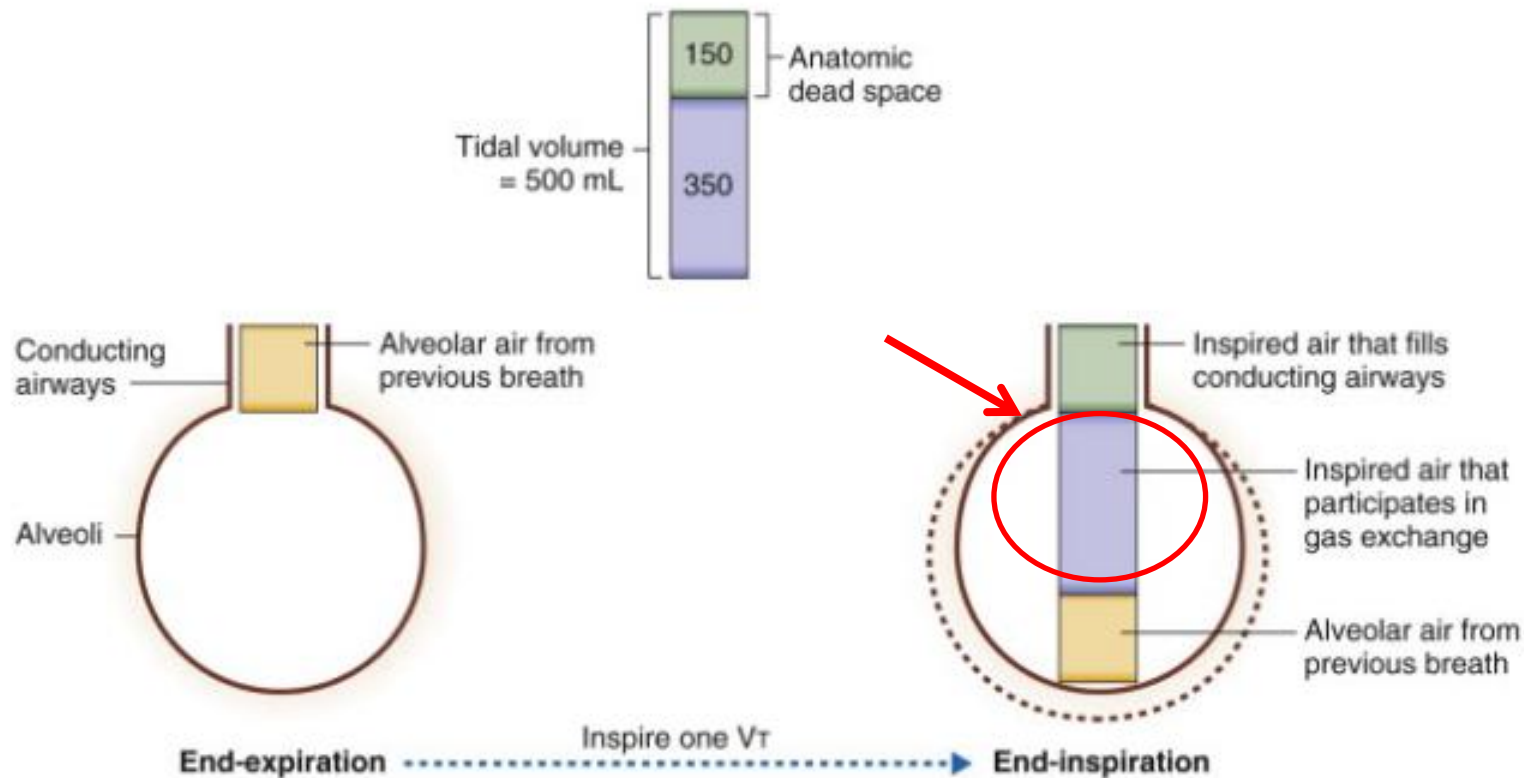


End-inspiration

$$V_d/V_t = (P_a\text{CO}_2 - P_e\text{CO}_2) / P_a\text{CO}_2$$

$$V_d/V_T = 0,6 \Rightarrow V_d = 0,6 \times V_T \Rightarrow V_d = 360\text{ml} \times 0,6 = 216 - 26\text{ml (traqueia extensora)} = 190 / 360 = \mathbf{0,52}$$



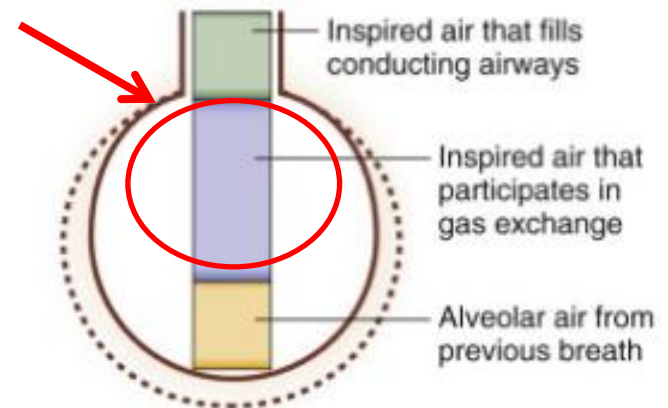
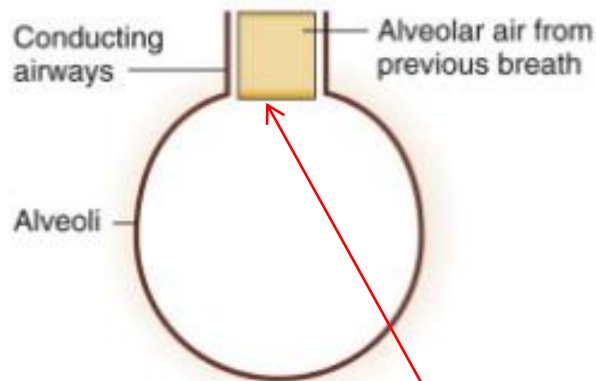
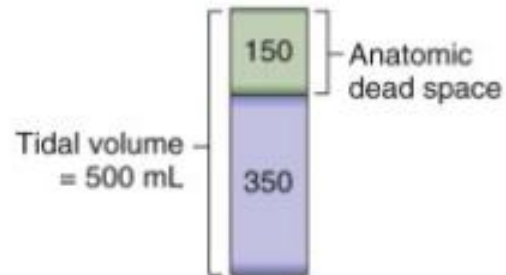


DIMINUEM “volume de troca”

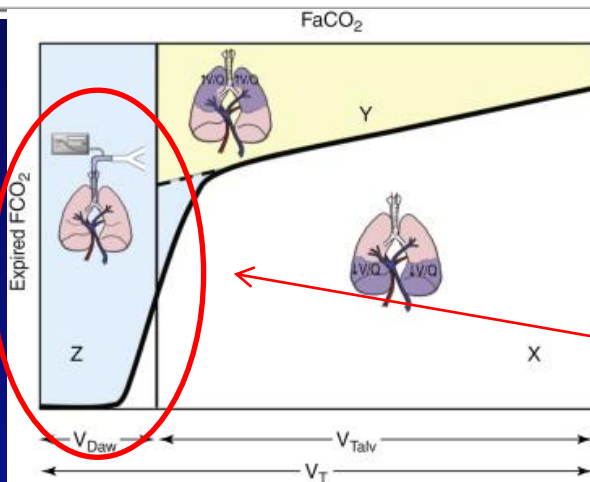
- Peep acima da ideal.
- T_i curto.
- T_e curto.
- FR alta.
- EM anatômico.
- Aumento de resistência

Lei de Poiseuille.

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

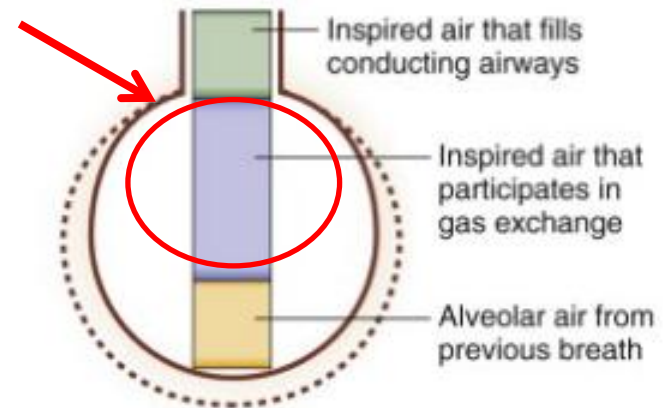
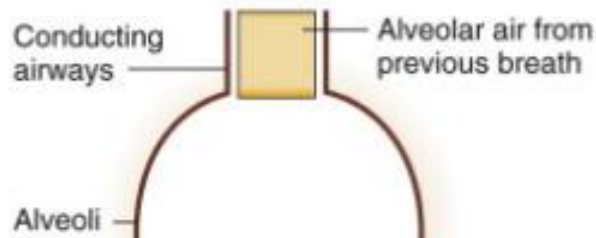
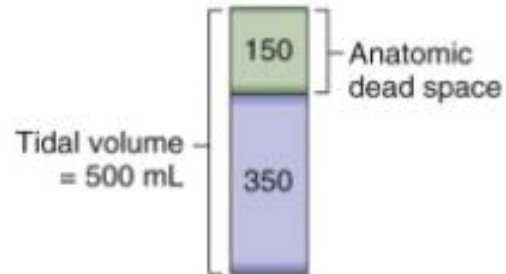


