

Fysiologie in extremen “Hoogte”

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Longfysioloog



CONFLICT OF INTEREST DISCLOSURE

I have no real or perceived conflicts of interest that relate to this presentation.

“We are not rich, but we’re happy”

Sectie Longfysiologie (SLF)



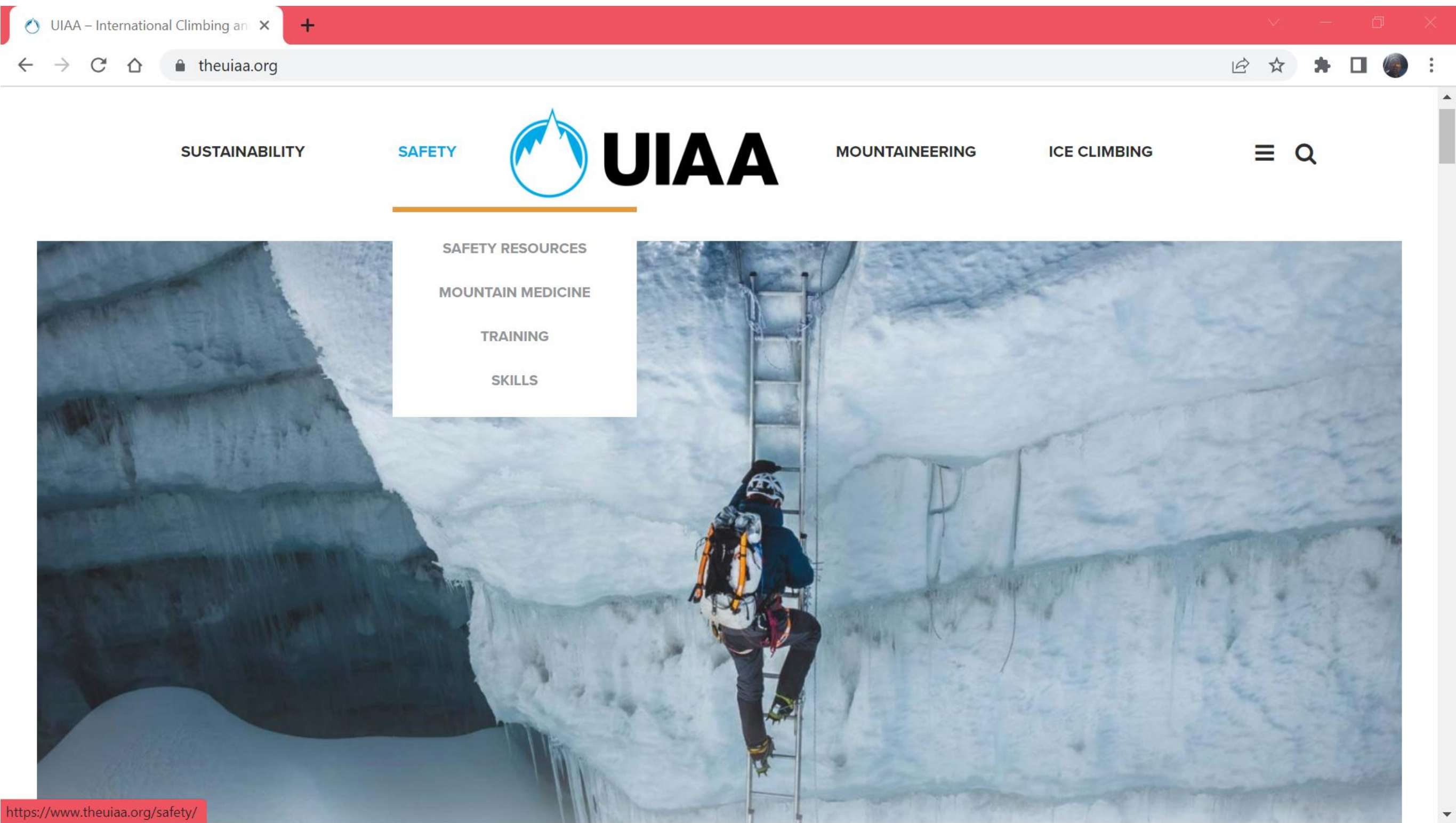
ter opstelling van

Position paper:

Ademhaling onder bijzondere omstandigheden – duiken, vliegen en hoogte

van de Nederlandse Vereniging van Artsen voor Longziekten en Tuberculose

Versie 15 -2-2021



Richtlijnen: [www.theuiaa.org](https://www.theuiaa.org/safety/)





UC San Diego
SCHOOL OF MEDICINE

Respiratory Physiology

John B. West, MD, PhD

Youtube: John B. West



INHOUD

- ▶ Effecten van hoogte
- ▶ Acute hypoxie
- ▶ Acclimatisatie
- ▶ Bloedgassen op hoogte
- ▶ Hypoxische ventilatoire respons
- ▶ Hypercapnische ventilatoire respons
- ▶ Hypoxische vasoconstrictie
- ▶ Vragen





EFFECTEN VAN

HOOGTE

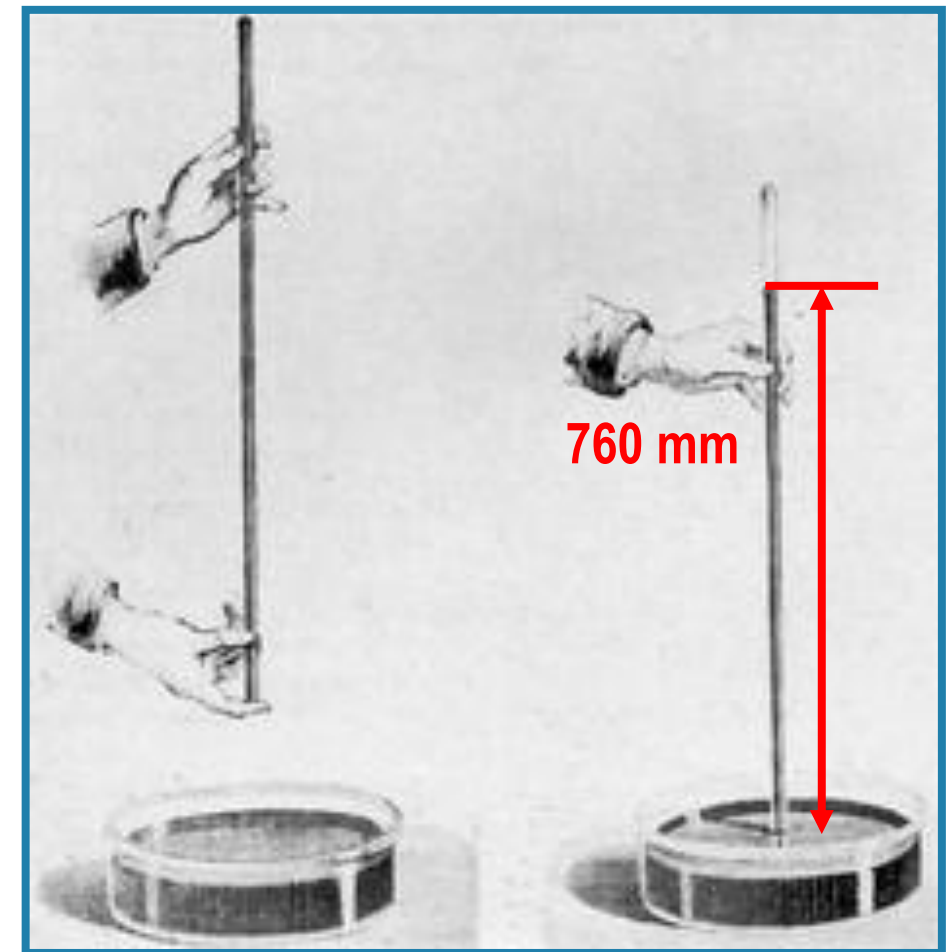
EFFECTEN VAN HOOGTE

- ▶ Temperatuur
- ▶ “ijle lucht” oftewel hypobare hypoxie

HYPOBARE HYPOXIE

Torrecelli (1644)

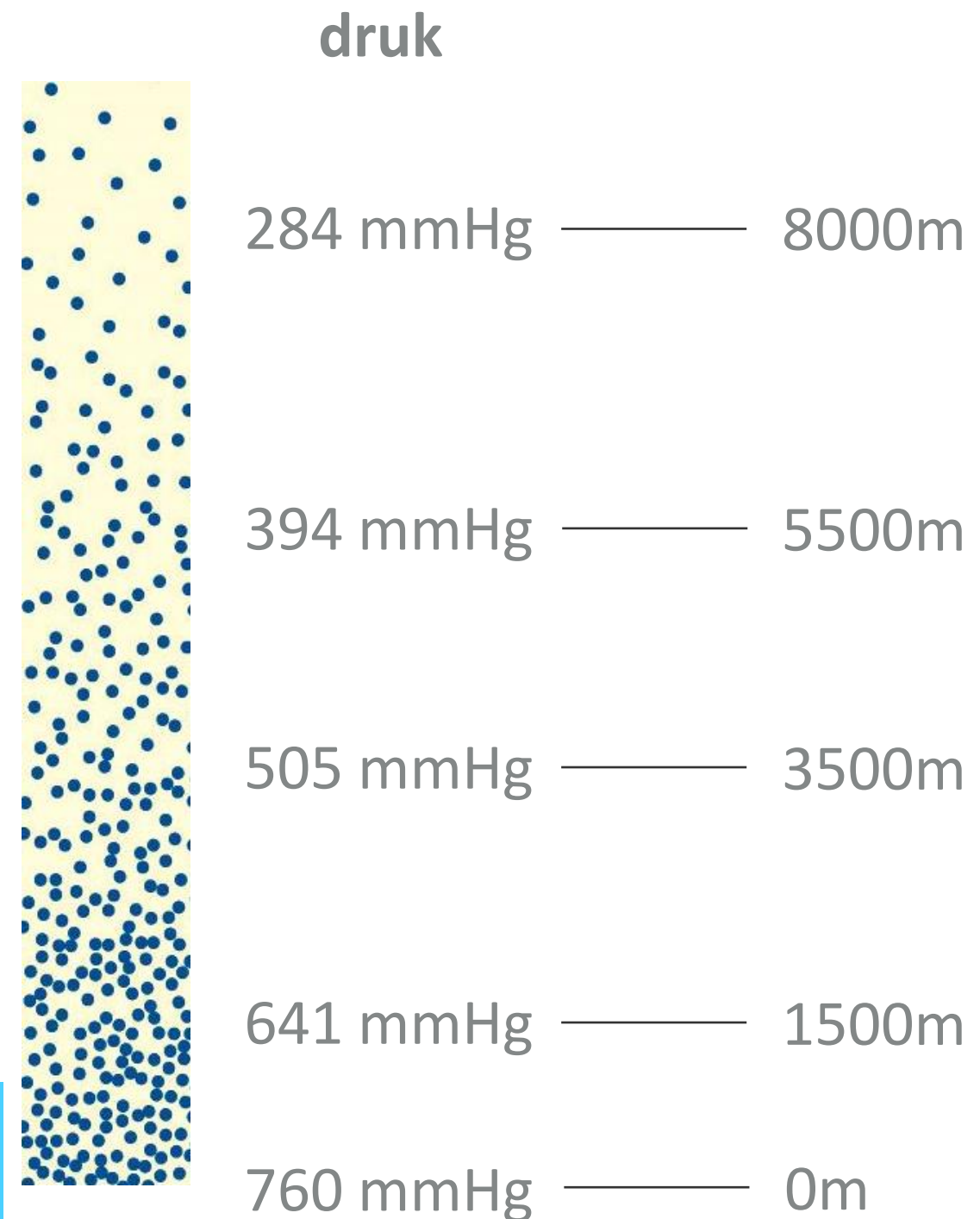
“we live submerged at the bottom of an ocean of the element air, which by unquestioned experiments is known to have weight, ..”



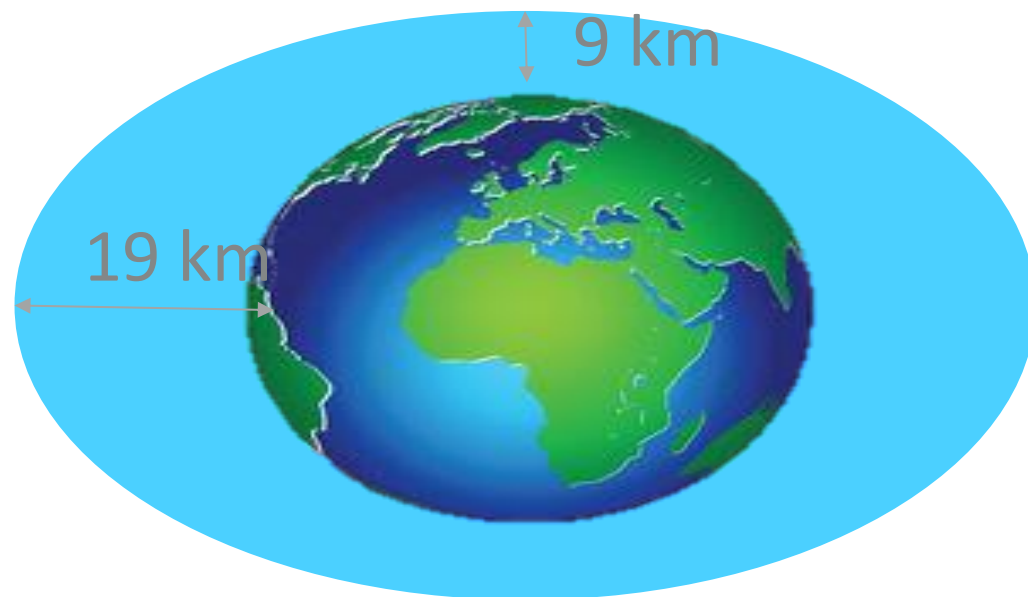
ATMOSPHERIC PRESSURE



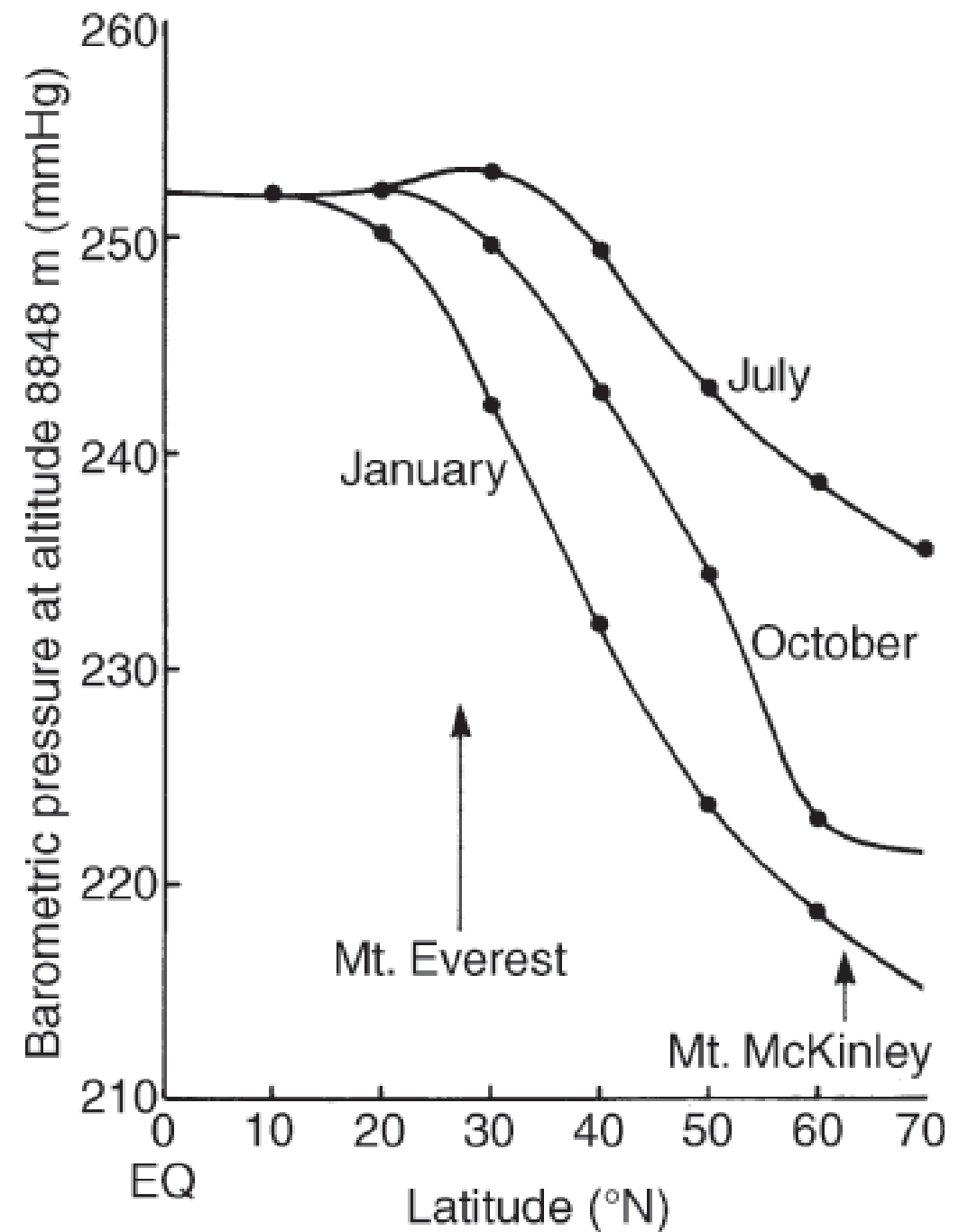
$$PO_2 = 0.21 \times (\text{barometric pressure})$$



