ČSARIM Prague 9th October 2025

Day 1: Acid base and gas exchange for anaesthetists

Physiology of CO_2 regulation

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Case 1

Confusion in a **35 year-old man**

pH 7.36	$PaCO_2$ 14 mmHg **1.8 KPa**
PO_2 95 mmHg **12.7 KPa**	HCO_3^- 7.9 mEq/L
Hb 14 g/dL	BE -15.5 mEq/L

≈ 48 hours **diarrhoea** and **vomiting**

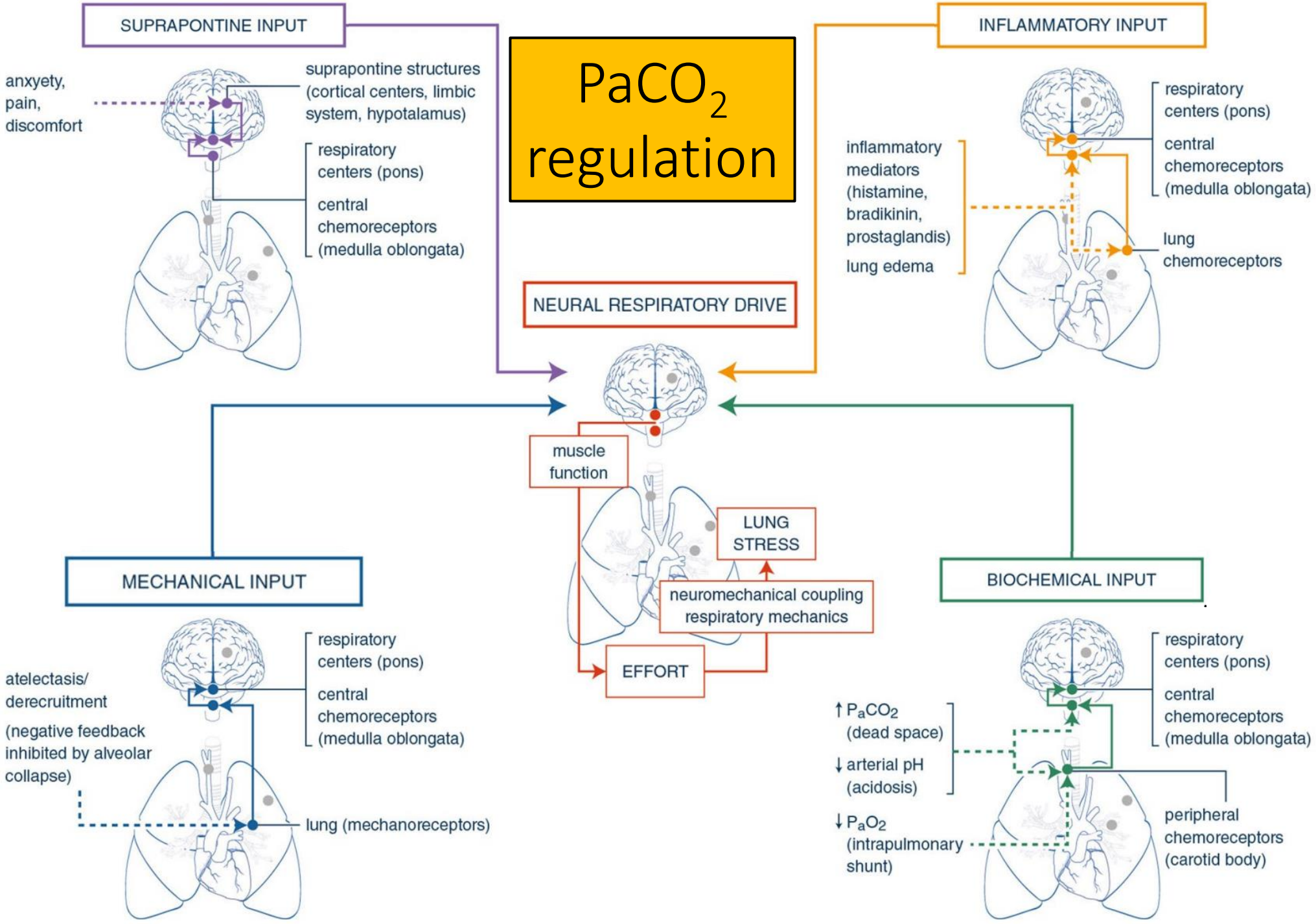
Case 2

Cyanosis in a **50 year-old woman**

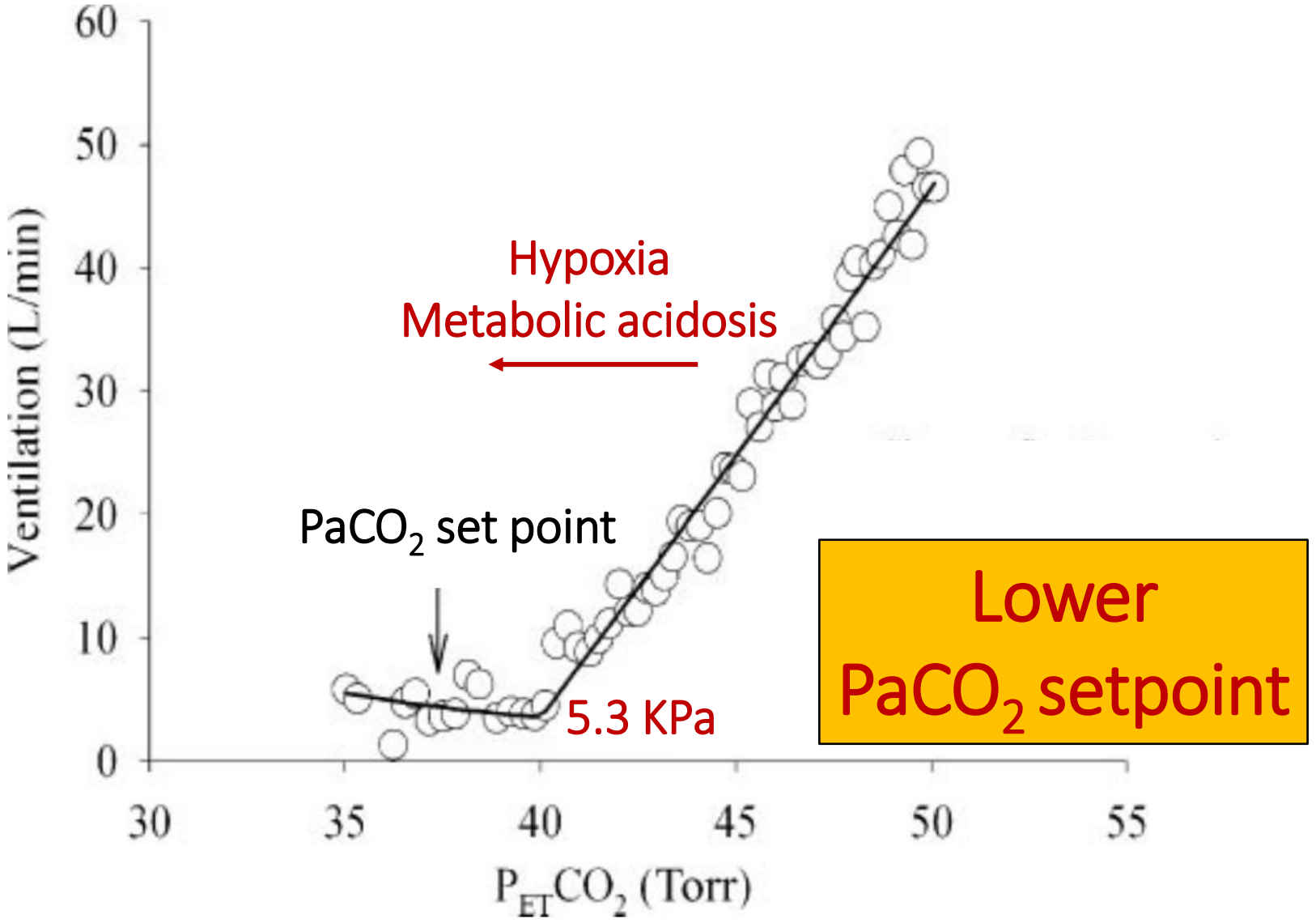
pH 7.50	$PaCO_2$ 29 mmHg **3.8 KPa**
PO_2 43 mmHg **5.7 KPa**	HCO_3^- 22.1 mEq/L
Hb 15 g/dL	BE - 0.6 mEq/L

COVID – 19 swab **positive**

Respiratory rate : 16 bpm
No dyspnoea


SUPRAPONTINE INPUT
anxyety, pain, discomfort
suprapontine structures (cortical centers, limbic system, hypotalamus)
respiratory centers (pons)
central chemoreceptors (medulla oblongata)
PaCO2 regulation
INFLAMMATORY INPUT
inflammatory mediators (histamine, bradikinin, prostaglandis)
lung edema
respiratory centers (pons)
central chemoreceptors (medulla oblongata)
lung chemoreceptors
NEURAL RESPIRATORY DRIVE
muscle function
LUNG STRESS
neuromechanical coupling respiratory mechanics
EFFORT
MECHANICAL INPUT
atelectasis/ derecruitment
(negative feedback inhibited by alveolar collapse)
respiratory centers (pons)
central chemoreceptors (medulla oblongata)
lung (mechanoreceptors)
BIOCHEMICAL INPUT
↑ PaCO2 (dead space)
↓ arterial pH (acidosis)
↓ PaO2 (intrapulmonary shunt)
respiratory centers (pons)
central chemoreceptors (medulla oblongata)
peripheral chemoreceptors (carotid body)

CO_2 sensitivity curve



Lower $PaCO_2$ setpoint

J Appl Physiol 96: 1197–1205, 2004

How much ?