End-expiration Inspire one V_T End-inspiration

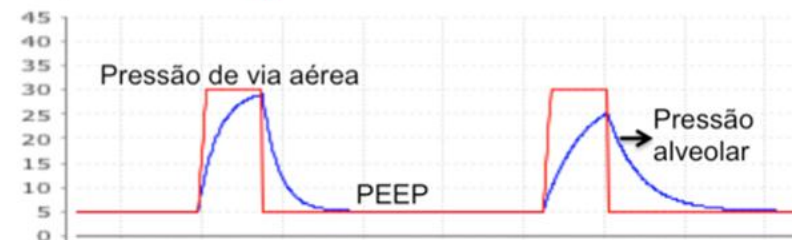
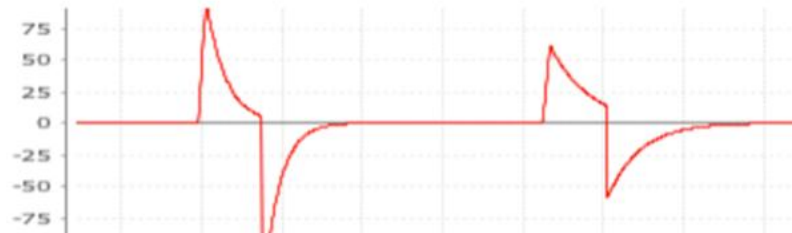
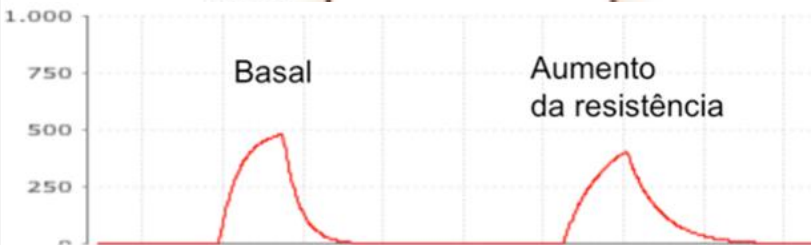


DIMINUEM "volume de troca"

- Peep acima da ideal.
- T_i curto.
- T_e curto.
- FR alta.
- EM anatômico.
- Aumento de resistência



pire one V_T → End-inspiration



DIMINUEM “volume de troca”

- Peep acima da ideal.
- T_i curto.
- T_e curto.
- FR alta.
- EM anatômico.
- Aumento de resistência