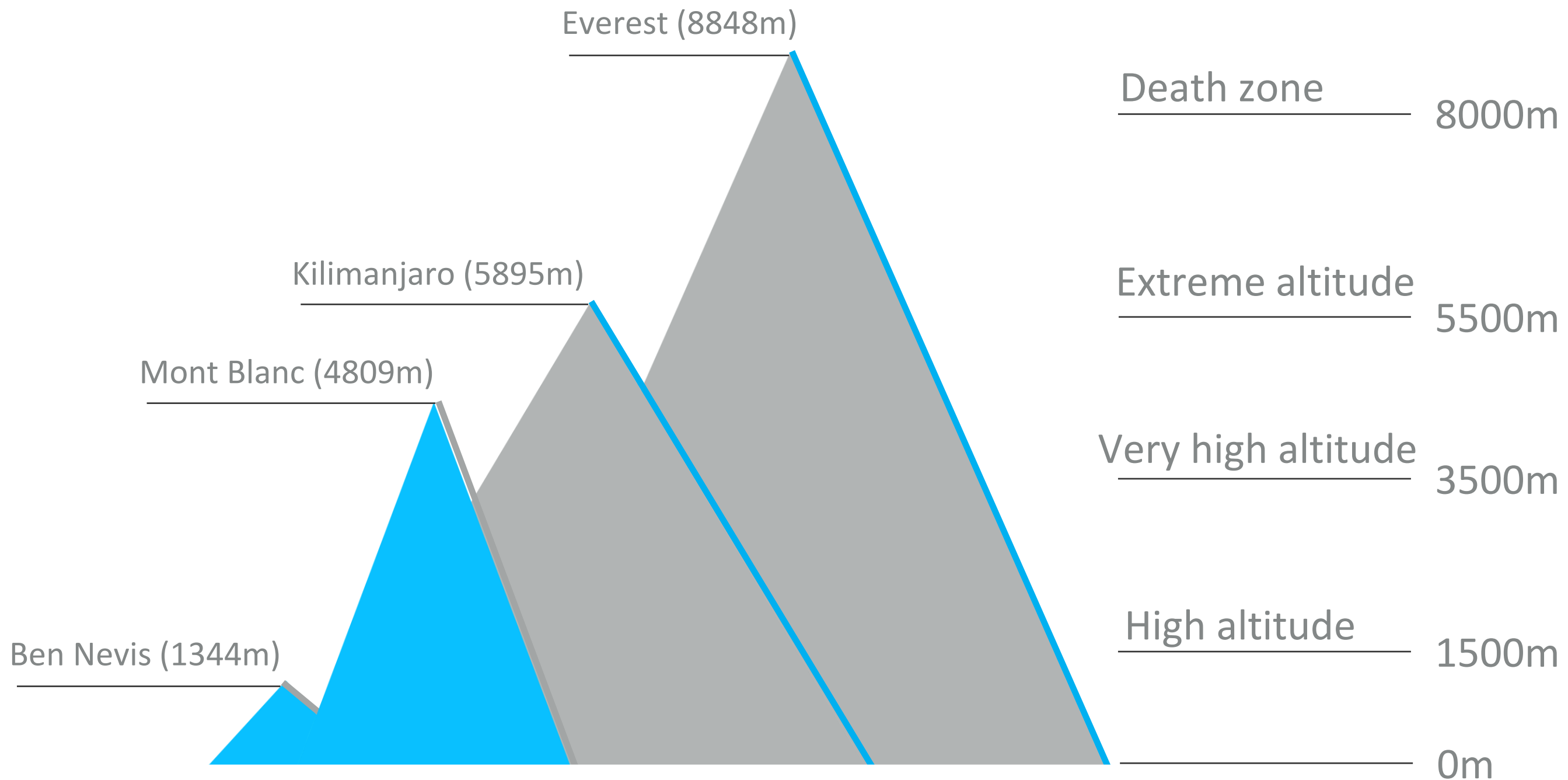
ATMOSPHERIC PRESSURE



Barometric pressure, from West, 2014 (2)



ALTITUDE



Altitude definitions , adapted from Wilson, 2009

HOOGTE

- ▶ Hoogte (1500 -3500m)

SATURATIE ROND DE 90%
VERMINDERDE INSPANNINGSTOLERANTIE
TOEGENOMEN VENTILATIE
AMS KOMT FREQUENT VOOR (VEEL MENSEN -
SNEL OMHOOG)

HOOGTE

- ▶ Hoogte (1500 -3500m)
- ▶ Grote hoogte (3500 – 5500m)

SATURATIE ROND DE 80-90%
ERNSTIGE HYPOXEMIA TIJDENS INSPANNING ($\pm$ SLAAP)
AMS MEESTAL ERNSTIG
GROTERE KANS OP HAPE AND HACE

SATURATIE < 85%

ERNSTIGE HYPOXEMIE, HYPOCAPNIE EN ALKALOSE

ERNSTIGE AANTASTING FYSIOLOGISCHE- EN

COGNITIEVE FUNCTIES

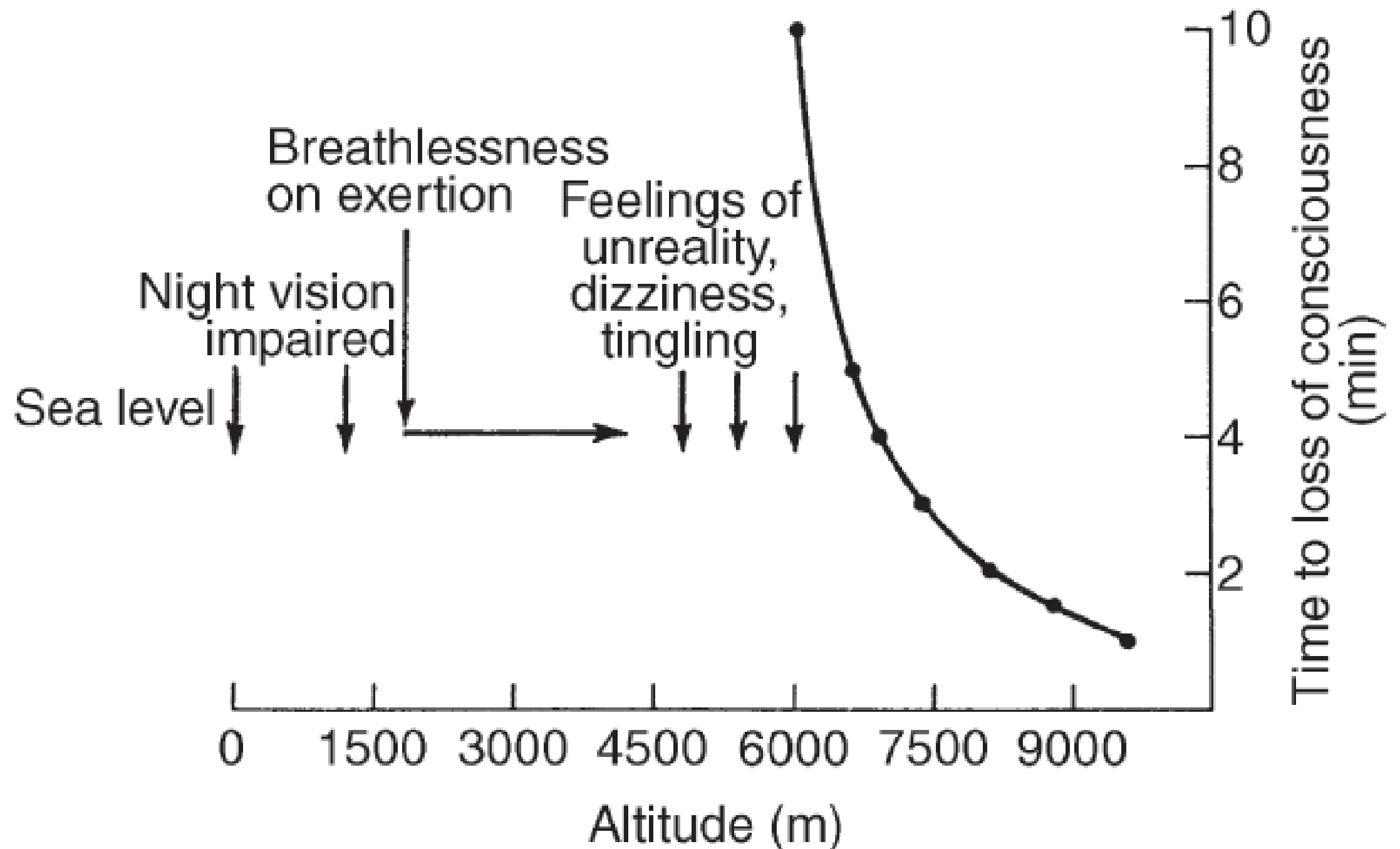
GEEN ACCLIMATISATIE MEER MOGELIJK

- ▶ Extreme hoogte (> 5500 m)

ACUTE HYPOXIE



ACUTE HYPOXIE



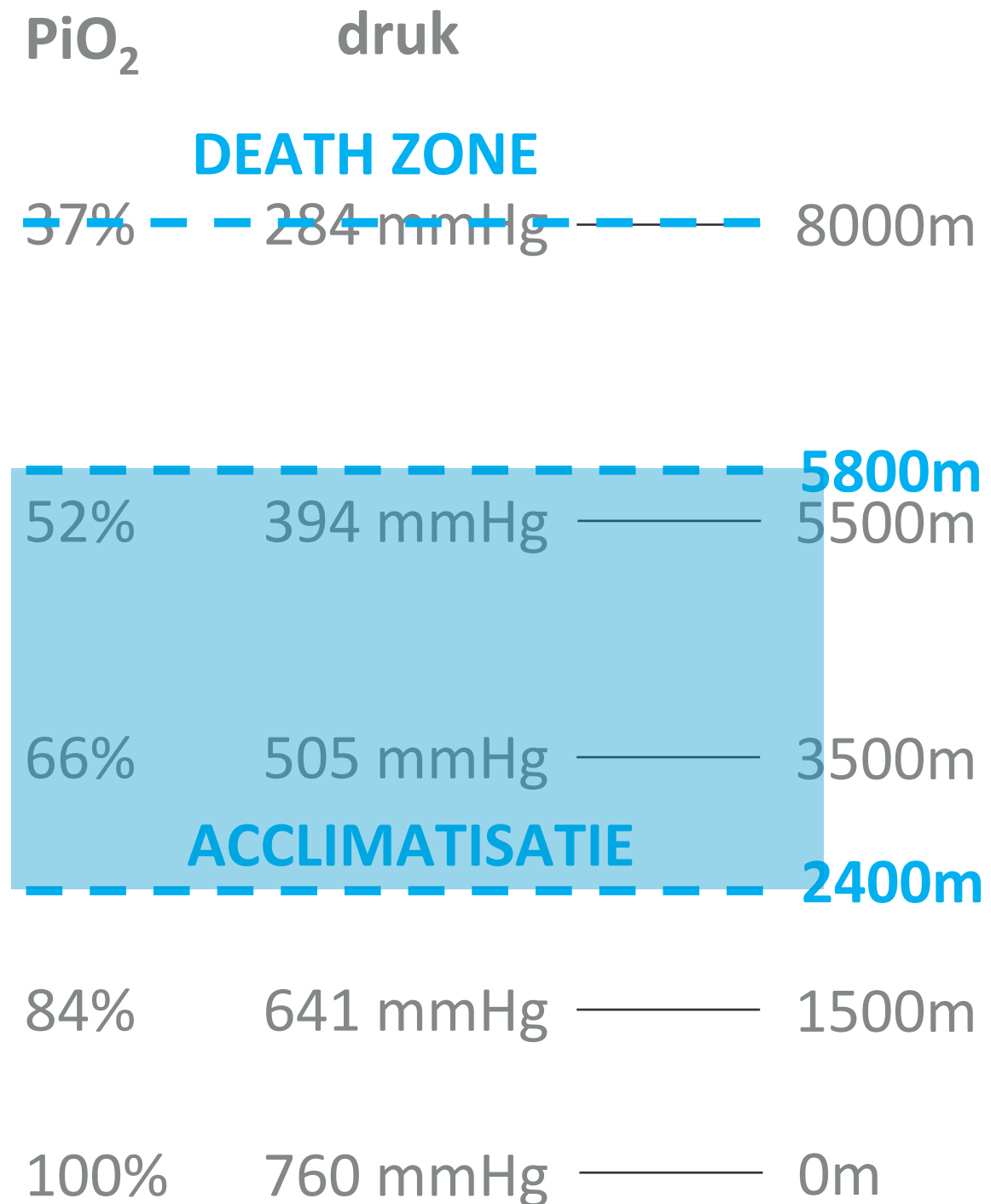
The effect of sudden exposure to various altitudes, from West, 2014

ACCLIMATISATIE

“Adaptation to a new climate”

(a new temperature or altitude or environment)