Ventilatory response to metabolic acidosis

pH 7.36	$PaCO_2$ 14 mmHg 1.8 KPa
PO_2 95 mmHg 12.7 KPa	HCO_3^- 7.9 mEq/L
Hb 14 g/dL	BE -15.5 mEq/L

DISORDER	BOSTON RULES HCO_3^- (mmol/L)	PCO_2 (mmHg)
		KPa: $[HCO_3^-]/5 + 1$
Metabolic acidosis	< 22	$= 1.5 * [HCO_3^-] + 8$
Metabolic alkalosis	> 26	$= 0.7 * [HCO_3] + 21$
Acute respiratory acidosis	$= (PCO_2 - 40)*1/10 + 24$ "*up one-for-ten*"	> 45
Chronic respiratory acidosis	$(PCO_2 - 40)*4/10 + 24$ "*up four-for-ten*"	> 45
Acute respiratory alkalosis	$= 24 - (40 - PCO_2) *2/10$ "*down two-for-ten*"	< 35
Chronic respiratory alkalosis	$= 24 - (40 - PCO_2)*5/10$ "*down five-for-ten*"	< 35

Overcompensating ?

→ Expected $PaCO_2$

20 mmHg

2.7 KPa

Limitations

Healthy subjects

Spontaneously breathing

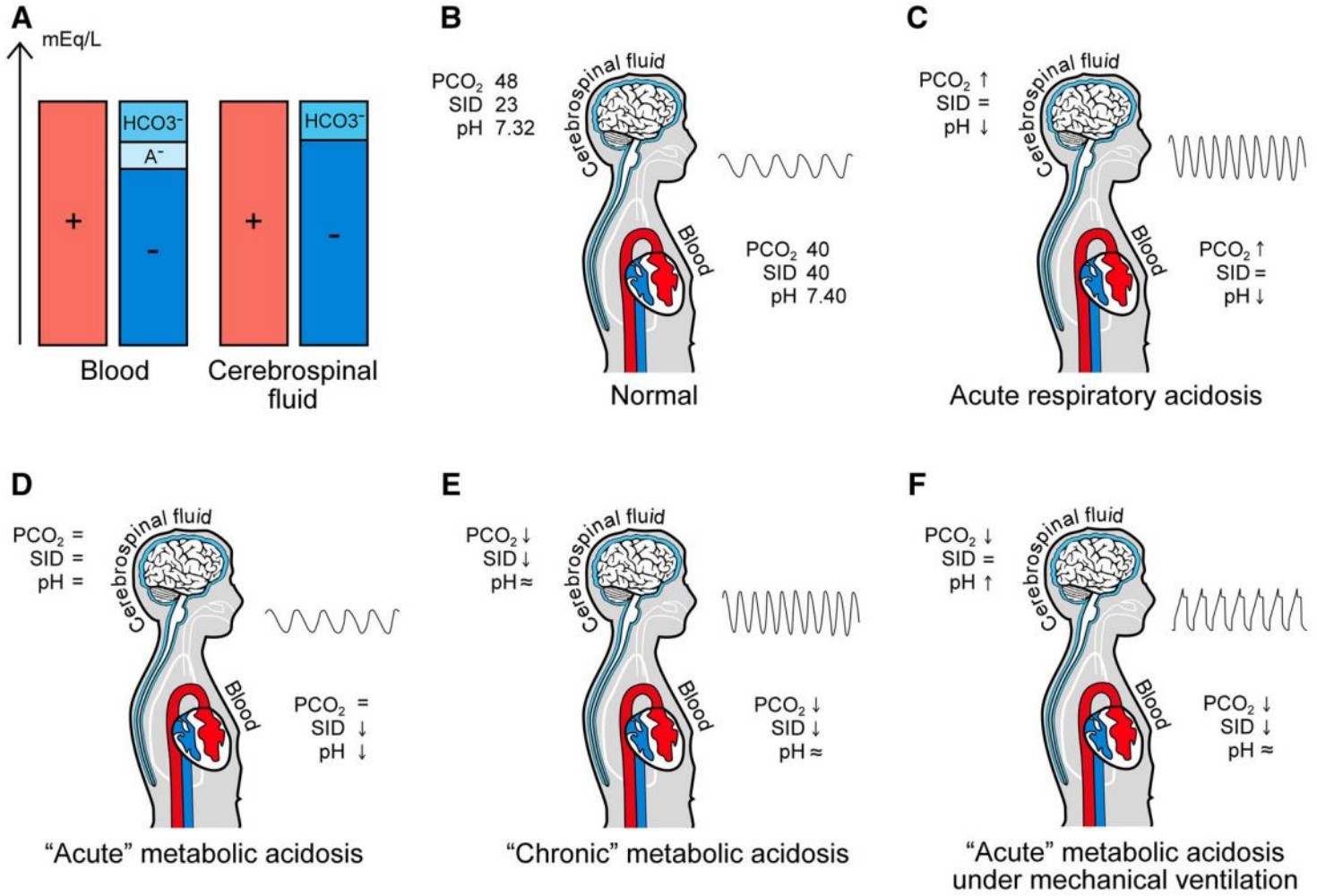
Crit Care & Resusc. 2006. 8:19-30

«Delayed» respiratory response

Acidosis Onset

12 hrs before hyperventilation begins

≈ 12-24 hrs for plasma – CSF equilibration



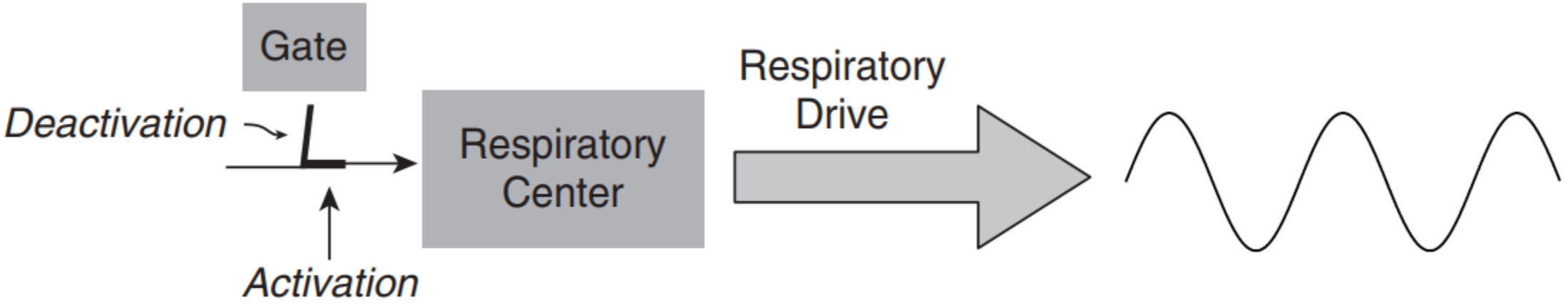
Acidosis Treatment

12 hrs prolonged hyperventilation

Treatment started 4 hours earlier

Intensive Care Med (2016) 42:436–439

Respiratory drive and rate