Manter Vt Efetivo

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

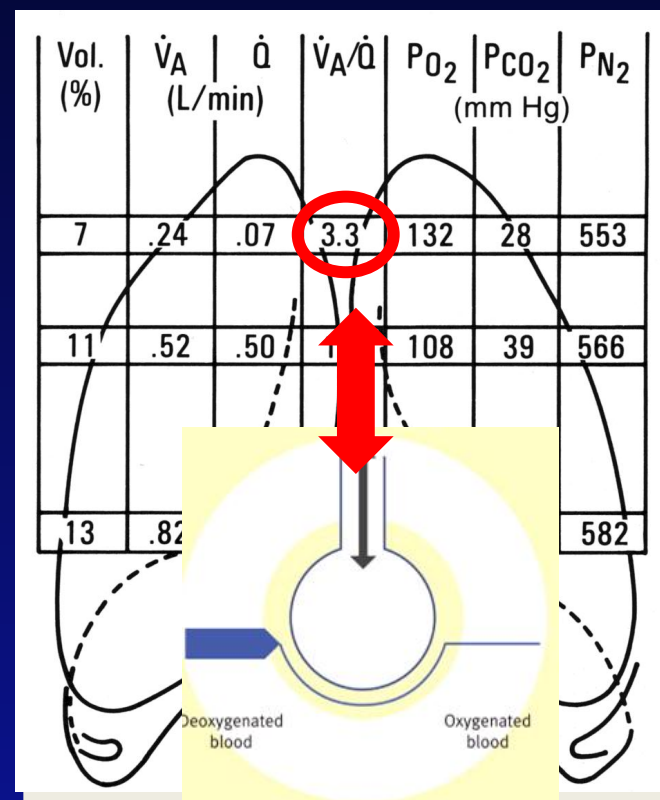
Espaço Morto

- Espaço morto anatômico
- Espaço morto alveolar

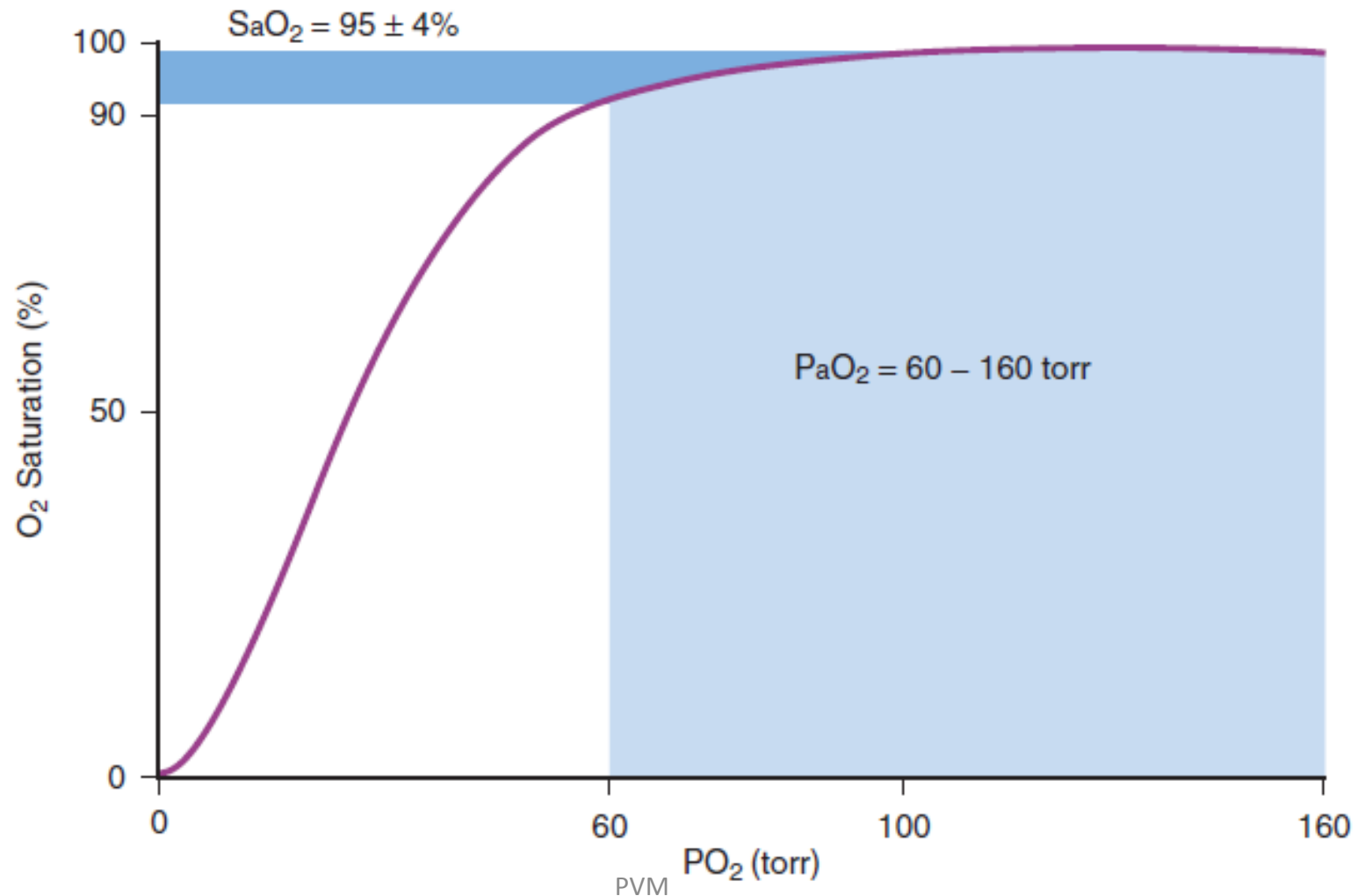


Espaço morto fisiológico

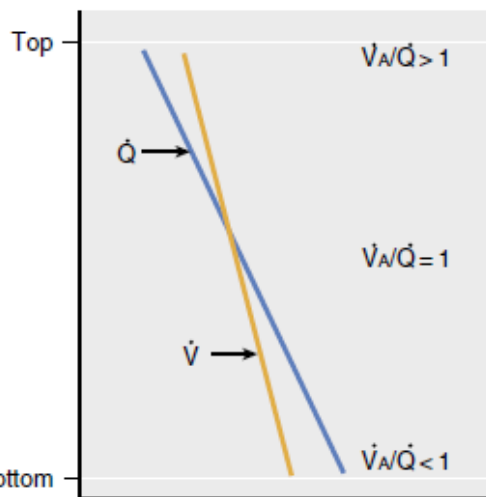
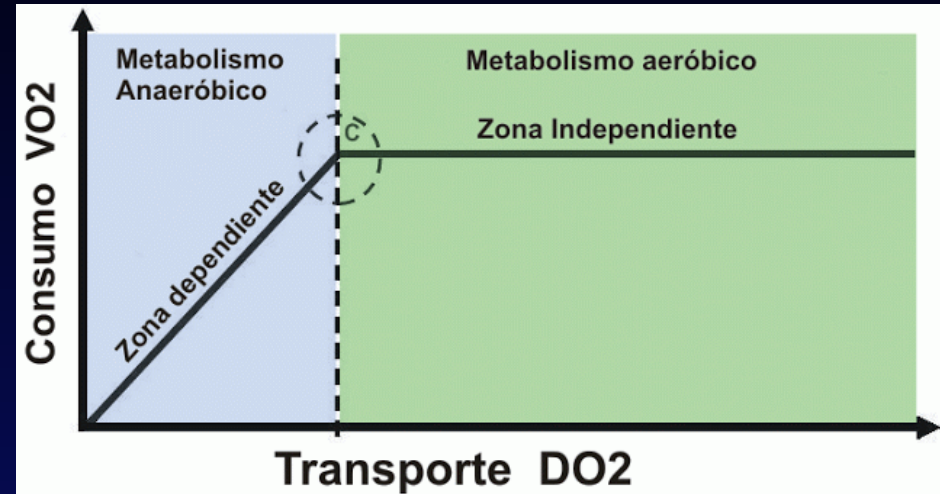