ACCLIMATISATIE



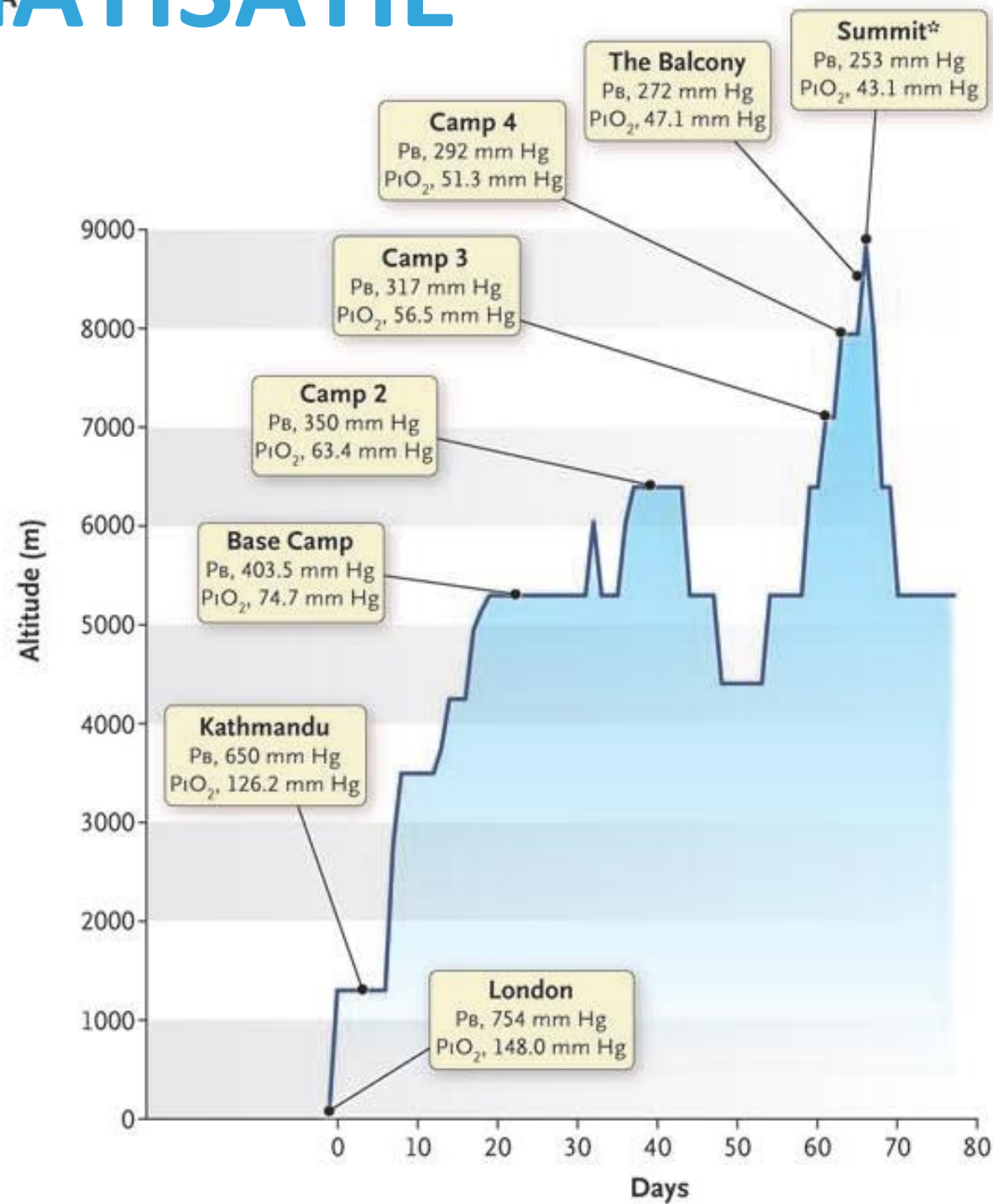
ACCLIMATISATIE

- ▶ Especially sleeping height is important
- ▶ Above 2500 meter:
 - ▶ Increase of sleeping height of max 500 meter per night
 - ▶ Every 3th night remaining on the same altitude
 - ▶ Further ascent during the day might be favorable

ACCLIMATISATIE

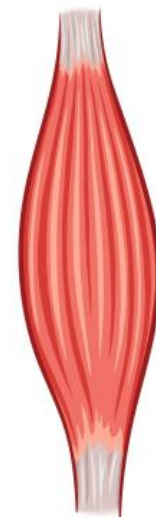
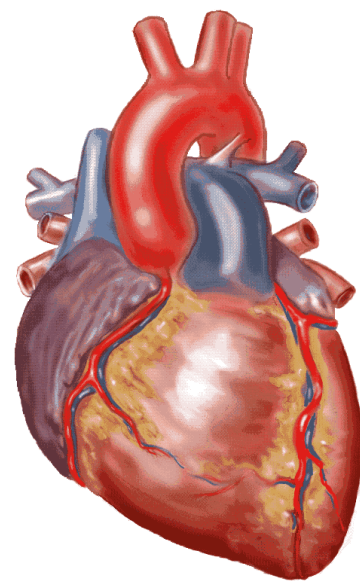
- ▶ Duration depends on the altitude
- ▶ No complete acclimatization above $\pm 5500\text{m}$
- ▶ By rapid ascent serious health risks

ACCLIMATISATIE

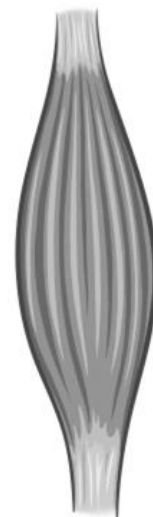
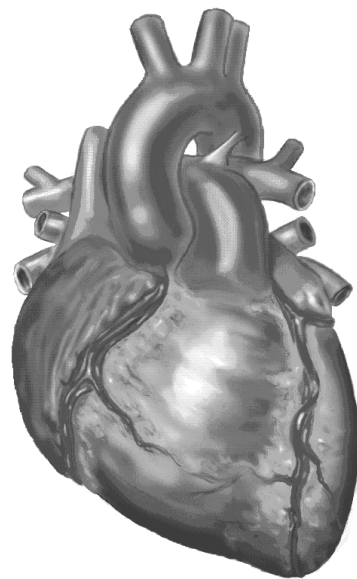


Grocott et al. N Engl J Med 2009;360:140-9.

ACCLIMATISATIE



ACCLIMATISATIE



CAUDWELL XTREME EVEREST 2007



ARTERIELE BLOEDGASSEN



ARTERIELE BLOEDGASSEN

	Sealevel	5300 m	6400 m	7100 m	8400 m
PiO ₂	148				
PaO ₂	100				
PaCO ₂	36.6				
PH	7.40				

ARTERIELE BLOEDGASSEN

	Sealevel	5300 m	6400 m	7100 m	8400 m
PiO ₂	148	74.7			
PaO ₂	100	± 50			
PaCO ₂	36.6	20.4			
PH	7.40	7.46			

Grocott et al. N Engl J Med 2009;360:140-9.

ARTERIELE BLOEDGASSEN

	Sealevel	5300 m	6400 m	7100 m	8400 m
PiO ₂	148	74.7	63.4		
PaO ₂	100	± 50	± 45		
PaCO ₂	36.6	20.4	18.2		
PH	7.40	7.46	7.51		

Grocott et al. N Engl J Med 2009;360:140-9.

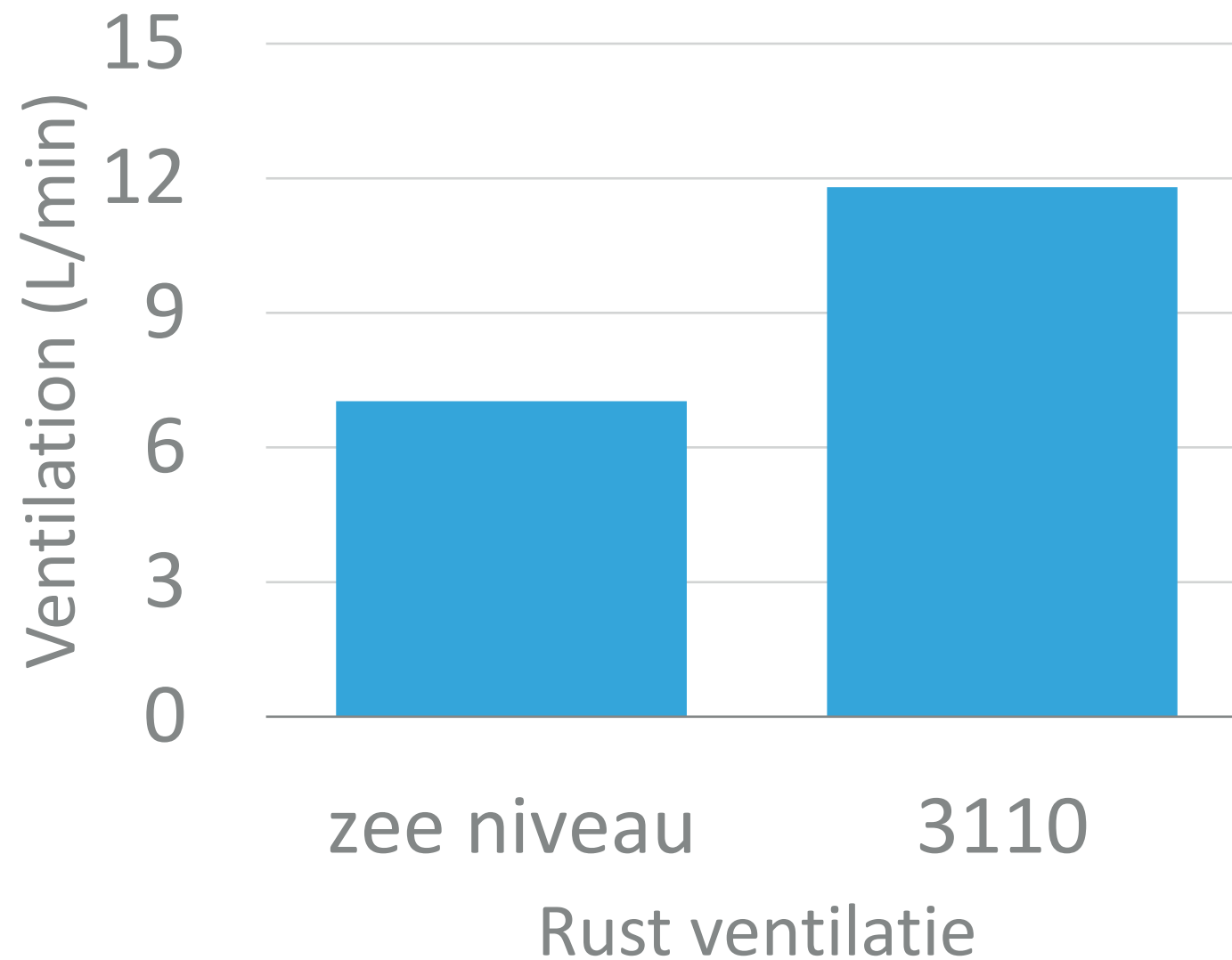
ARTERIELE BLOEDGASSEN

	Sealevel	5300 m	6400 m	7100 m	8400 m
PiO ₂	148	74.7	63.4	56.5	
PaO ₂	100	± 50	± 45	± 40	
PaCO ₂	36.6	20.4	18.2	16.7	
PH	7.40	7.46	7.51	7.53	

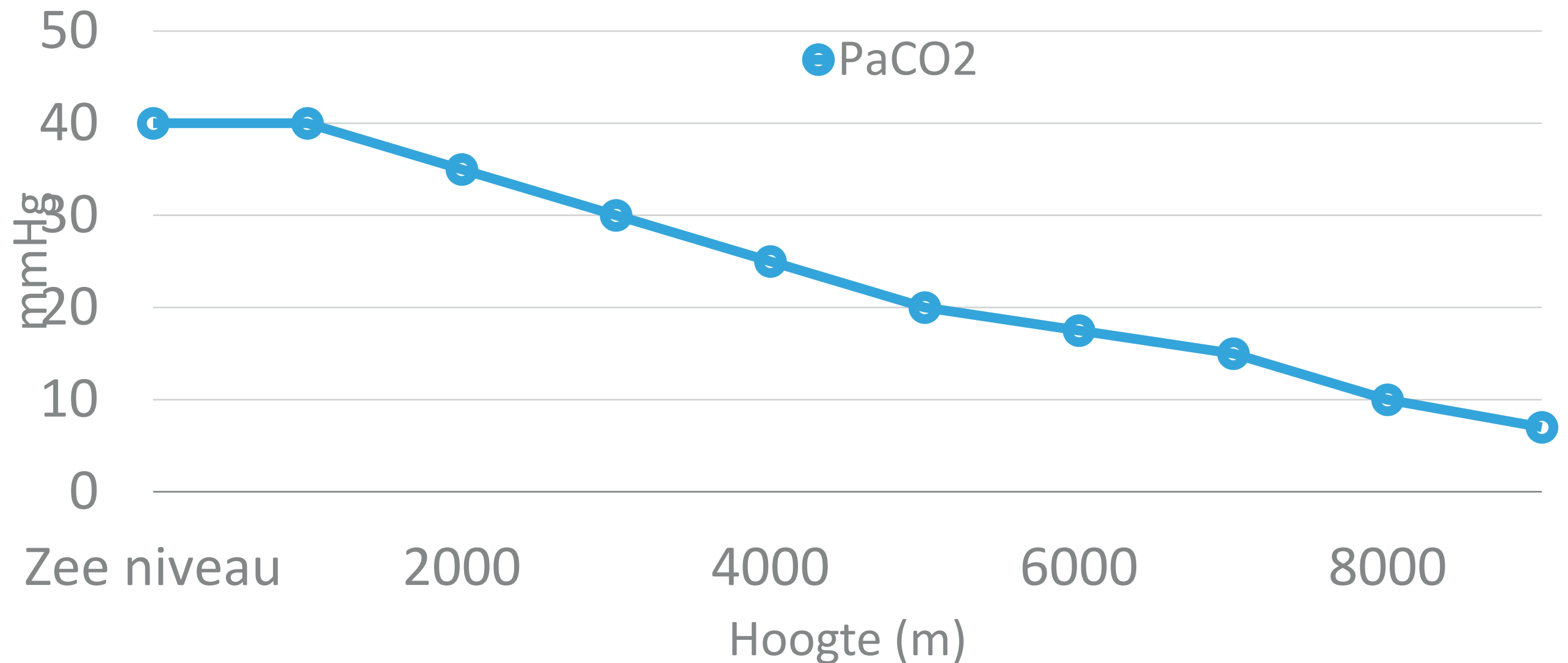
ARTERIELE BLOEDGASSEN

	Sealevel	5300 m	6400 m	7100 m	8400 m
PiO ₂	148	74.7	63.4	56.5	47.0
PaO ₂	100	± 50	± 45	± 40	24.6
PaCO ₂	36.6	20.4	18.2	16.7	13.3
PH	7.40	7.46	7.51	7.53	7.53

HYPOXIC VENTILATORY RESPONSE (HVR)



HYPOXIC VENTILATORY RESPONSE (HVR)