Timing of output: Respiratory rate

2-3 times increase

Intensity of output: Respiratory drive

Reflex feedback

- Mechanical
- Inflammatory

Chemical feedback

$PaCO_2$

pH

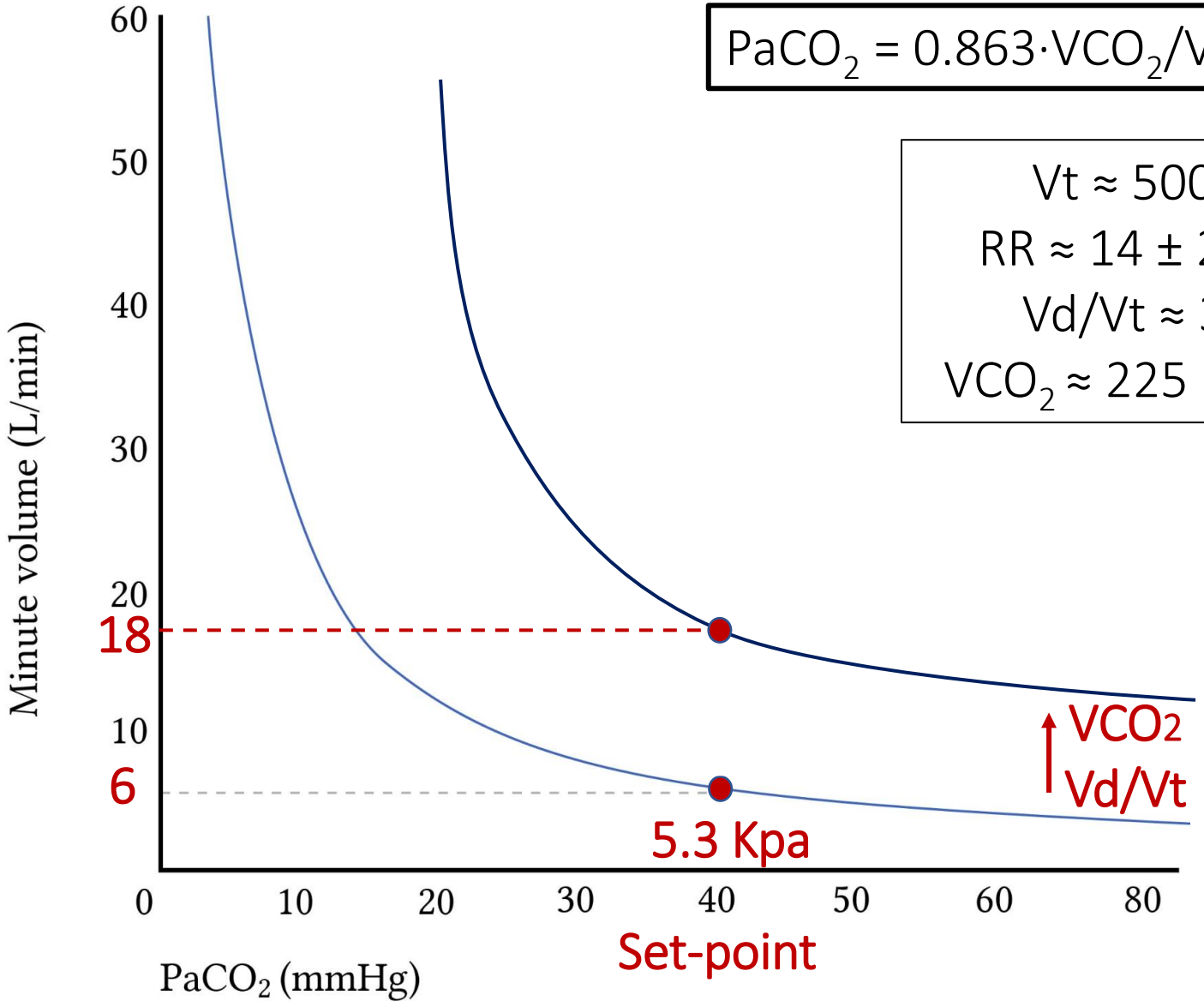
PaO_2

Behavioral feedback

Metabolic hyperbola

$$PaCO_2 = 0.863 \cdot VCO_2/Vt \cdot RR \cdot (1-V_d/V_t)$$

Vt ≈ 500 ml
RR ≈ 14 ± 2 bpm
Vd/Vt ≈ 30%
VCO_2 ≈ 225 mL/min

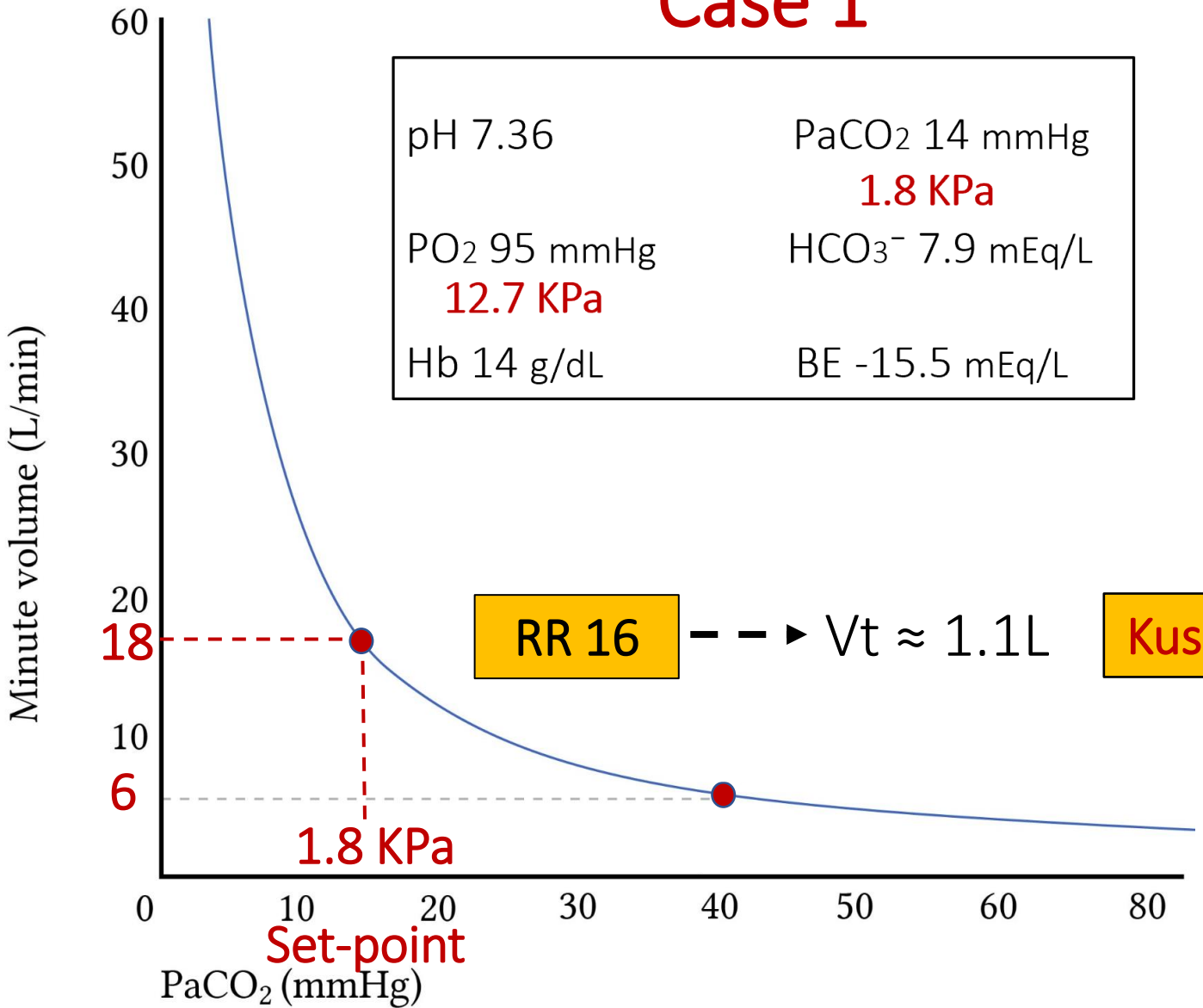


AJRCCM. 2020; 201 (1): 20–32

Metabolic acidosis

Case 1

pH 7.36	$PaCO_2$ 14 mmHg 1.8 KPa
PO_2 95 mmHg 12.7 KPa	HCO_3^- 7.9 mEq/L
Hb 14 g/dL	BE -15.5 mEq/L