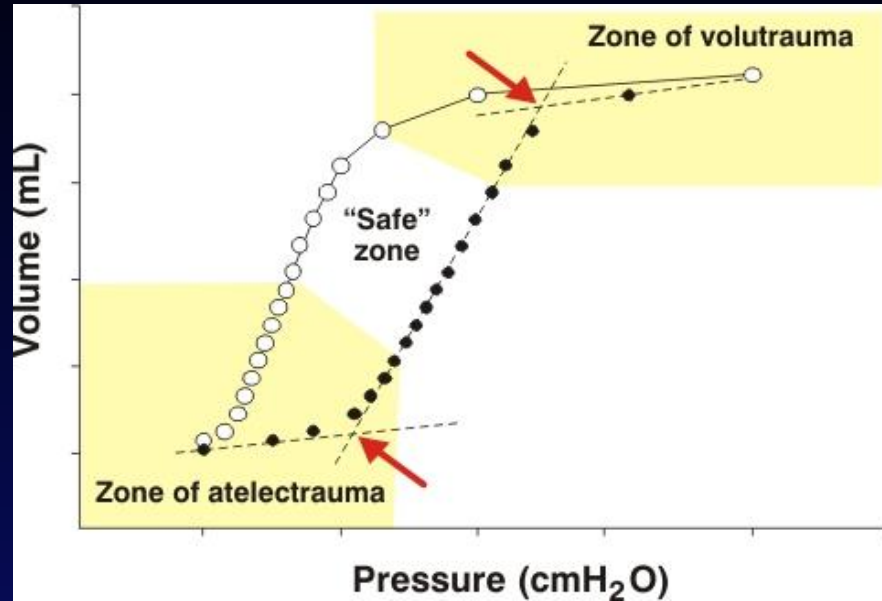
- Peep adequado
- Zona 1 de West
- Gradiente $P_{aCO_2} - P_{ETCO_2}$
- $V_D/V_T = (P_{aCO_2} - P_{ETCO_2}) / P_{aCO_2}$



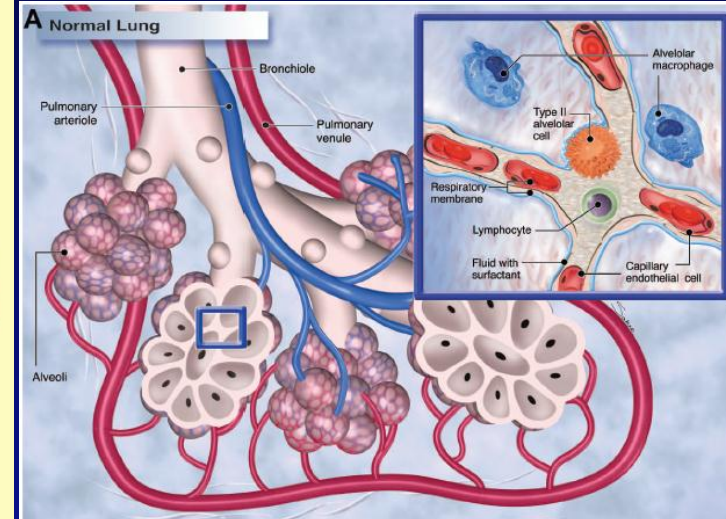
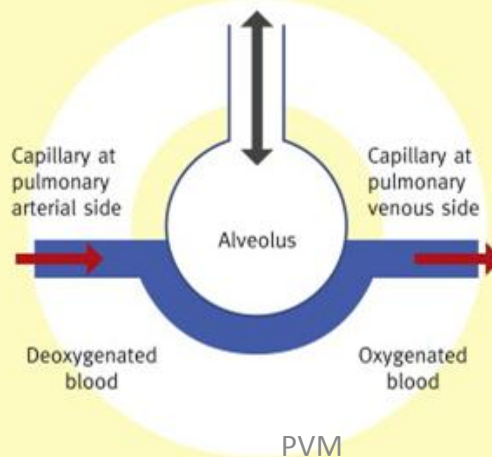
Oximetria

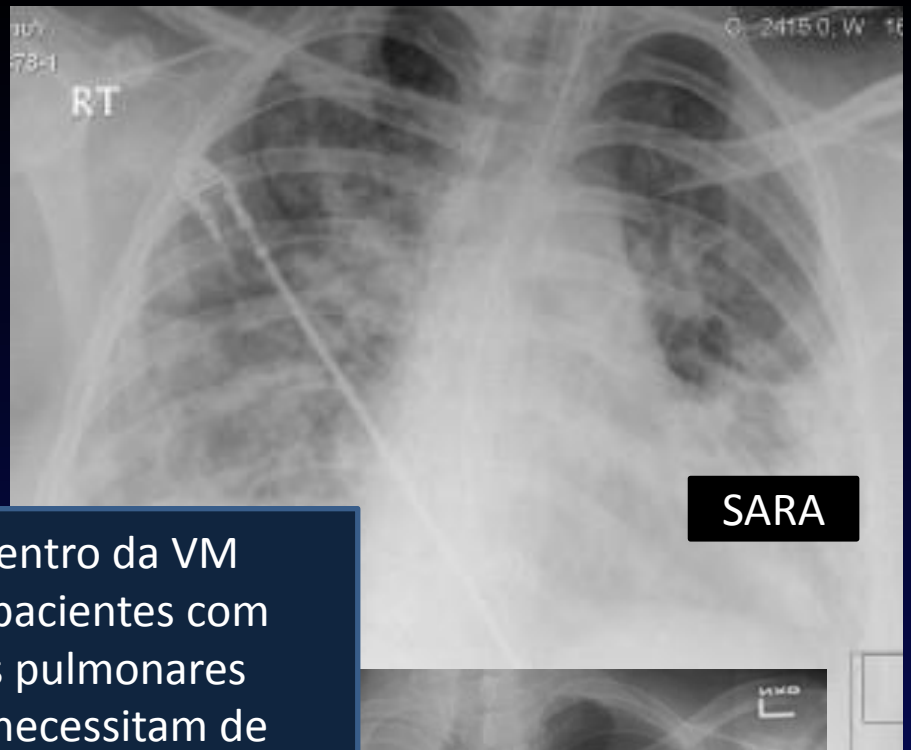
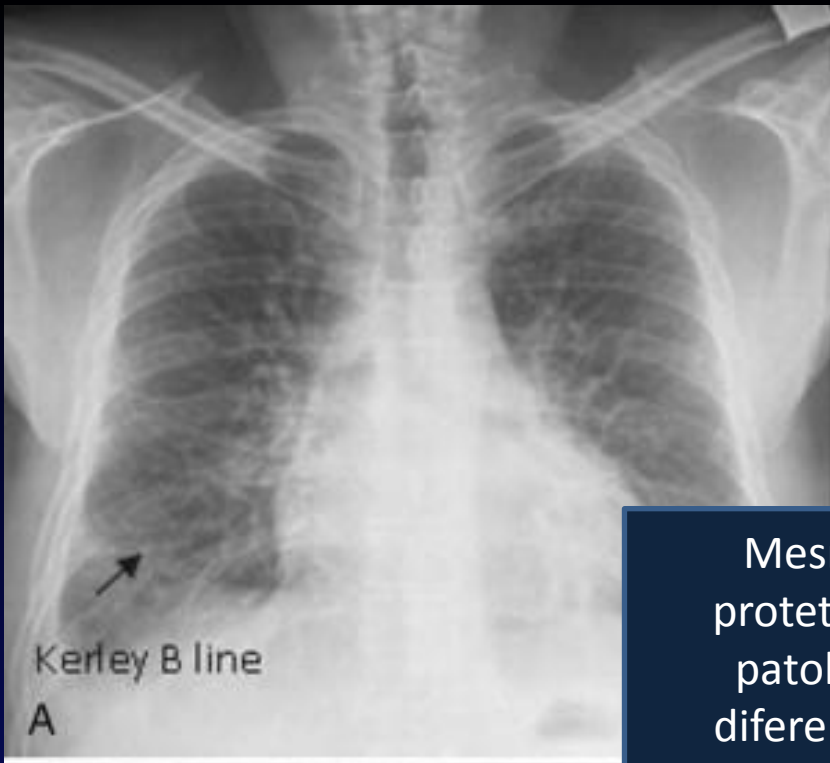