ALVEOLAIRE GAS VERGELIJKING



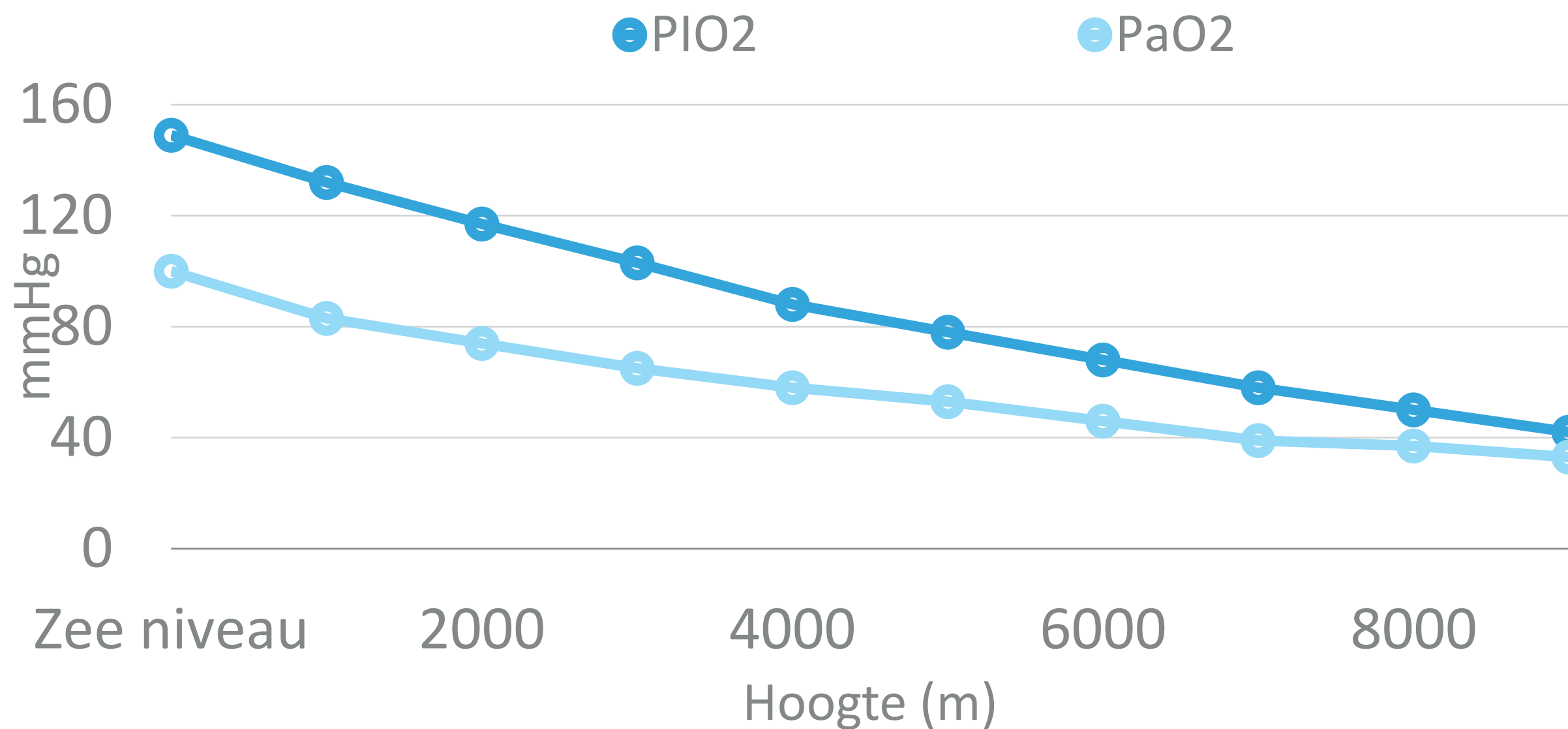
$$P_A O_2 = P_I O_2 - \frac{P_A CO_2}{RER}$$

$$P_A O_2 = 148 - \frac{36.6}{0.8} \approx 105$$

$$P_A O_2 = 47 - \frac{36.6}{0.8} \approx 2$$

$$P_A O_2 = 47 - \frac{13.3}{0.8} \approx 30$$

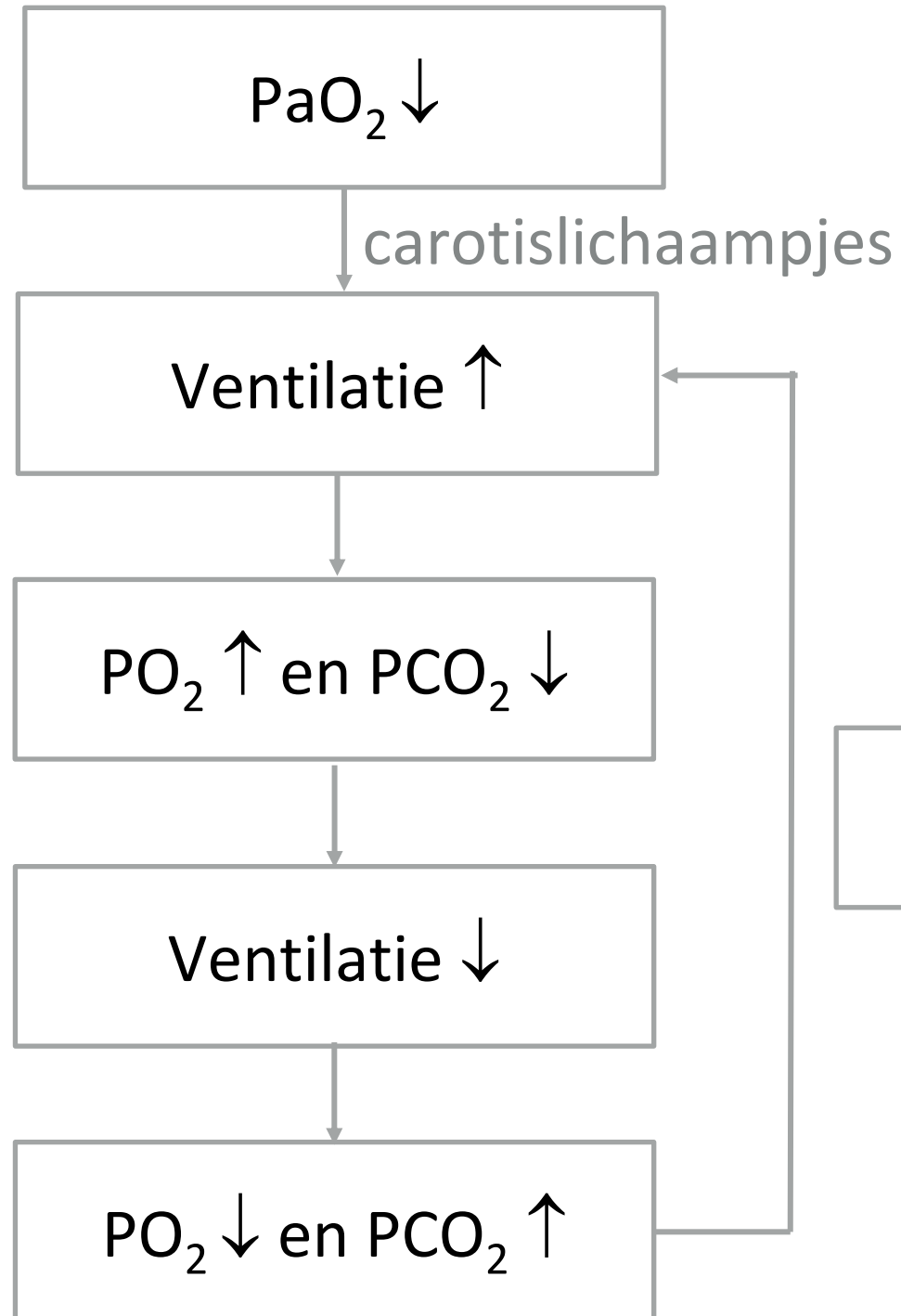
HYPOXIC VENTILATORY RESPONSE (HVR)





Hypoxische
ventilatoire response

Hypercapnische
ventilatoire response



HVR $\uparrow$
dagen-weken

Hypoxische
ventilatoire response

Hypercapnische
ventilatoire response

$\text{PCO}_2 \uparrow$

$\text{PCO}_2 \uparrow$ in ECF

$\text{H}^+ \uparrow$ in ECF

centraal

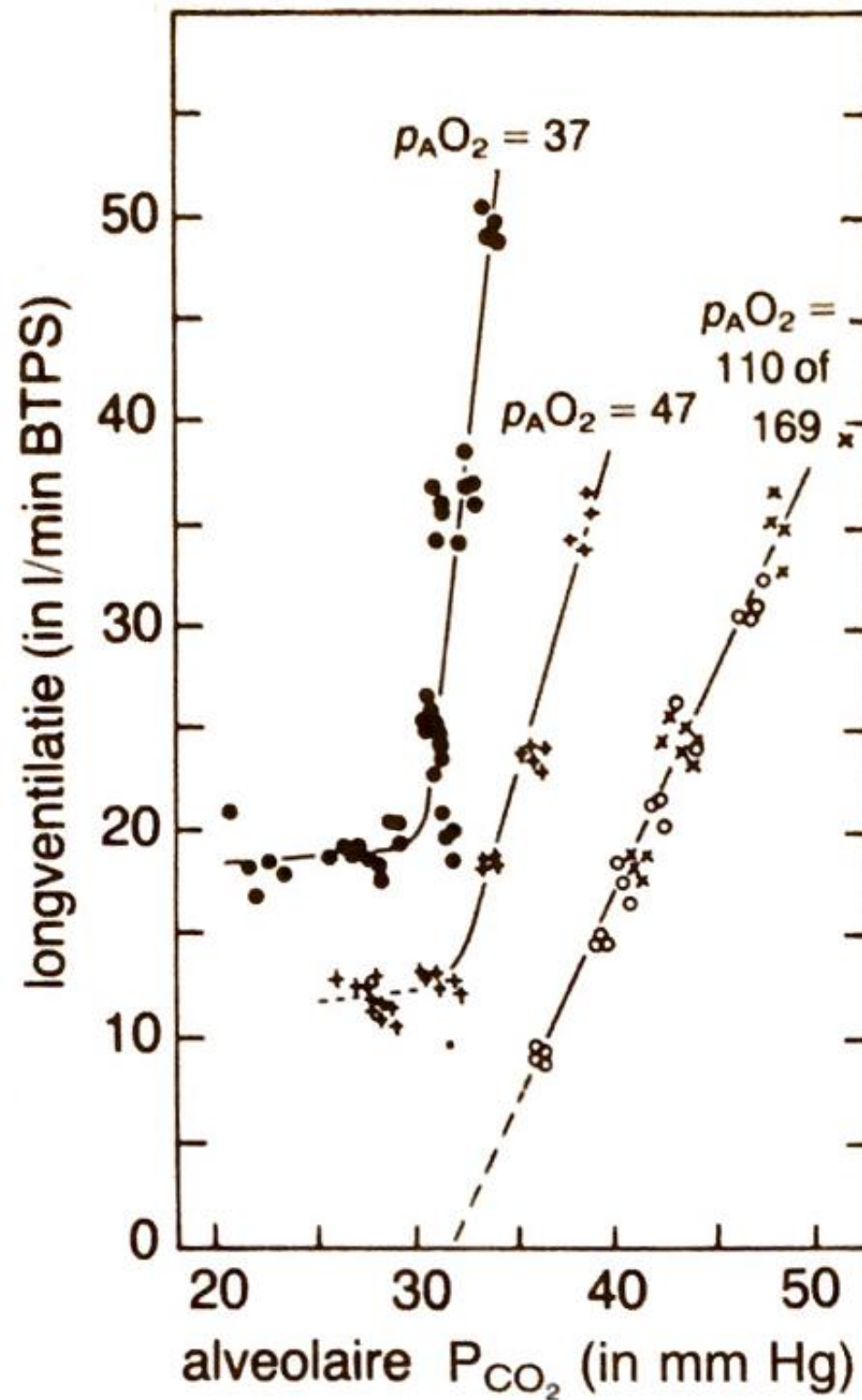
Ventilatie $\uparrow$



HCVR $\uparrow$

24u ($\pm 50\%$) – 2
weken

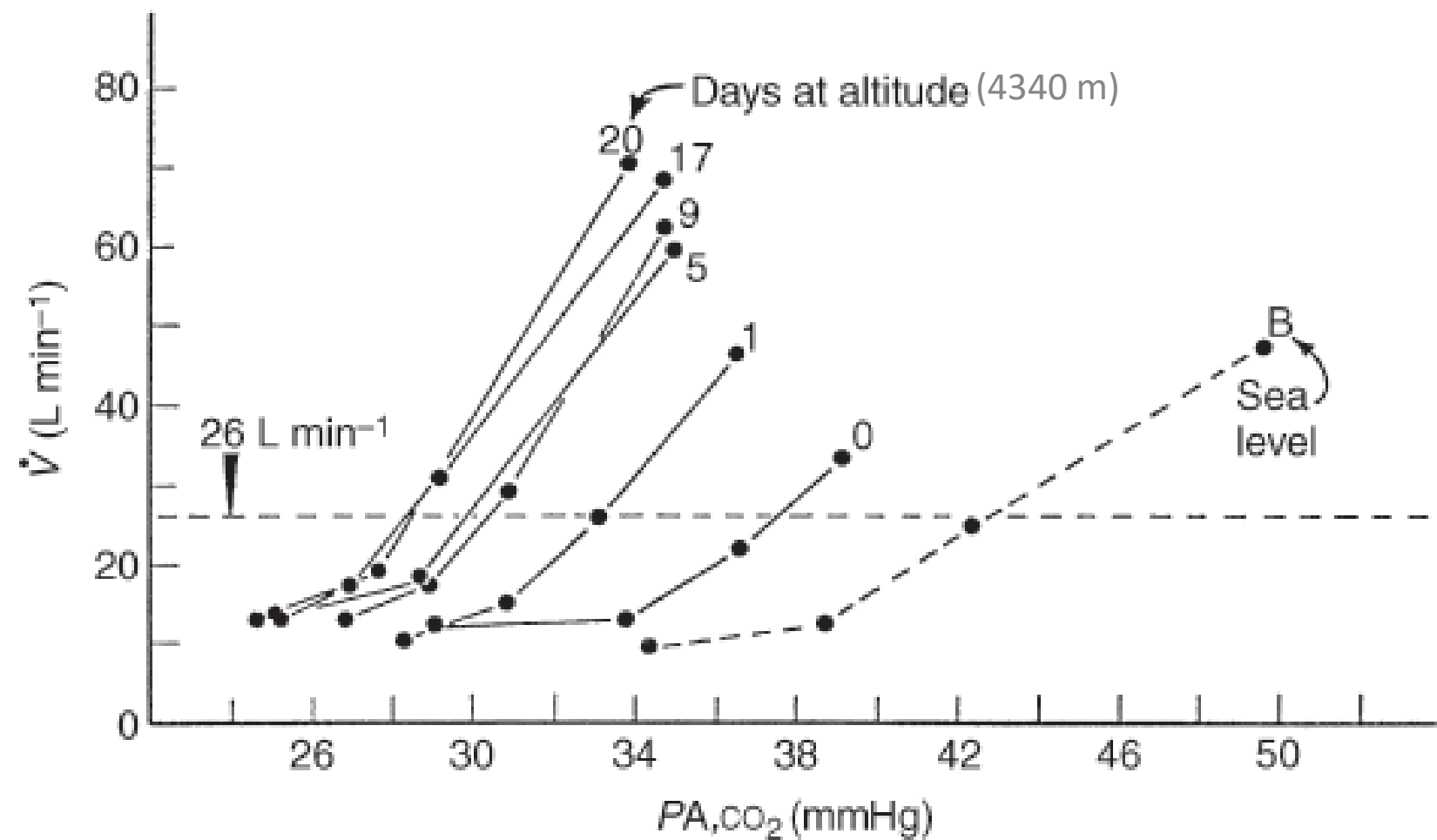
REACTIE VAN VENTILATIE OP CO₂

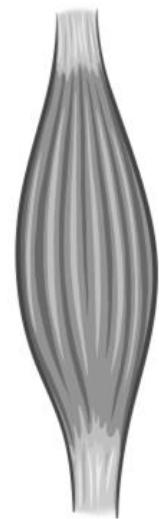
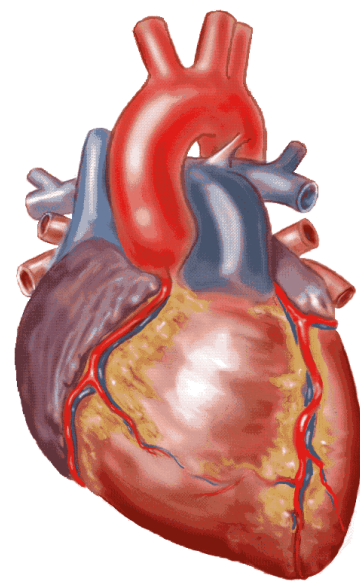