RR 16 - - ▸ Vt ≈ 1.1L

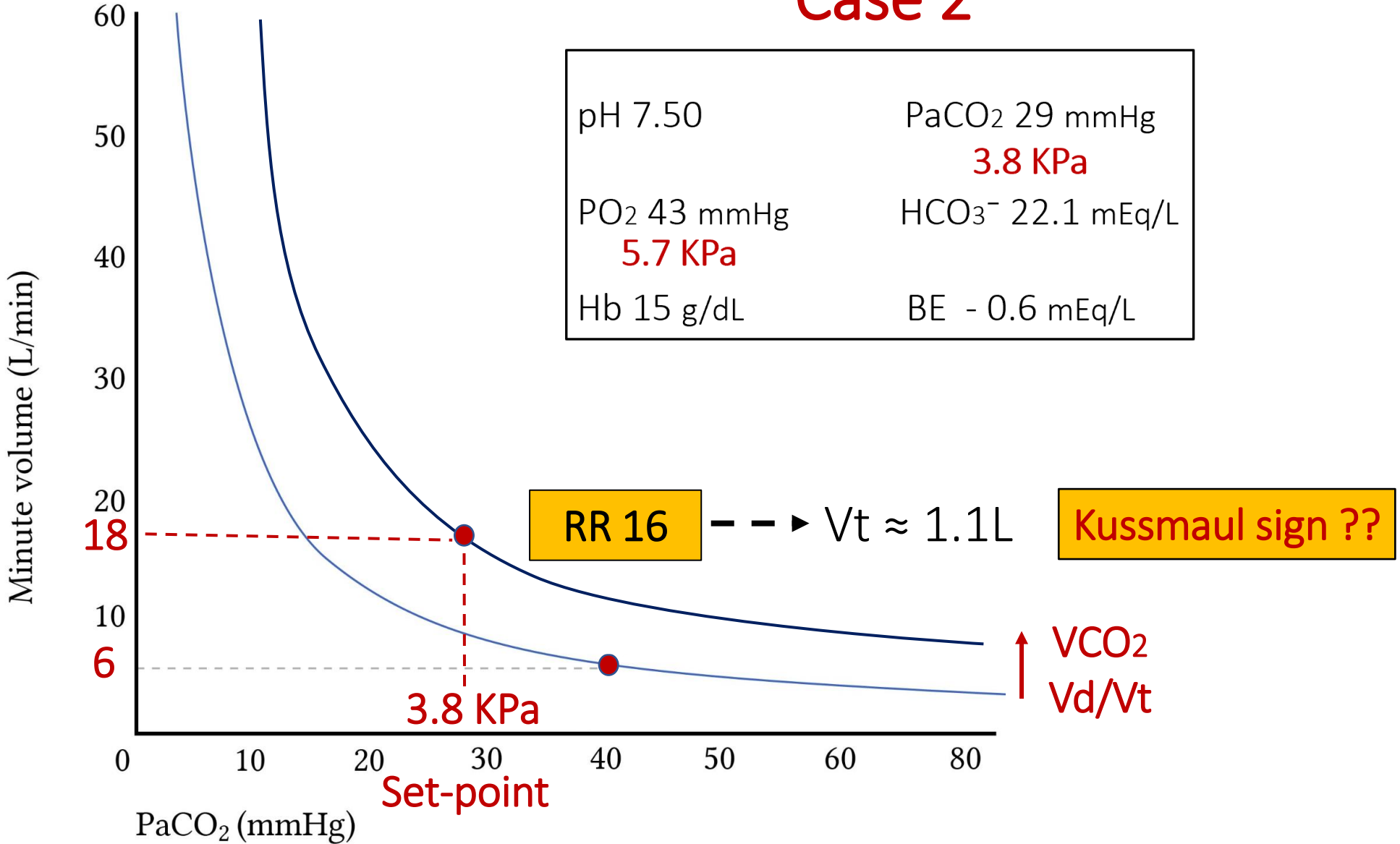
Kussmaul sign

AJRCCM. 2020; 201 (1): 20–32

Hypoxaemia

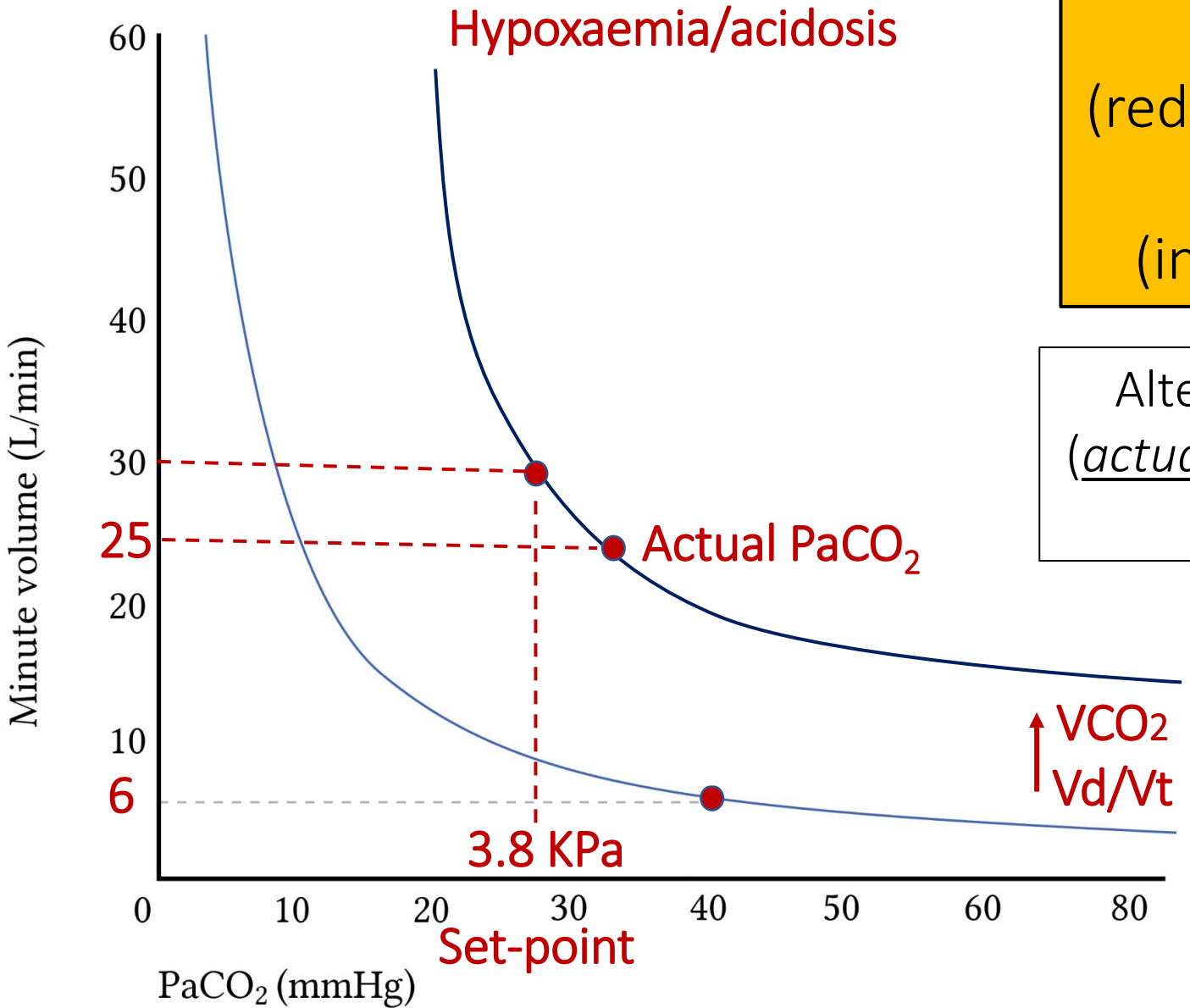
Case 2

pH 7.50	$PaCO_2$ 29 mmHg 3.8 KPa
PO_2 43 mmHg 5.7 KPa	HCO_3^- 22.1 mEq/L
Hb 15 g/dL	BE - 0.6 mEq/L



AJRCCM. 2020; 201 (1): 20–32

Dyspnoea ?