DOSIMETRIA

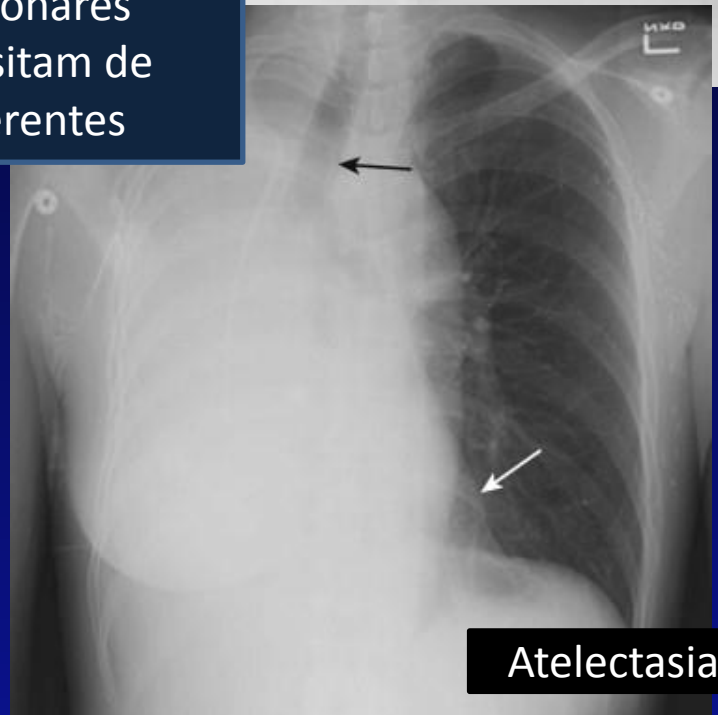


a Normal alveolar-capillary unit





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



PVM

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

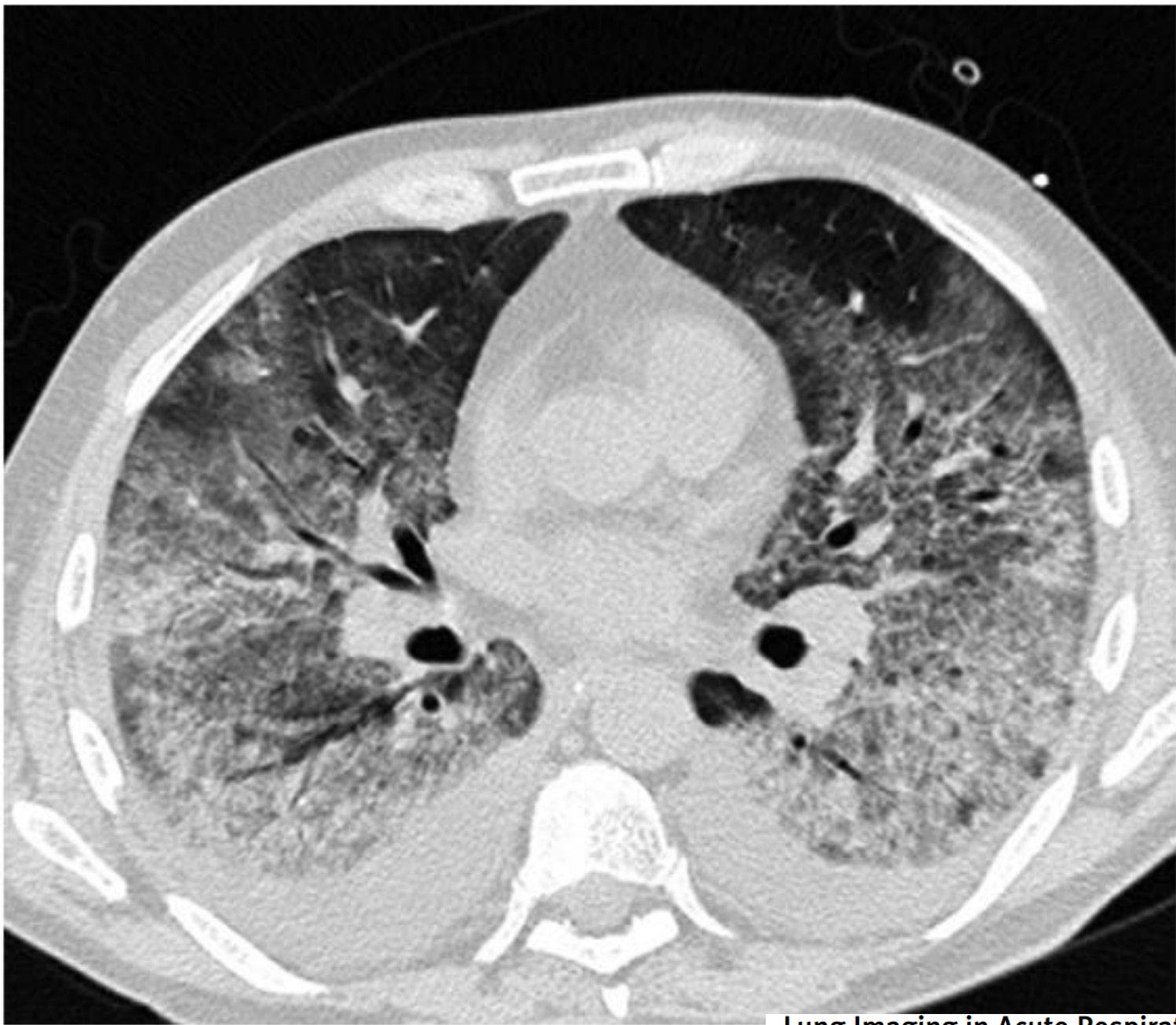
PVM



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

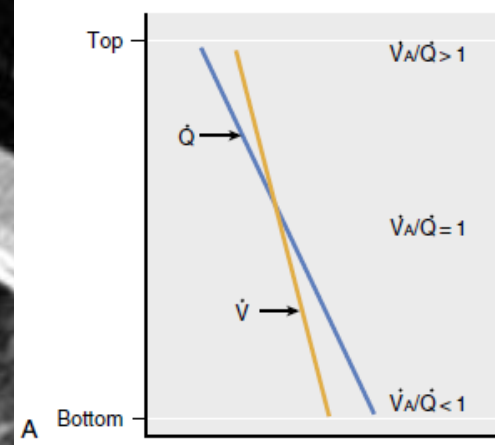
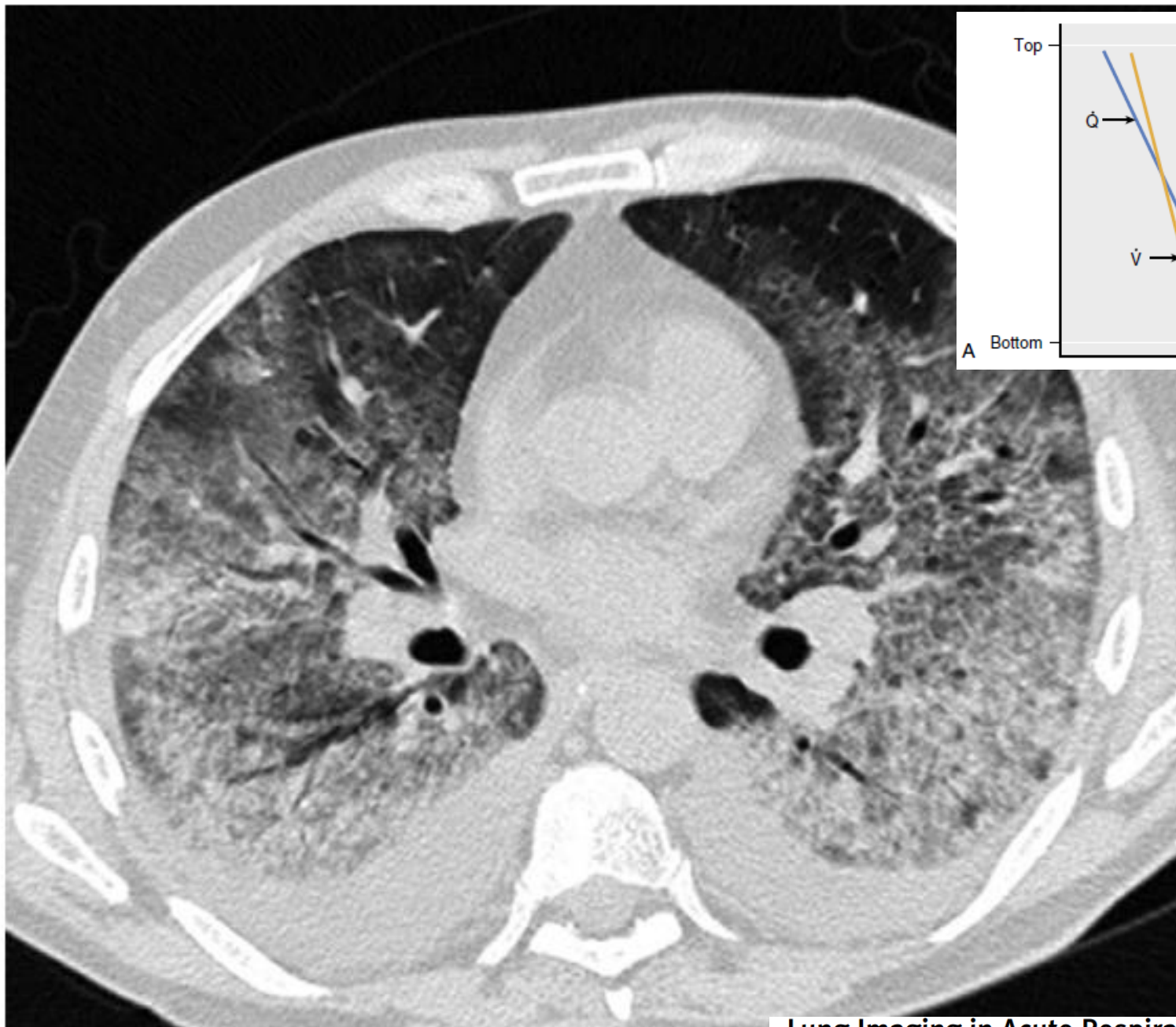
Klaus Markstaller and Hans-Ulrich Kauczor



PVM

Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

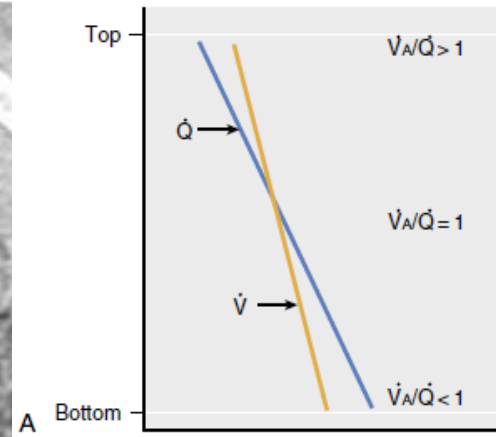
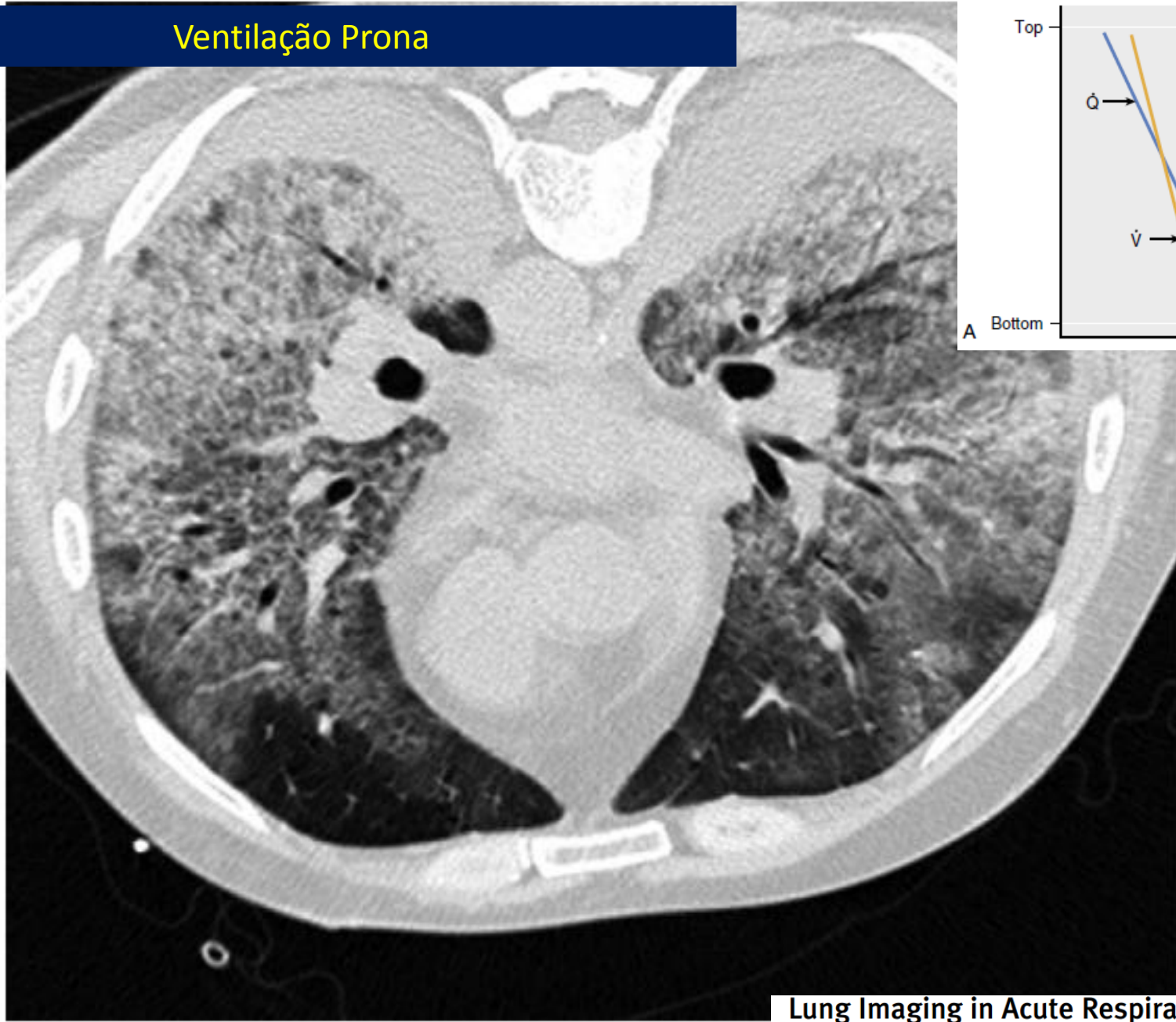
Klaus Markstaller and Hans-Ulrich Kauczor



Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

Klaus Markstaller and Hans-Ulrich Kauczor

Ventilação Prona



PVM

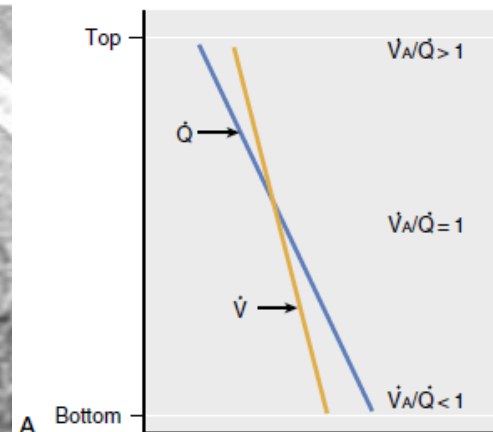
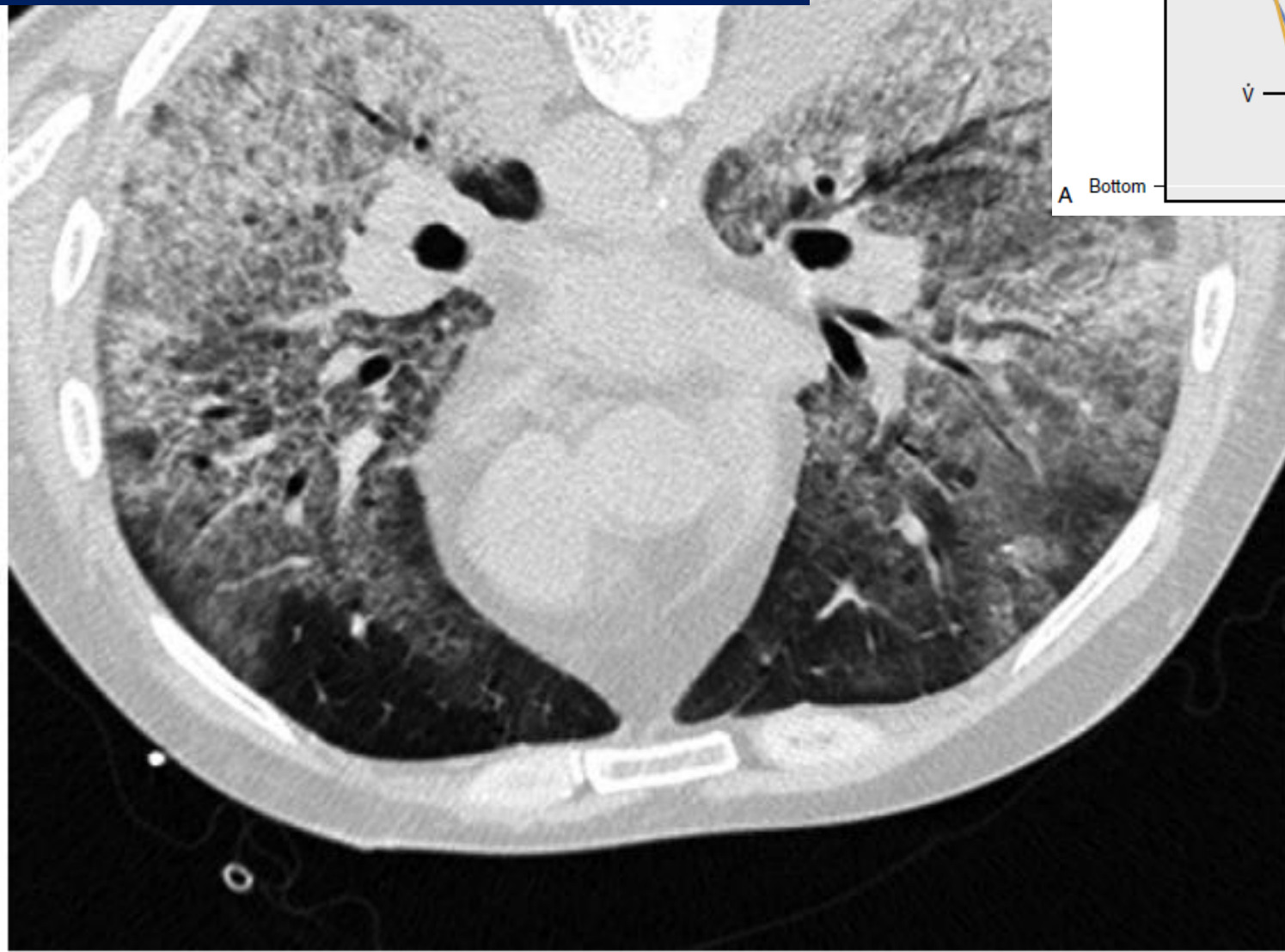
Lung Imaging in Acute Respiratory Distress Syndrome by Computed Tomography

Klaus Markstaller and Hans-Ulrich Kauczor

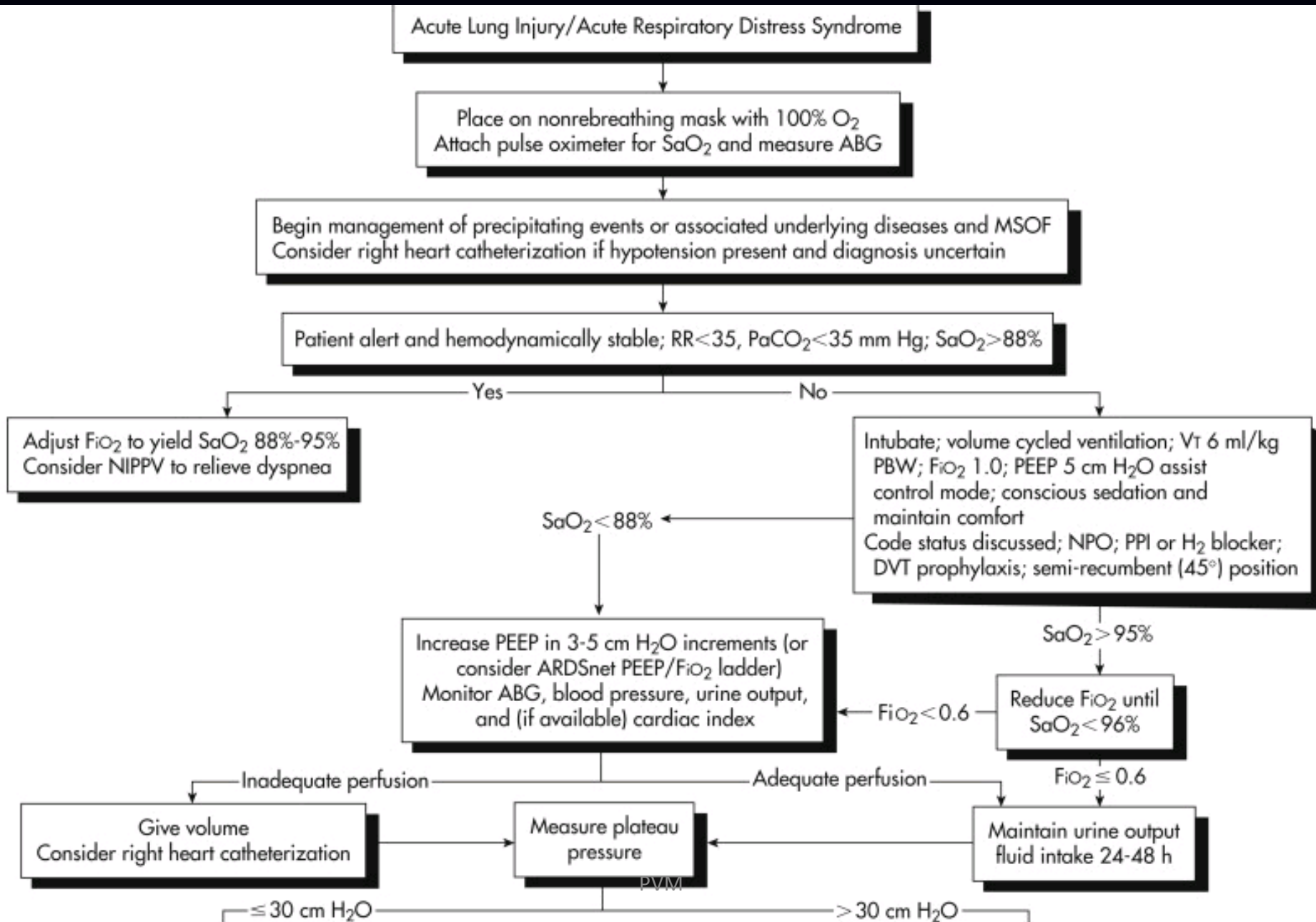
VM prona resolve dois problemas:

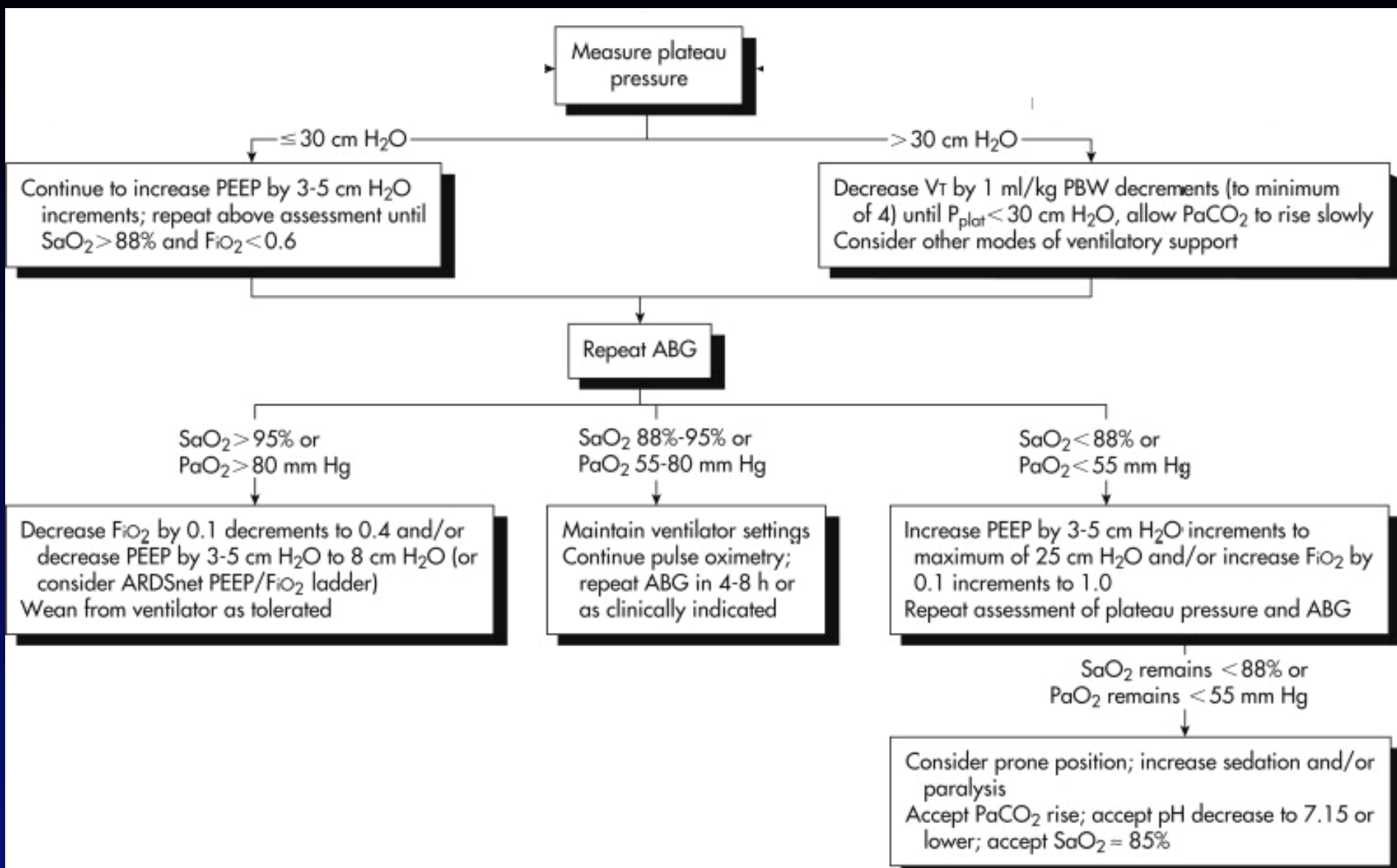
Compressão das regiões dependentes do pulmão OK