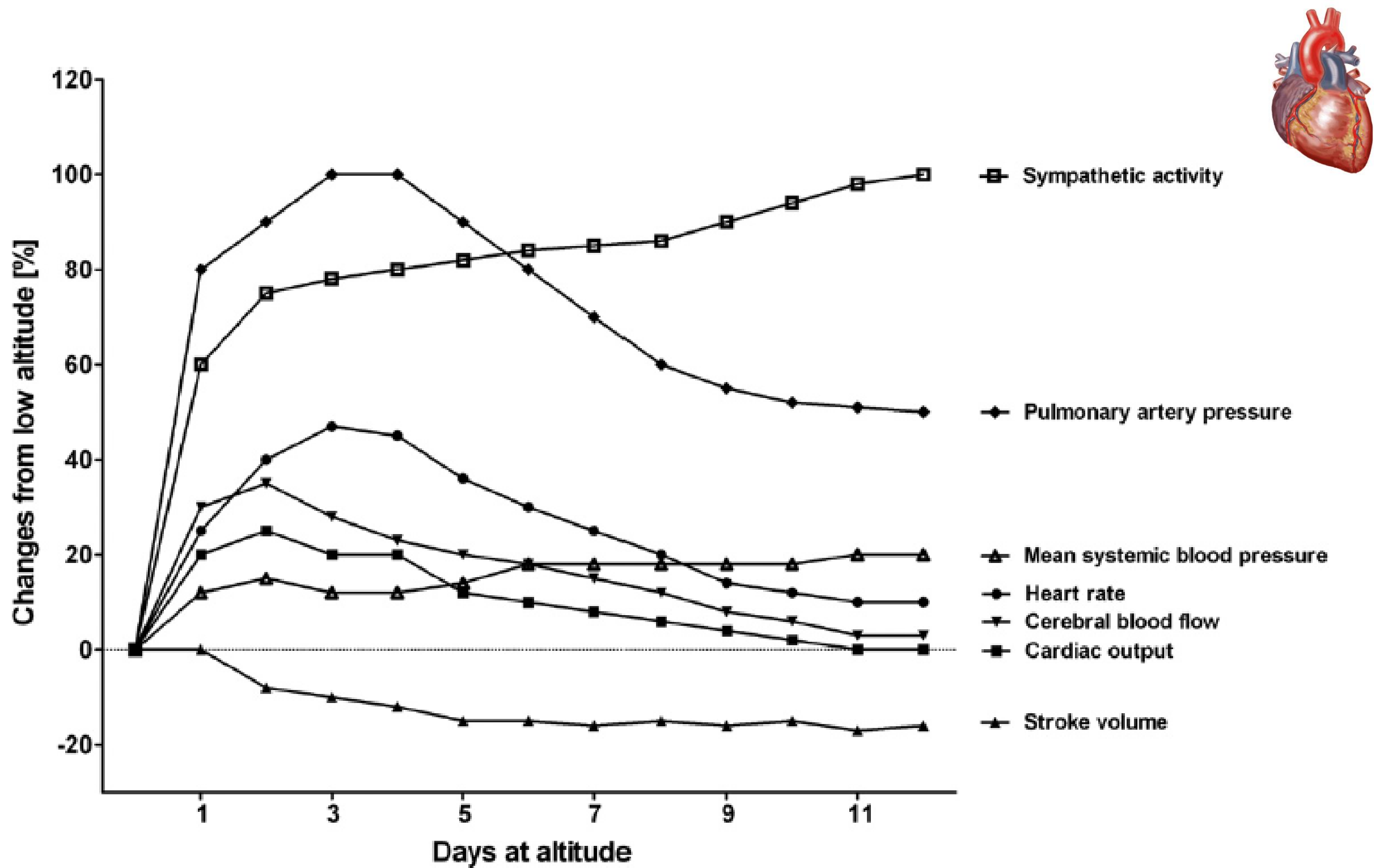
HCVR

Hypoxische
ventilatoire response

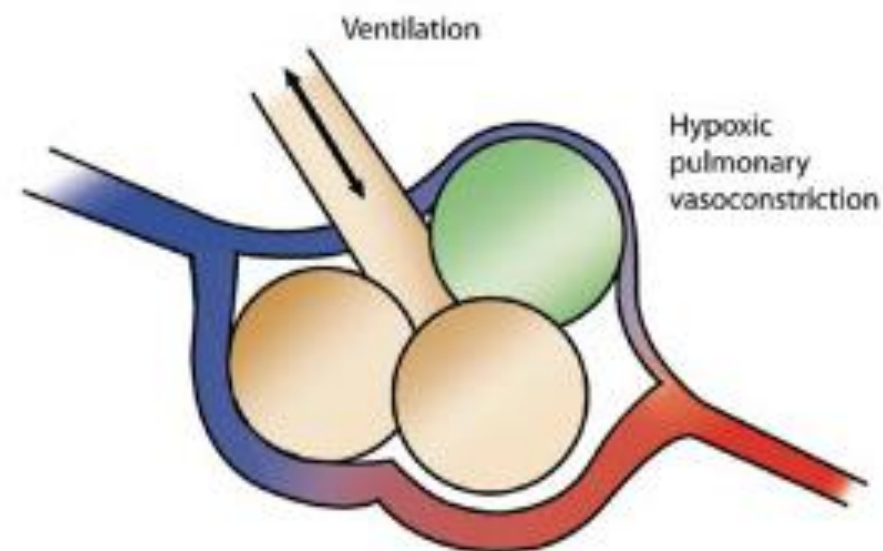
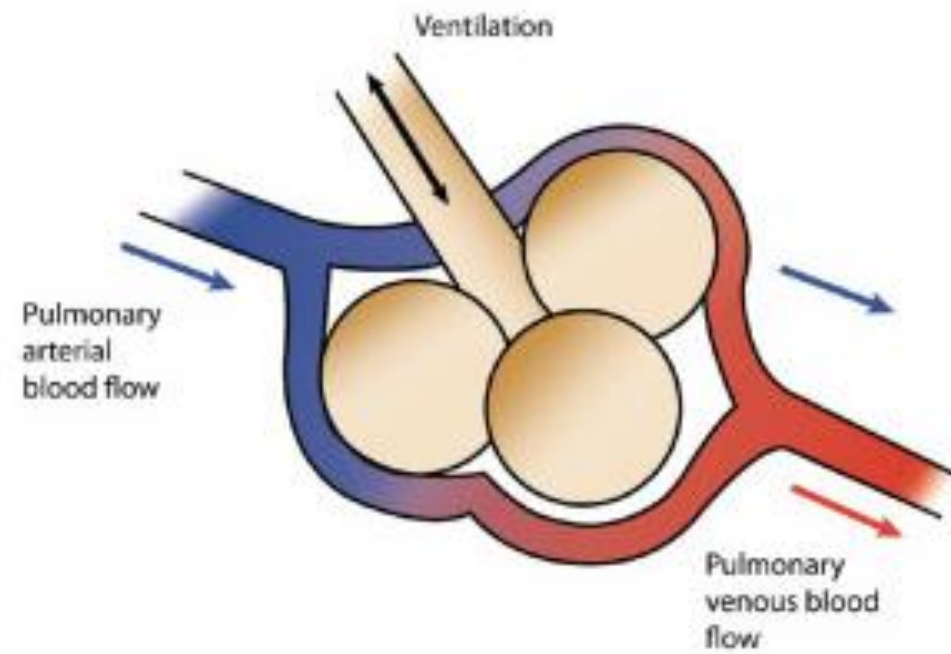
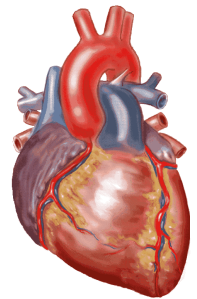
Hypercapnische
ventilatoire response

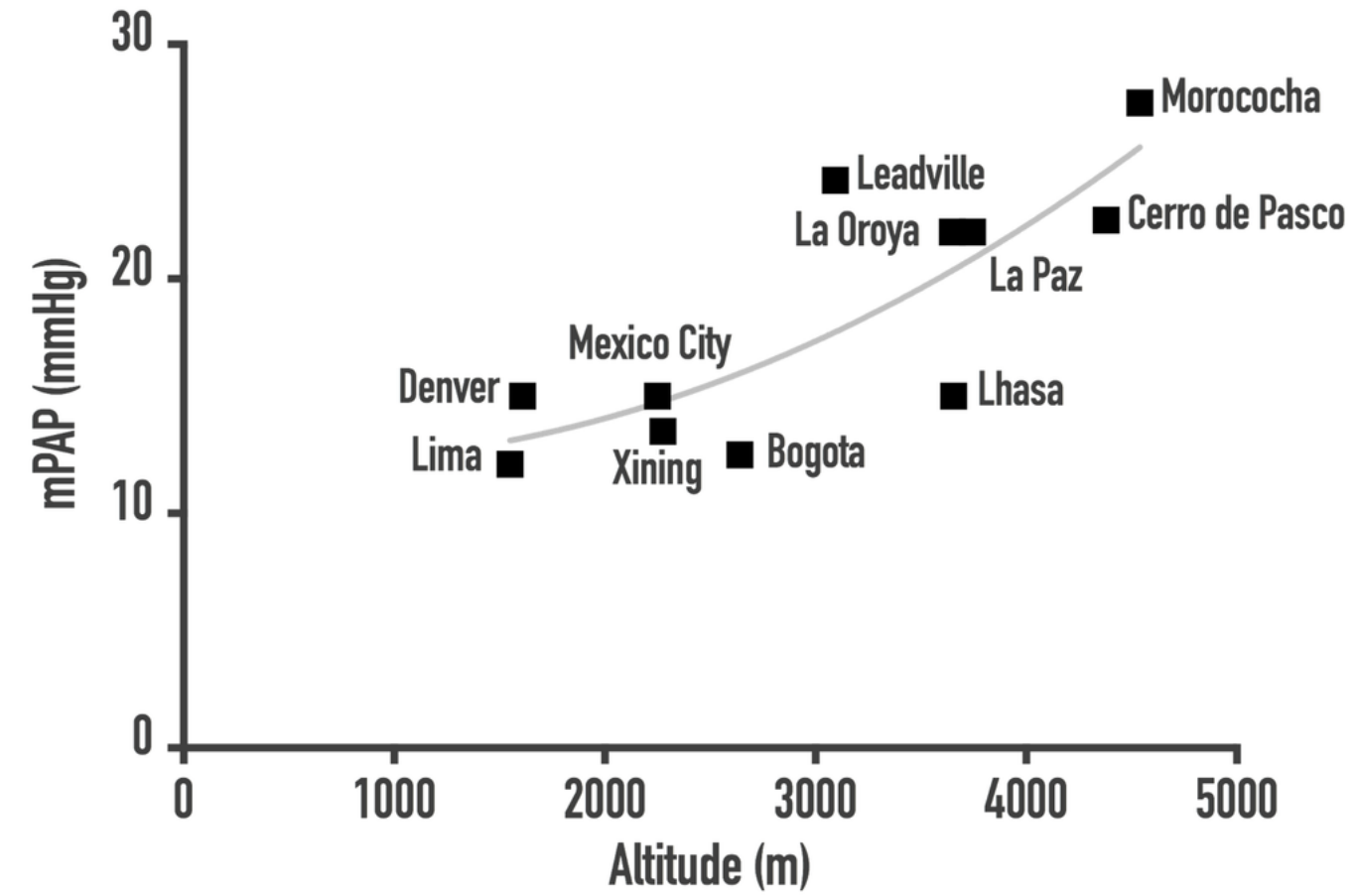
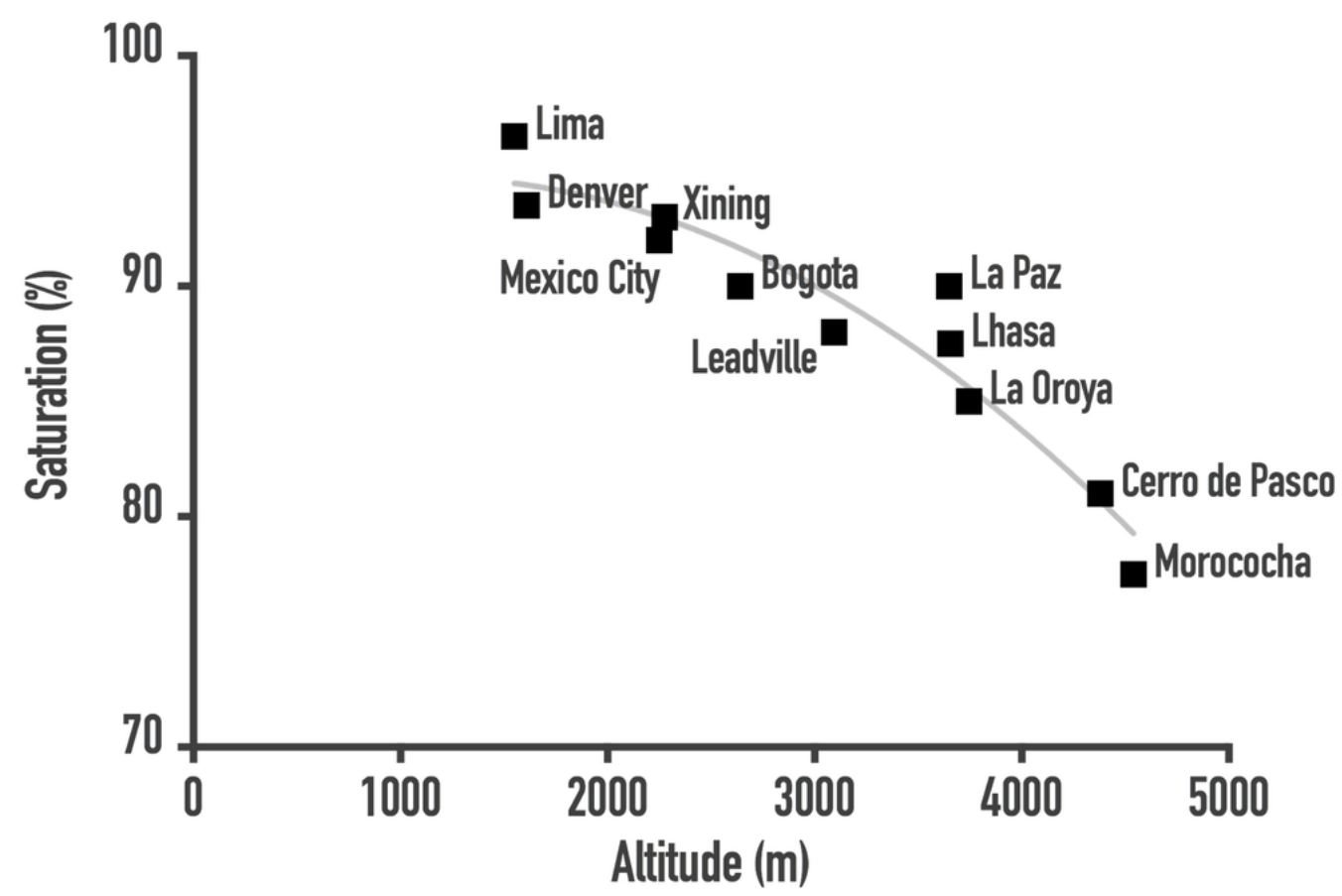
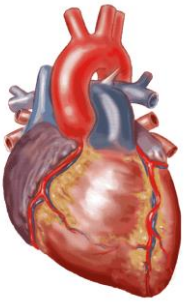