Severe Pneumonia
(reduced lung compliance)
COPD
(inefficient diaphragm)

Altered descending pathway
(*actual* $PaCO_2$ ǂ *set point* $PaCO_2$):
dyspnea

AJRCCM. 2020; 201 (1): 20–32

High Vt

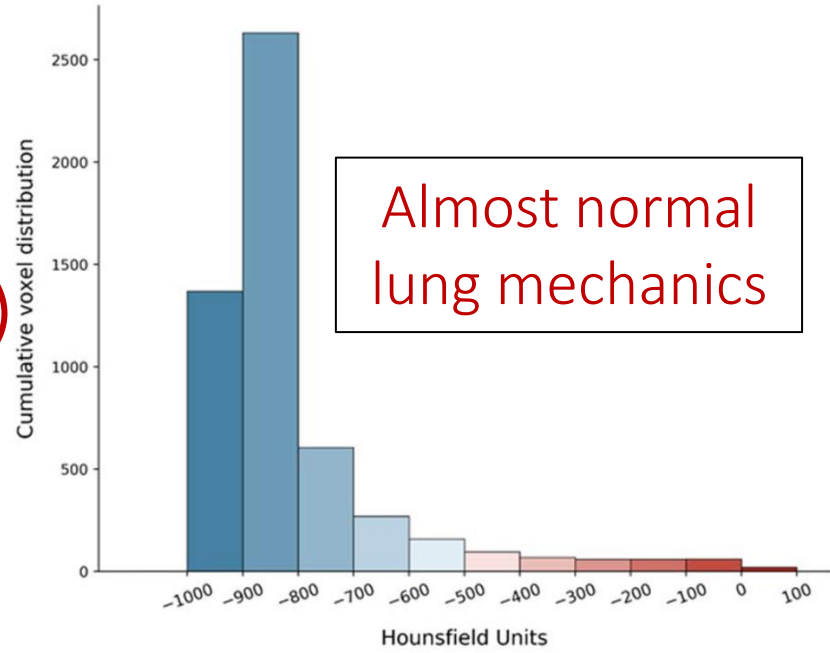
Hypocapnia

Dyspnea??

High RR

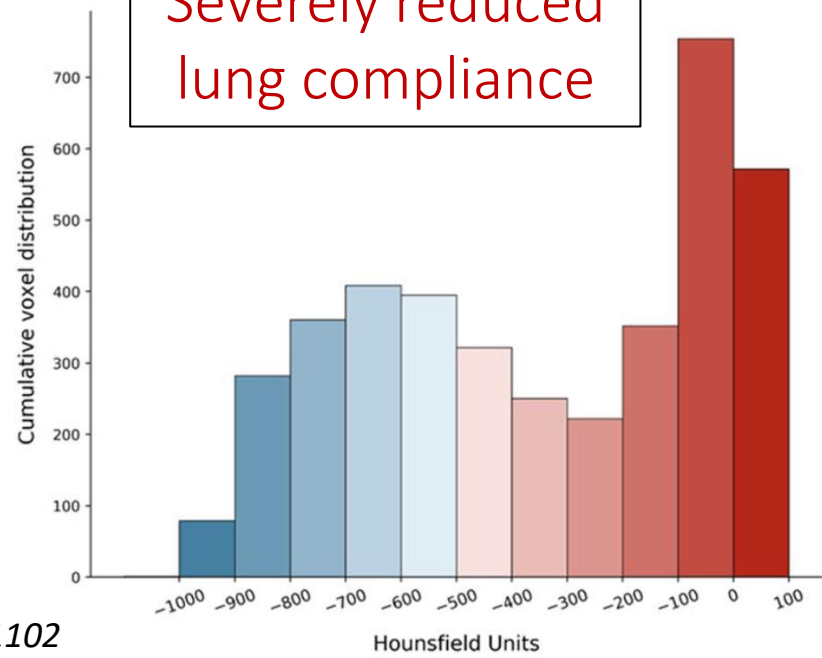
Hypo/normo/hyper capnia

PaO_2/FiO_2 95 mmHg



Almost normal lung mechanics

PaO_2/FiO_2 84 mmHg



Severely reduced lung compliance

ICM. 2020; 46:1099–1102

Conclusions

- $PaCO_2$ is the main regulator of respiratory drive
- Hypoxaemia and metabolic acidosis reduce the $PaCO_2$ set point
- VCO_2 and Vd/Vt determine the VE required for the new set point
- Kussmaul sign is normal in healthy lungs
- High respirtory rate reflects high drive or behaviour / inflammation
- Dyspnea reflects incapability to obtain desired $PaCO_2$ set point