Menor expansão da caixa torácica fixa no leito OK



“Bilhete do Pneumologista”:





“Bilhete do Pneumologista”:

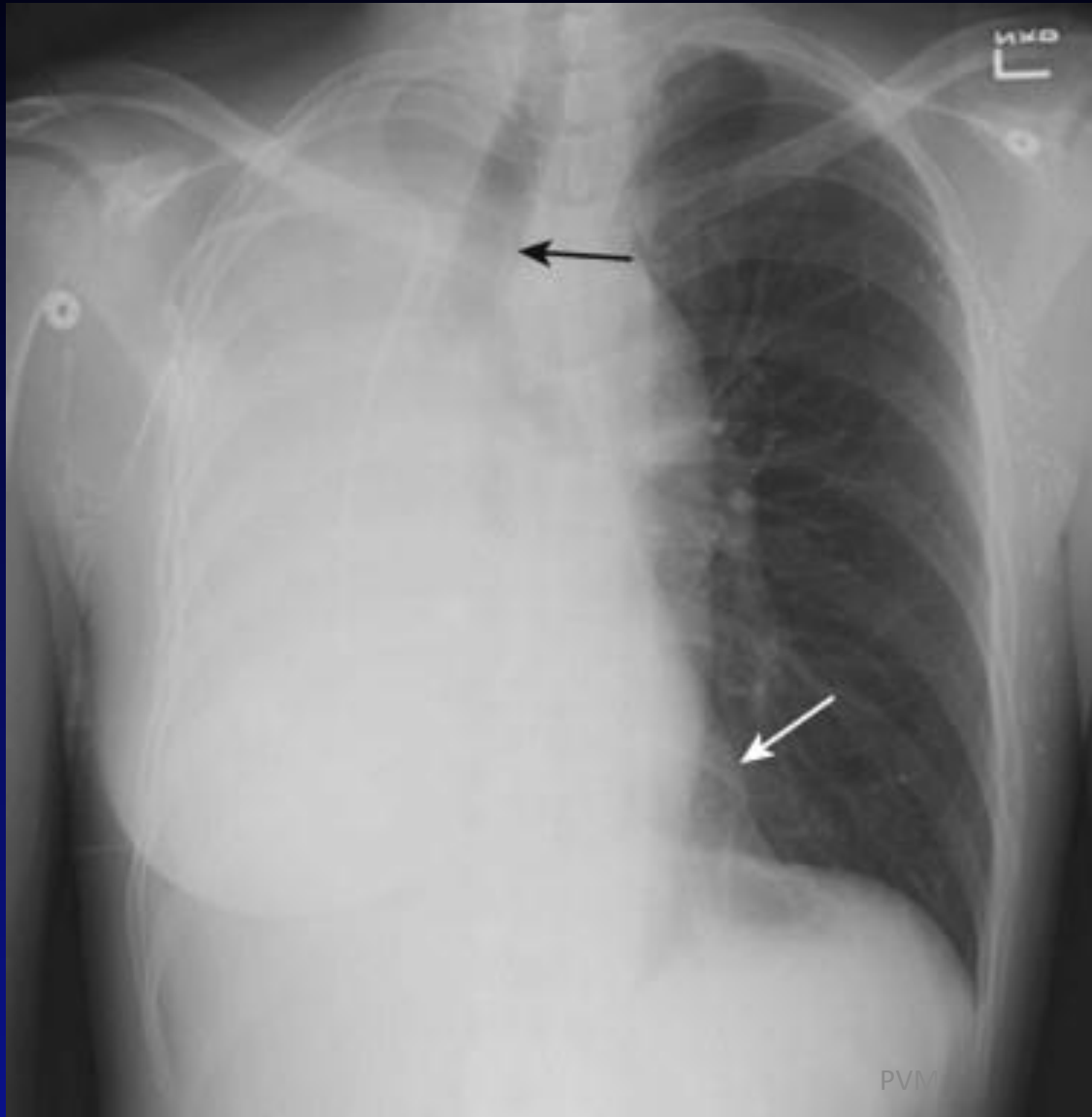
TABLE 90-3. Ventilation Protocol Used in the Acute Respiratory Distress Syndrome Network Study

Parameter	Protocol
Mode of ventilation	Volume assist-control
Tidal volume	≤6 mL/kg predicted body weight*
Plateau pressure	≤30 cm H ₂ O
Frequency	6–35 breaths/min, titrated for pH 7.30–7.45
I:E ratio	1:1 to 1:3
Oxygenation goal	PaO ₂ 55–80 mm Hg, or SpO ₂ 88%–95%
FiO ₂ /PEEP (cm H ₂ O) 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 FiO ₂ /PEEP ≤ 0.4/8

Dúvidas

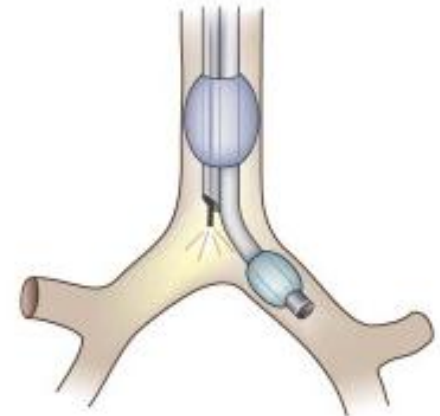
- Fração de espaço morto está associado a mortalidade
 - Como vou reduzir espaço morto?
- Qual o nível ideal de PEEP?
 - O que usar para chegar na PEEP ideal?

Estratégias diferenciadas



Bronchial cuff

RUL



D

Correct DLT position



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.

“Bilhete do Pneumologista”:

X

Saber “sair do protocolo”

The New England
Journal of Medicine

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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*