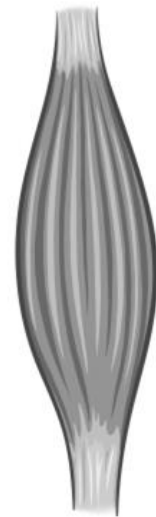
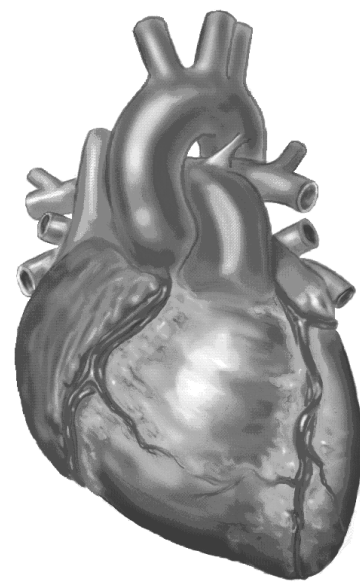


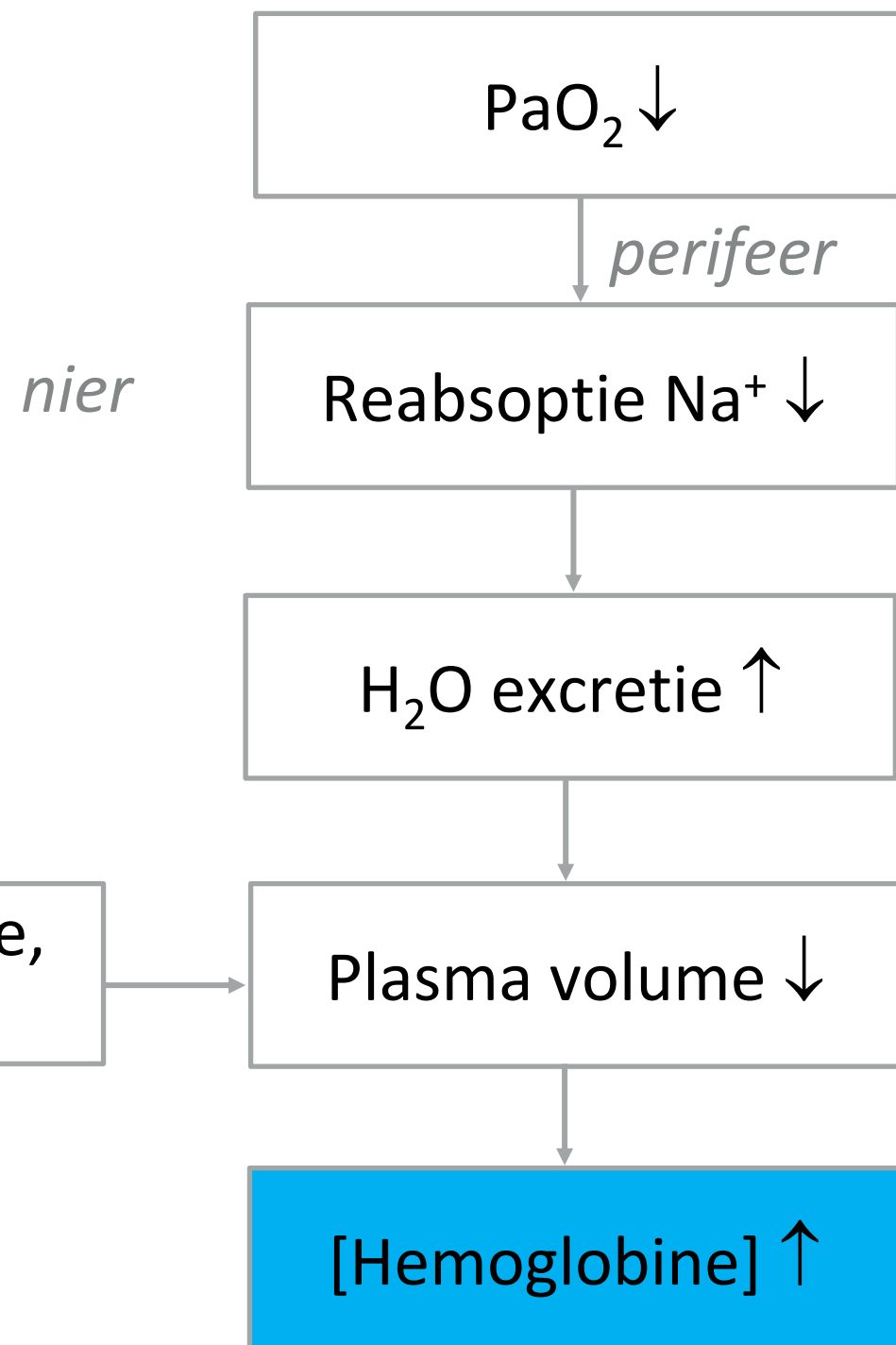


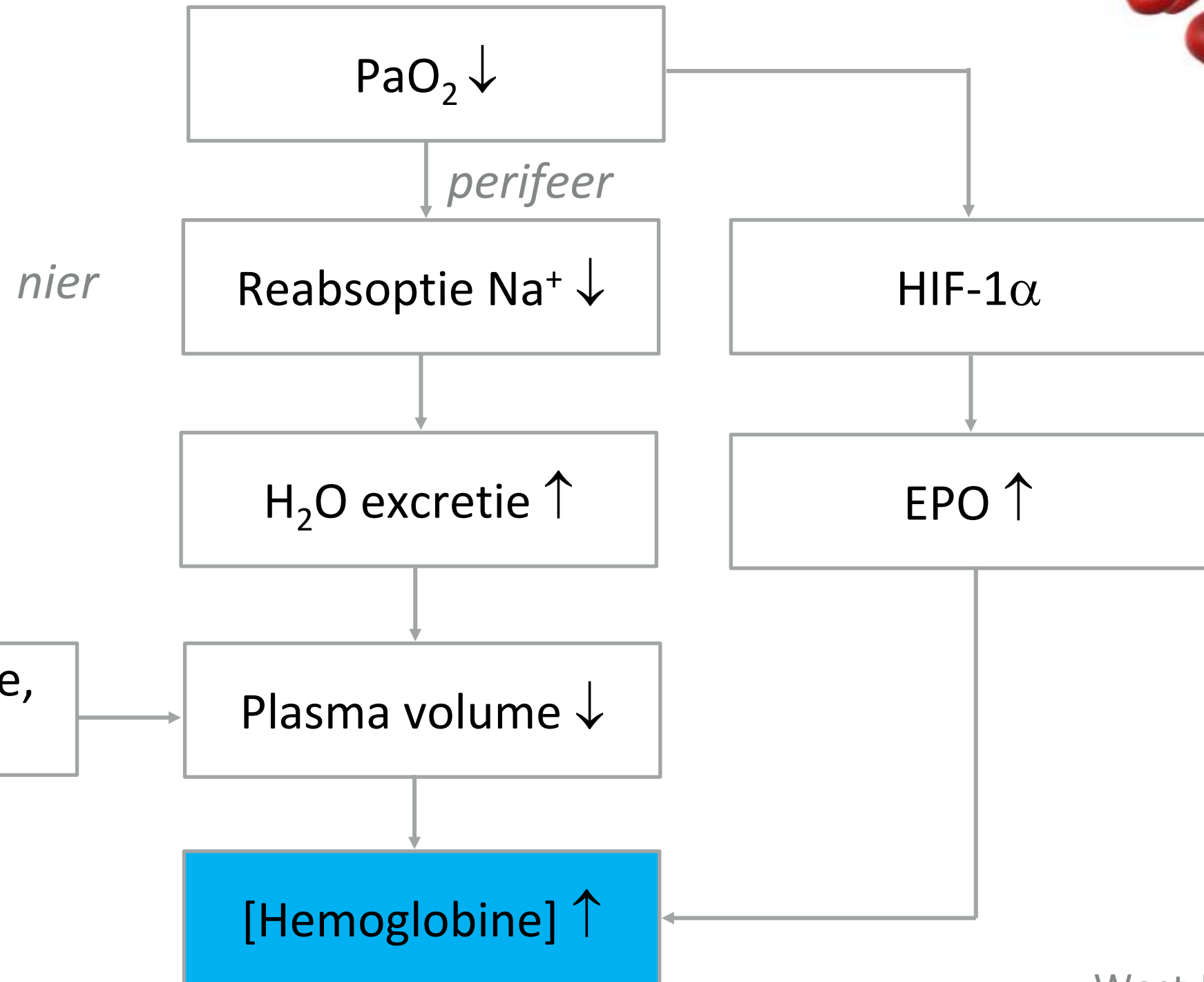
Hypoxische pulmonale vasoconstrictie



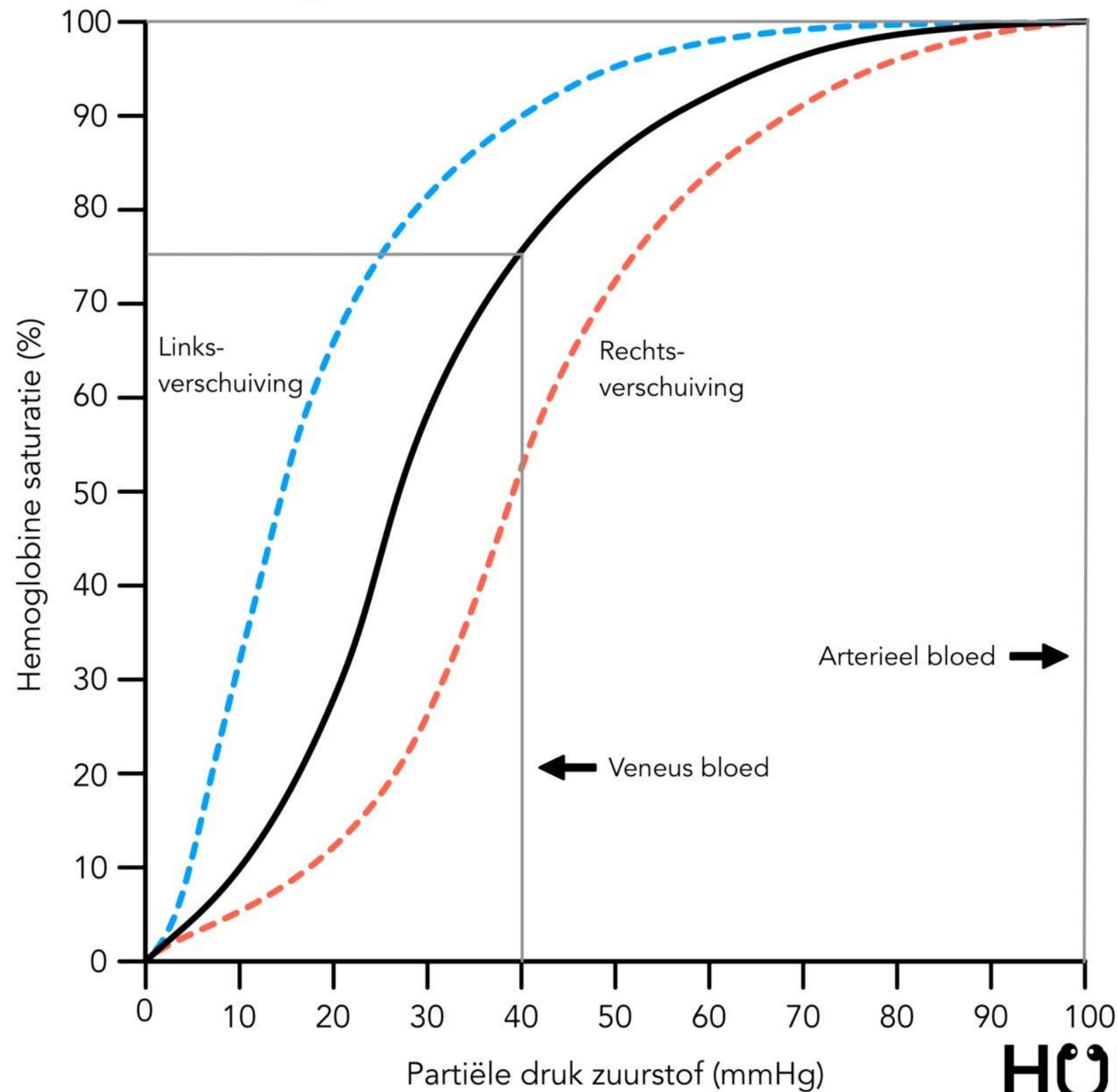








Hemoglobine-zuurstof dissociatiecurve



temperatuur



P_{CO_2}



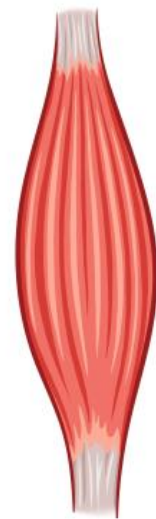
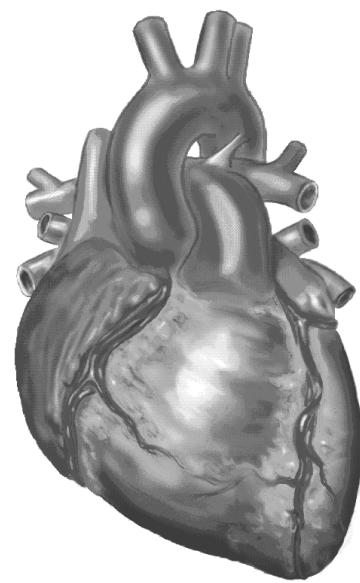
pH



2.3.-DPG

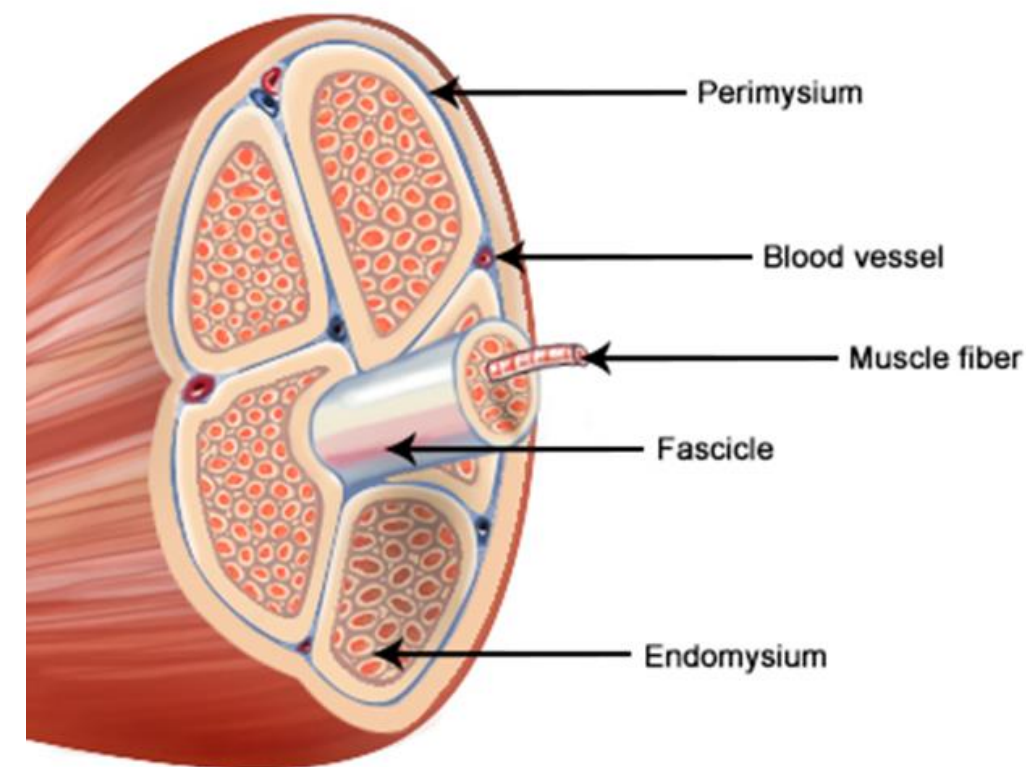
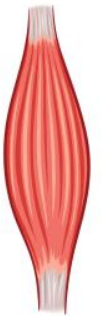


HUB.

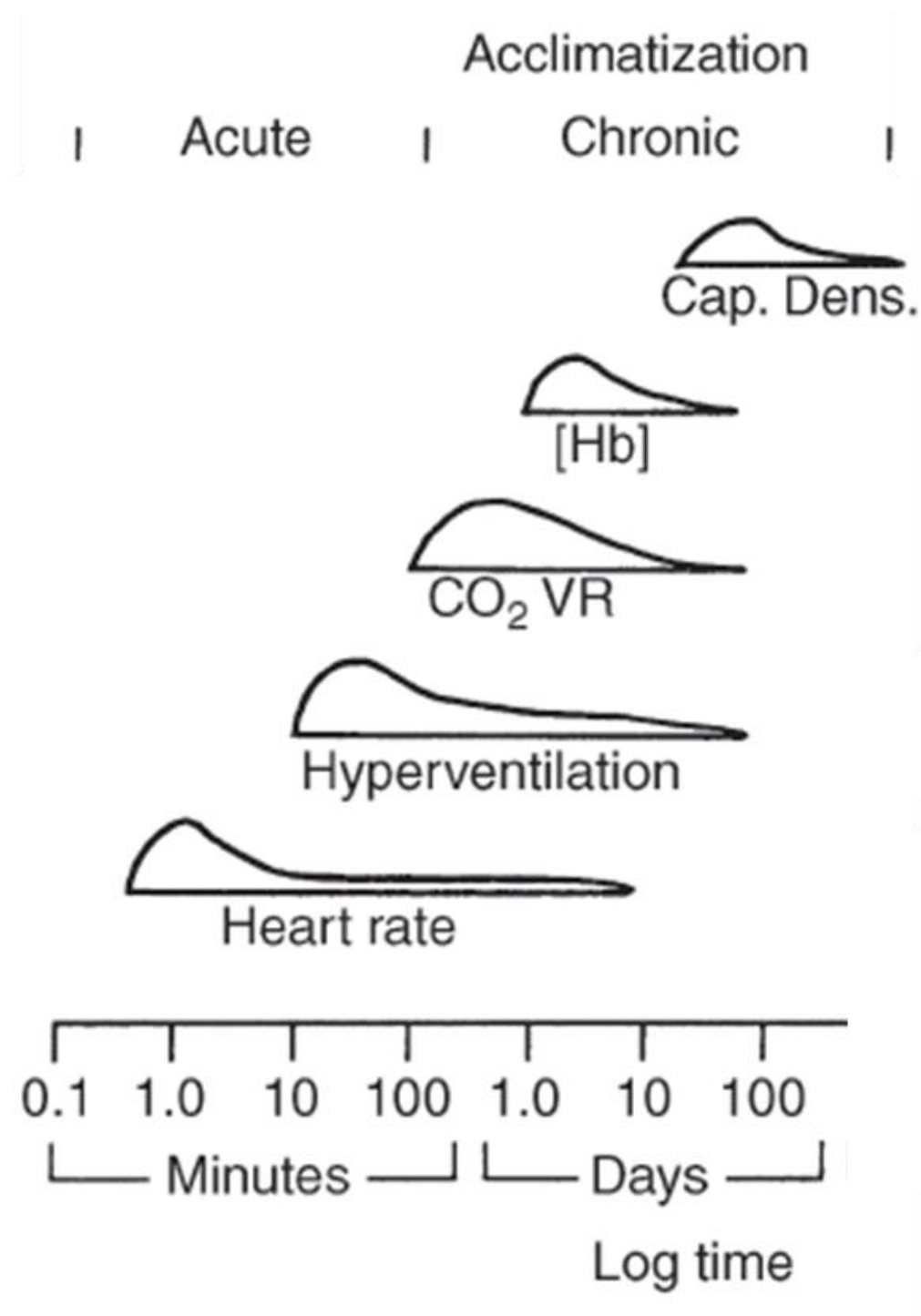


Aanpassingen in de spier

- Afname $\varnothing$ spiervezels > toename in capillaire densiteit > afname in diffusie afstand
- Toename [myoglobine]
- Afname in aantal mitochondriën
- Toename [oxidatieve enzymen]



ACCLIMATISATION TIMELINE





VRAGEN?

CERRO DE PASCO (4500 M)





UNIVERSIDAD PERUANA CAYETANO HEREDIA

INSTITUTO DE INVESTIGACIONES DE LA ALTURA

LABORATORIO DE CERRO DE PASCO





CHRONIC MOUNTAIN SICKNESS (CMS)

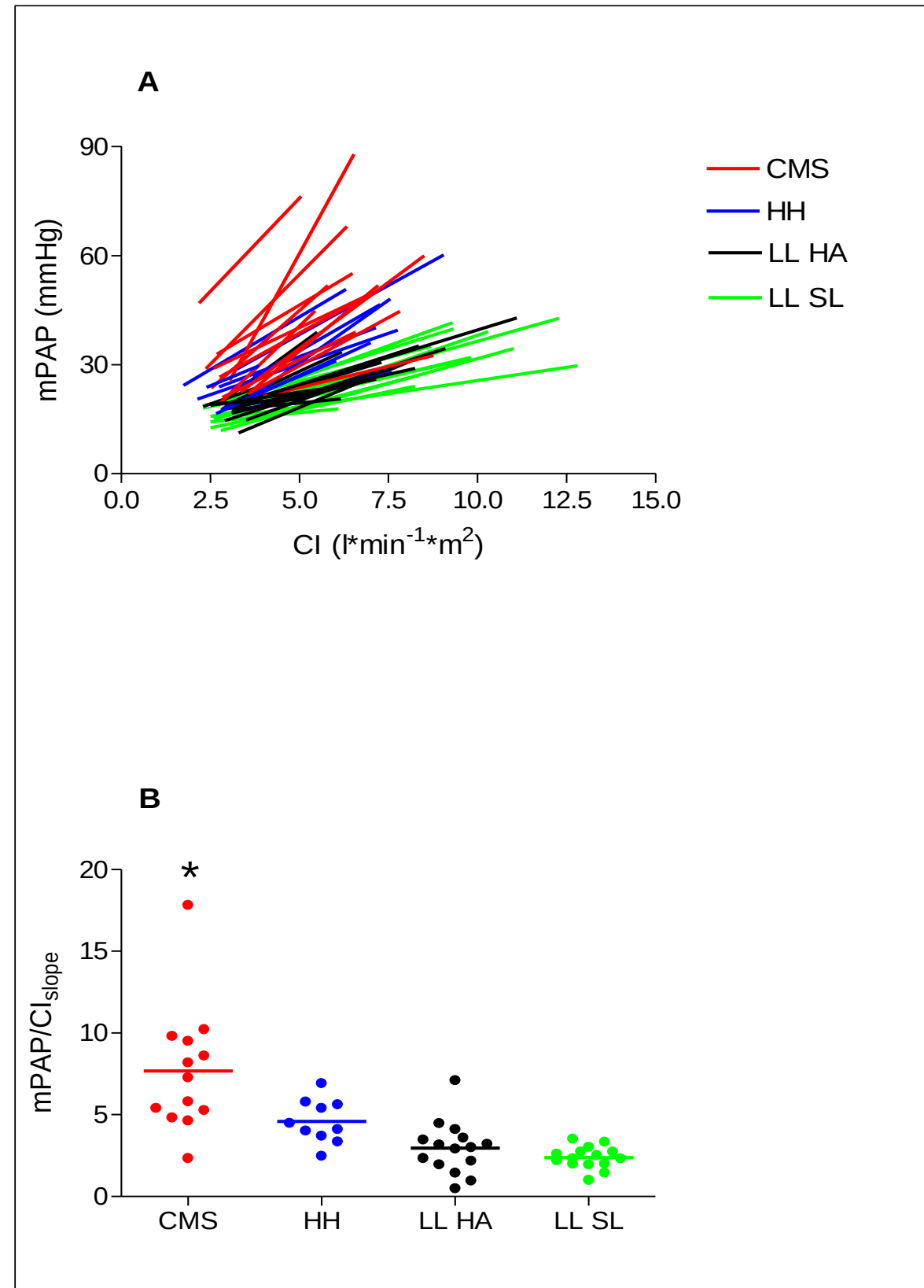
- ▶ polycythaemia (increased hematocrit)
- ▶ symptoms and signs are: headache, dizziness, tinnitus, breathlessness, palpitations, sleep disturbance, fatigue, anorexia, mental confusion, cyanosis, and dilation of veins.
- ▶ Pulmonary hypertension



HYPOTHESIS

CMS patients show a impaired exercise tolerance with a pathophysiological exercise response compared to healthy controls

	CMS	HH	LL HA
Power (w)	137 ± 27*	119 ± 35*	183 ± 14 [#]
V'O ₂ (L)	2.29 ± 0.12	1.96 ± 0.11*	2.43 ± 0.16 [#]
V'O ₂ (ml*kg ⁻¹)	32 ± 1	32 ± 2	33 ± 2 [#]
RER	1.13 ± 0.02	1.13 ± 0.01	1.14 ± 0.02 [#]
HR (beat*min ⁻¹)	145 ± 5 ^{\$,*}	160 ± 4	165 ± 4 [#]
HR (%pred)	85 ± 3	89 ± 3	89 ± 2 [#]
O ₂ pulse (ml*beat)	16 ± 1 ^{\$}	12 ± 1*	15 ± 1 [#]
SaO ₂ (%)	82 ± 1 ^{\$}	88 ± 1*	78 ± 1 [#]

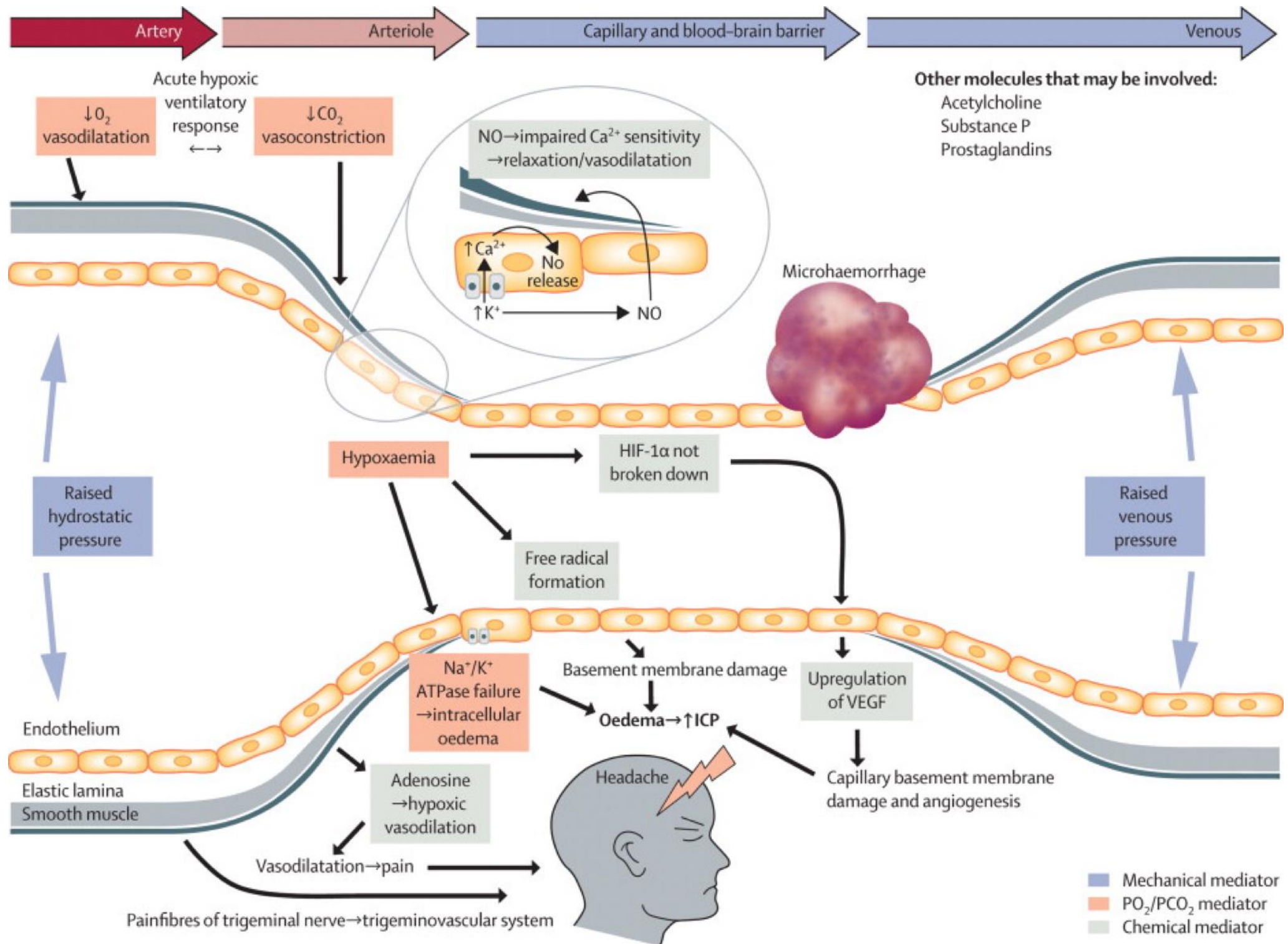


CONCLUSION

- ▶ Although increased hematocrit leads to an increase of the pulmonary vascular resistance maximal aerobic capacity is not hampered in mild CMS patients.
- ▶ HH can rely on their hypoxic ventilation response, to increase arterial oxygen tension.
- ▶ CMS patients, due to their blunted ventilatory response can not.
- ▶ This impaired ventilatory response of the CMS patients is counter balanced by an increased oxygen delivery to the peripheral muscles by an increased haemoglobin concentration and diffusion capacity.