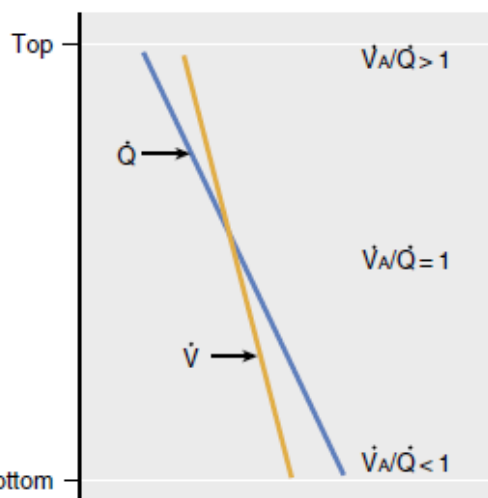
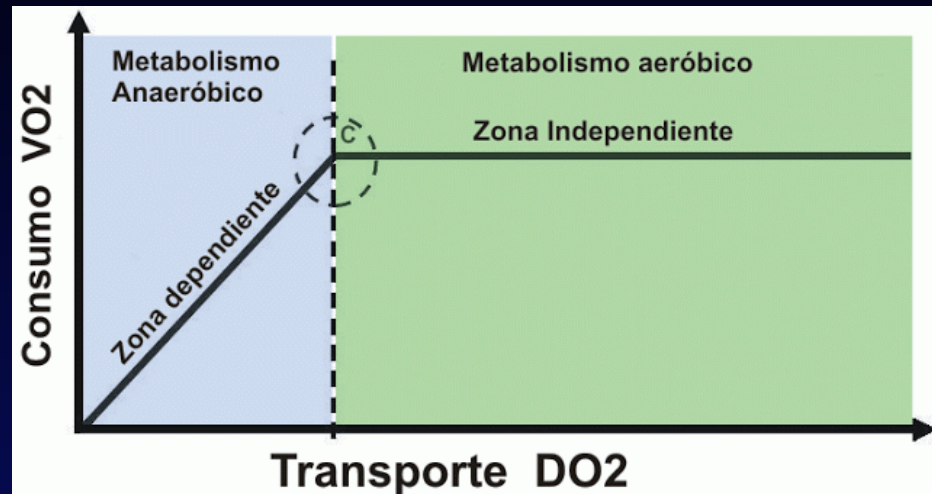
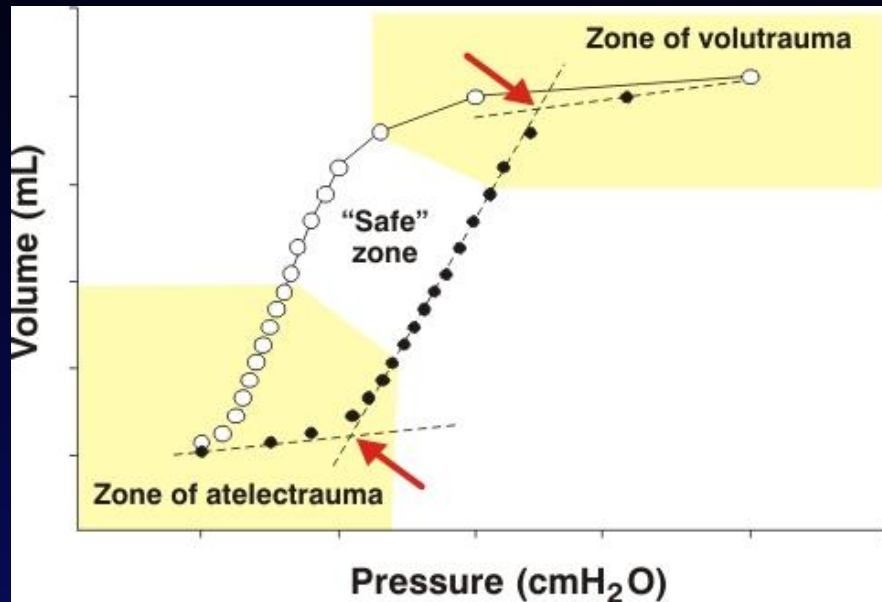
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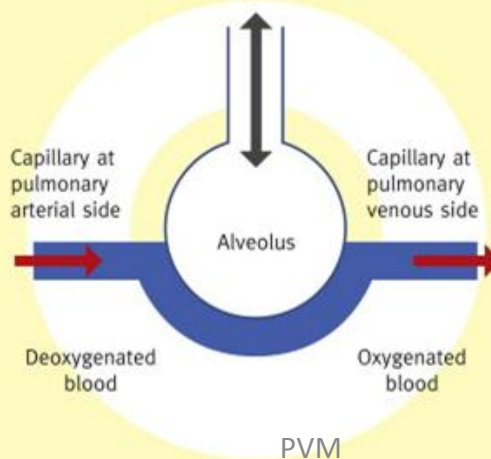
O que eu posso fazer

- VM protetora – ARDS net
- BUSCAR A PEEP IDEAL
 - Melhorar P/F sem aumentar dano: EM alveolar, DC, volutrauma.
 - Gradiente PaCO_2 - PETCO_2
 - Capnografia volumetrica
- Não deixar atelectasiar e recrutar
- Diminuir espaço morto anatômico
- Superficialização intermitente da sedação
- Nutrição
- Suporte hemodinâmico adequado

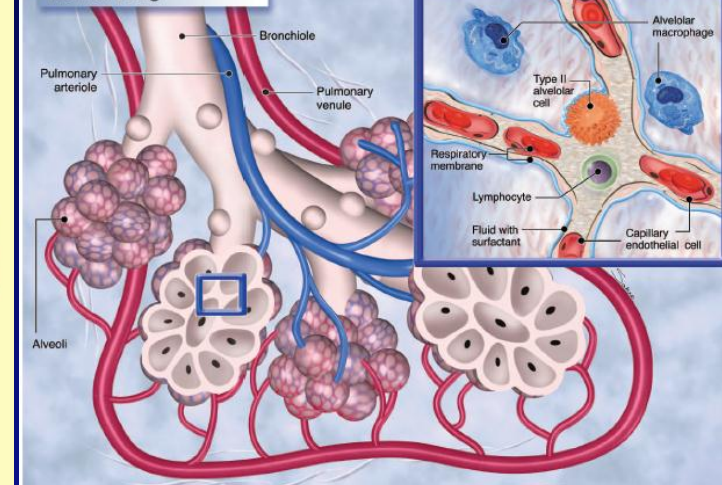
O que eu posso fazer



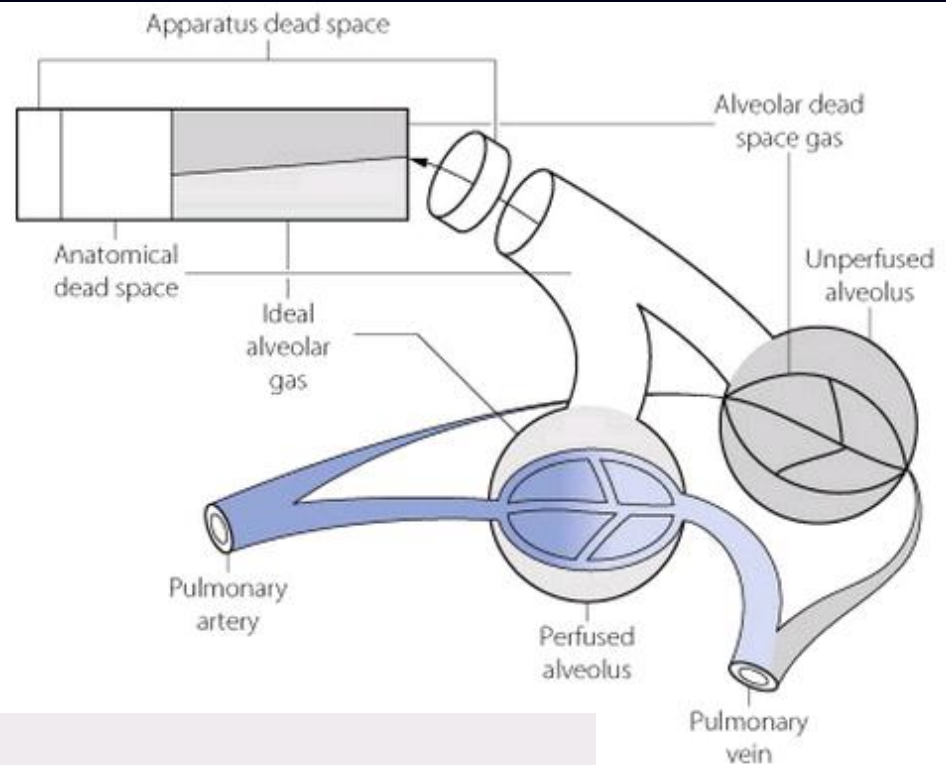
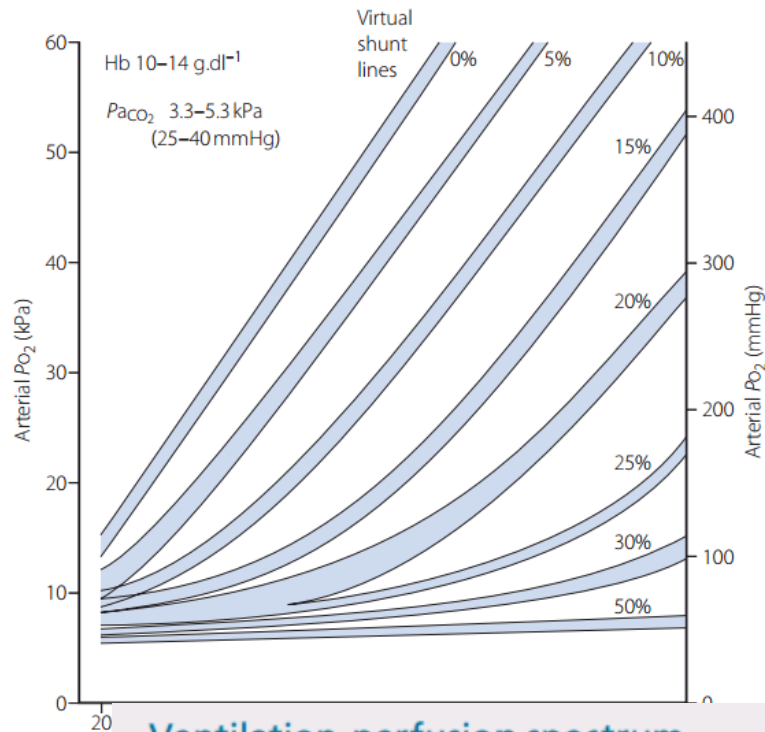
a Normal alveolar-capillary unit



A Normal Lung



O que eu posso fazer



Ventilation-perfusion spectrum