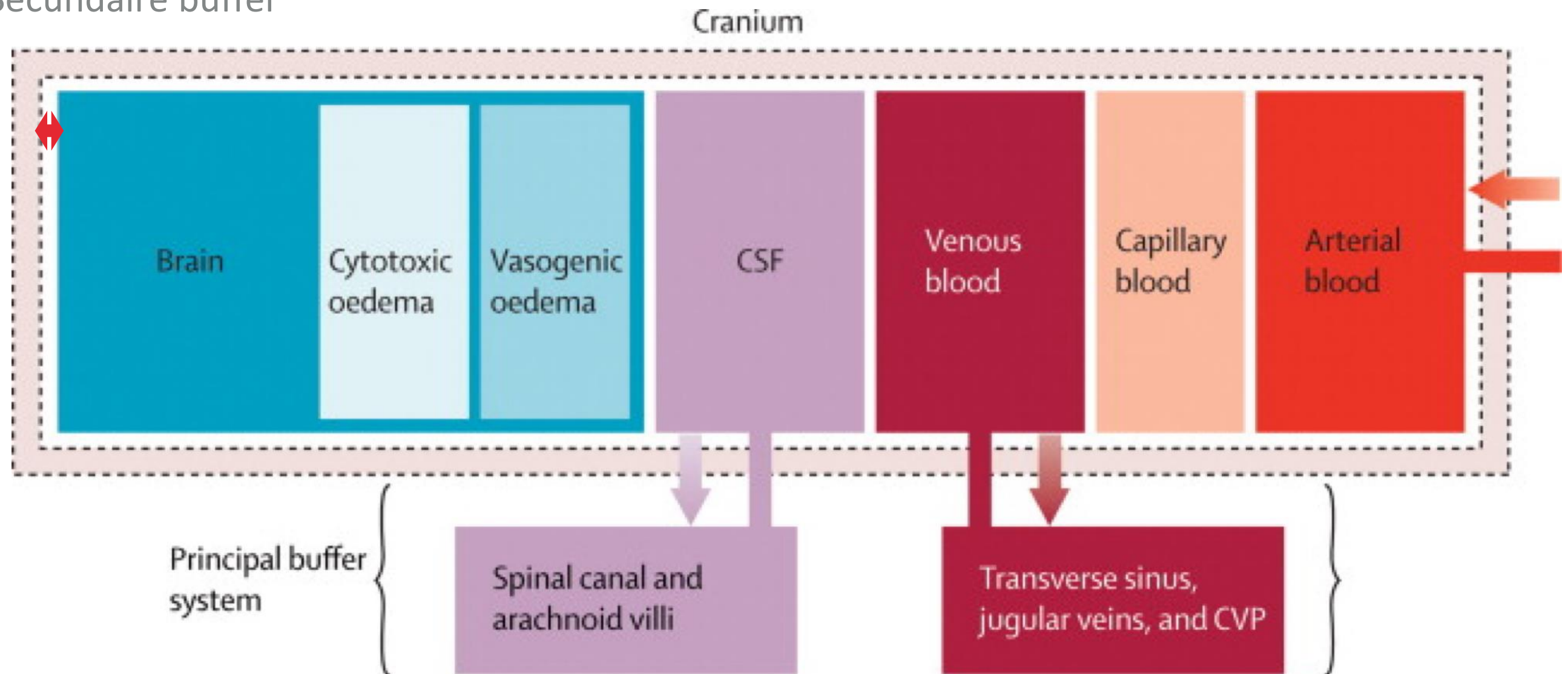


MECHANISME AMS - HACE

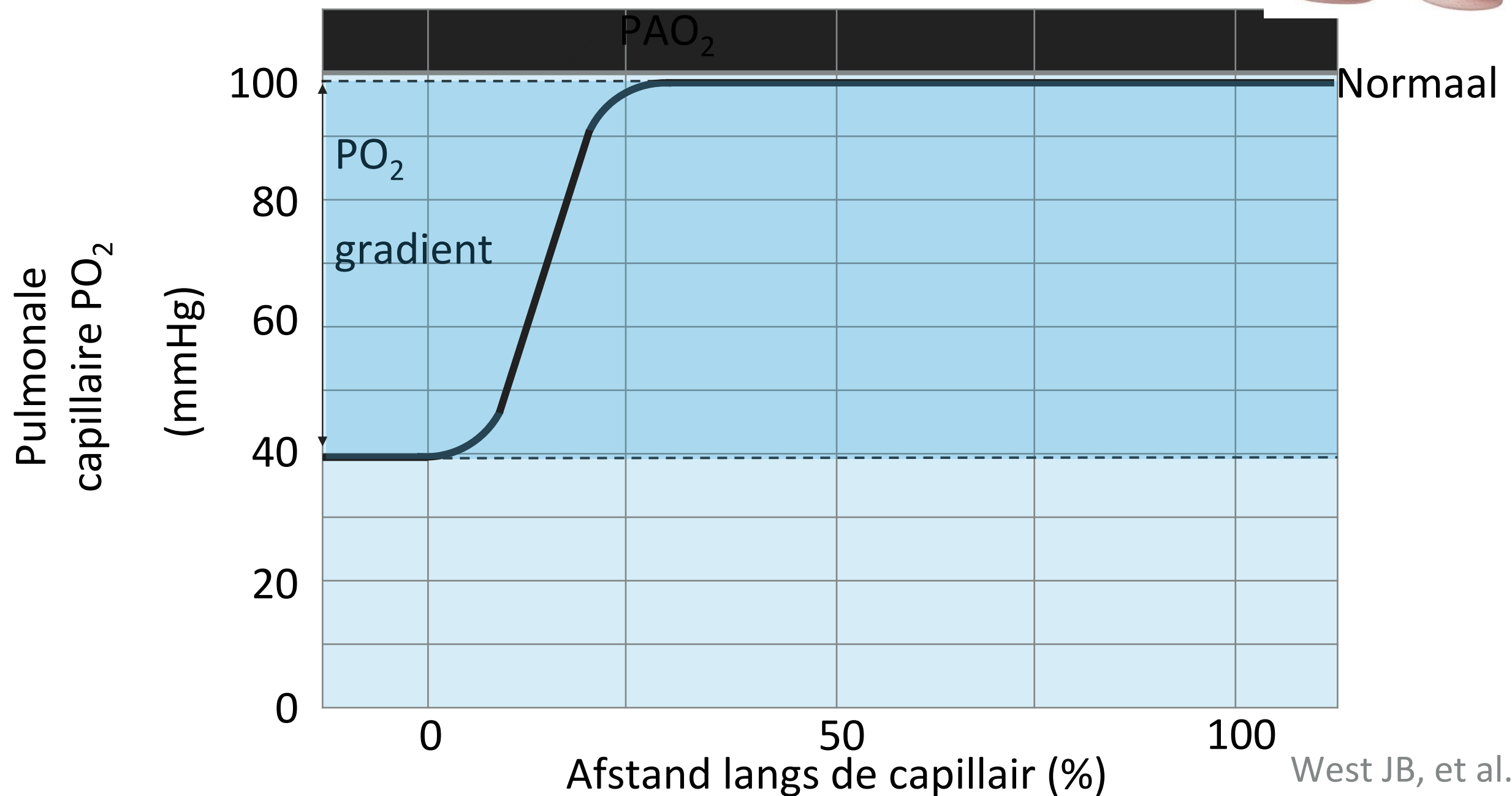


“TIGHT-FIT” HYPOTHESIS

Secundaire buffer



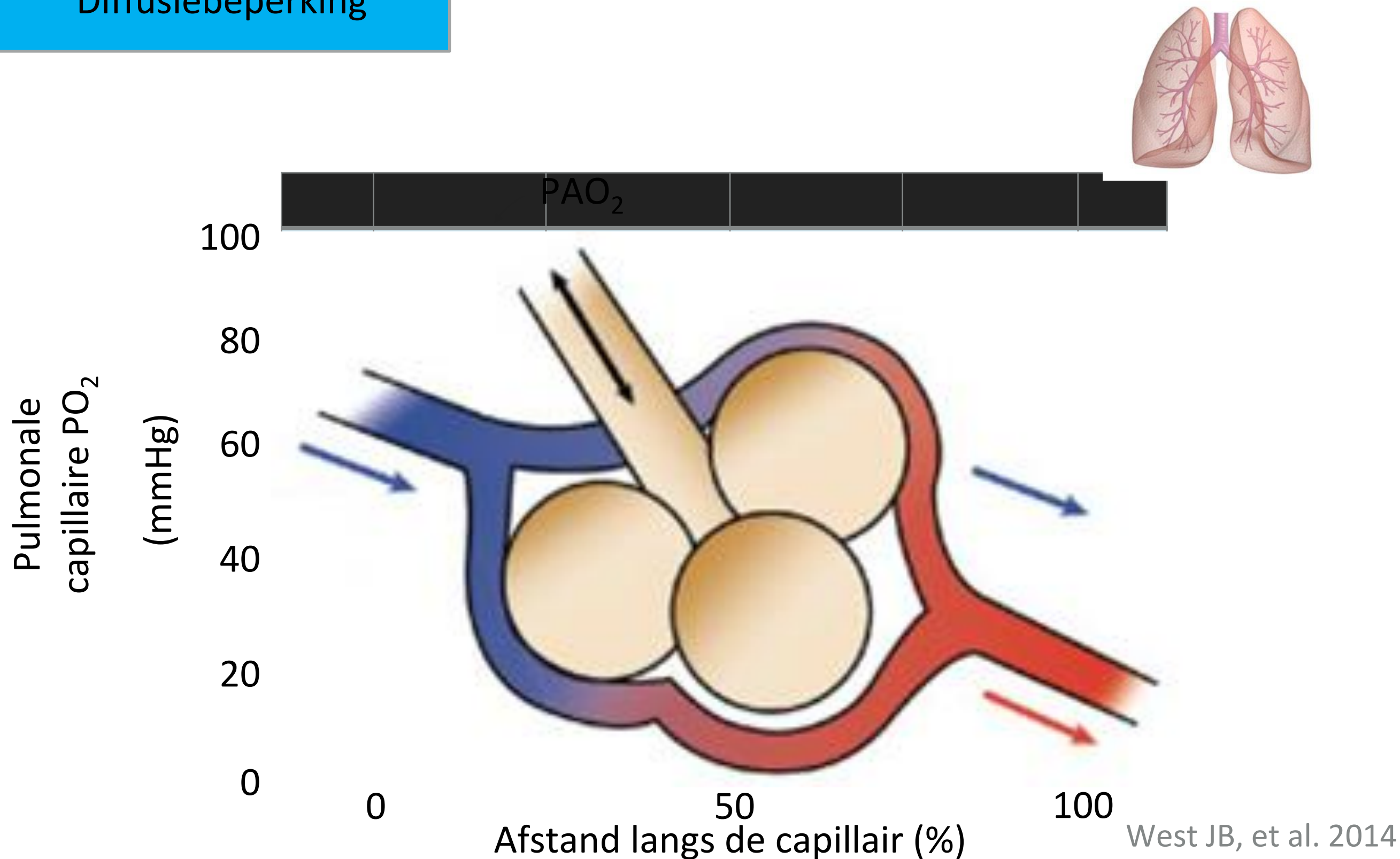
Diffusiebeperking



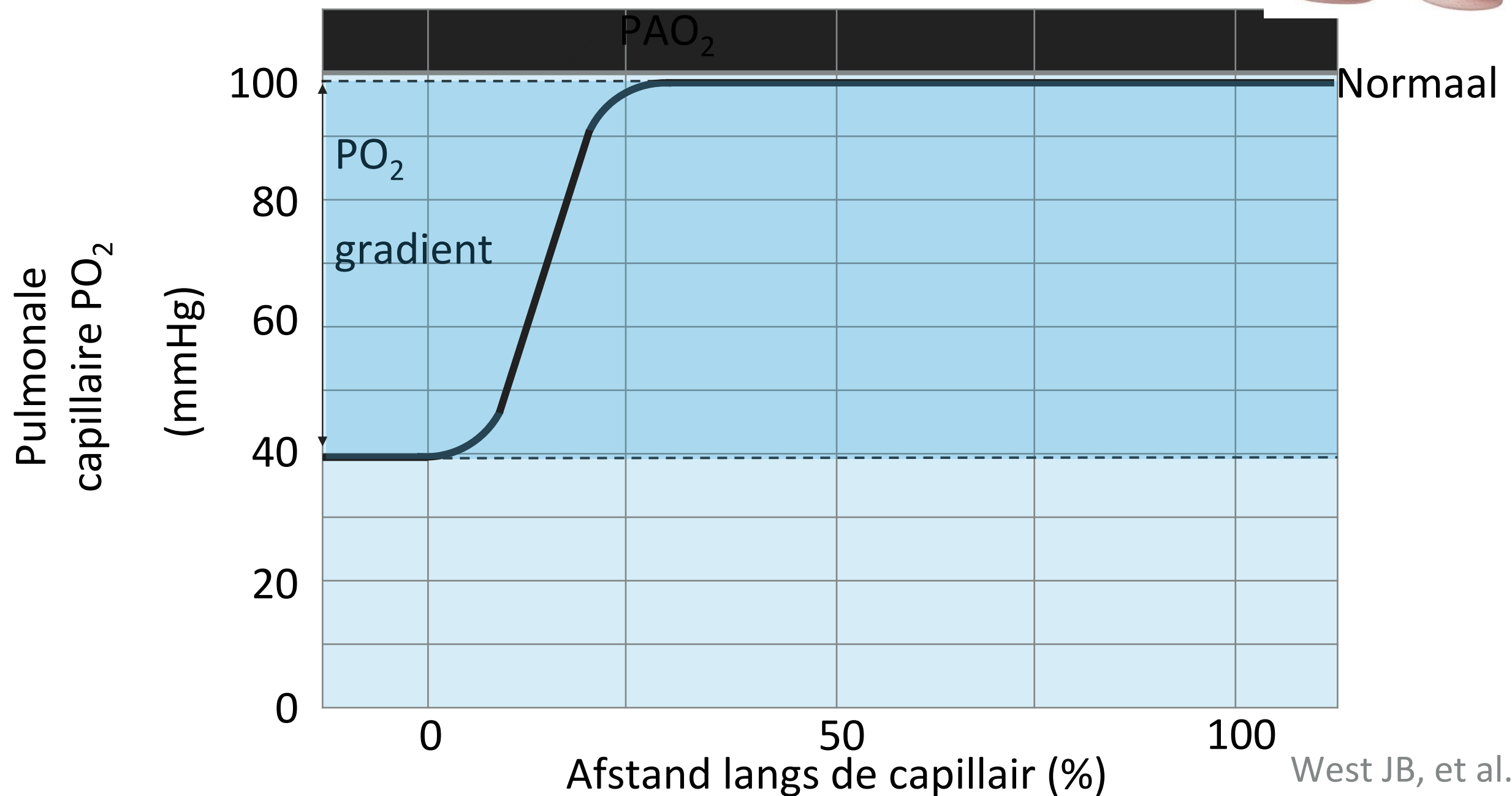
EFFECT VAN HOOGTE



Diffusiebeperking



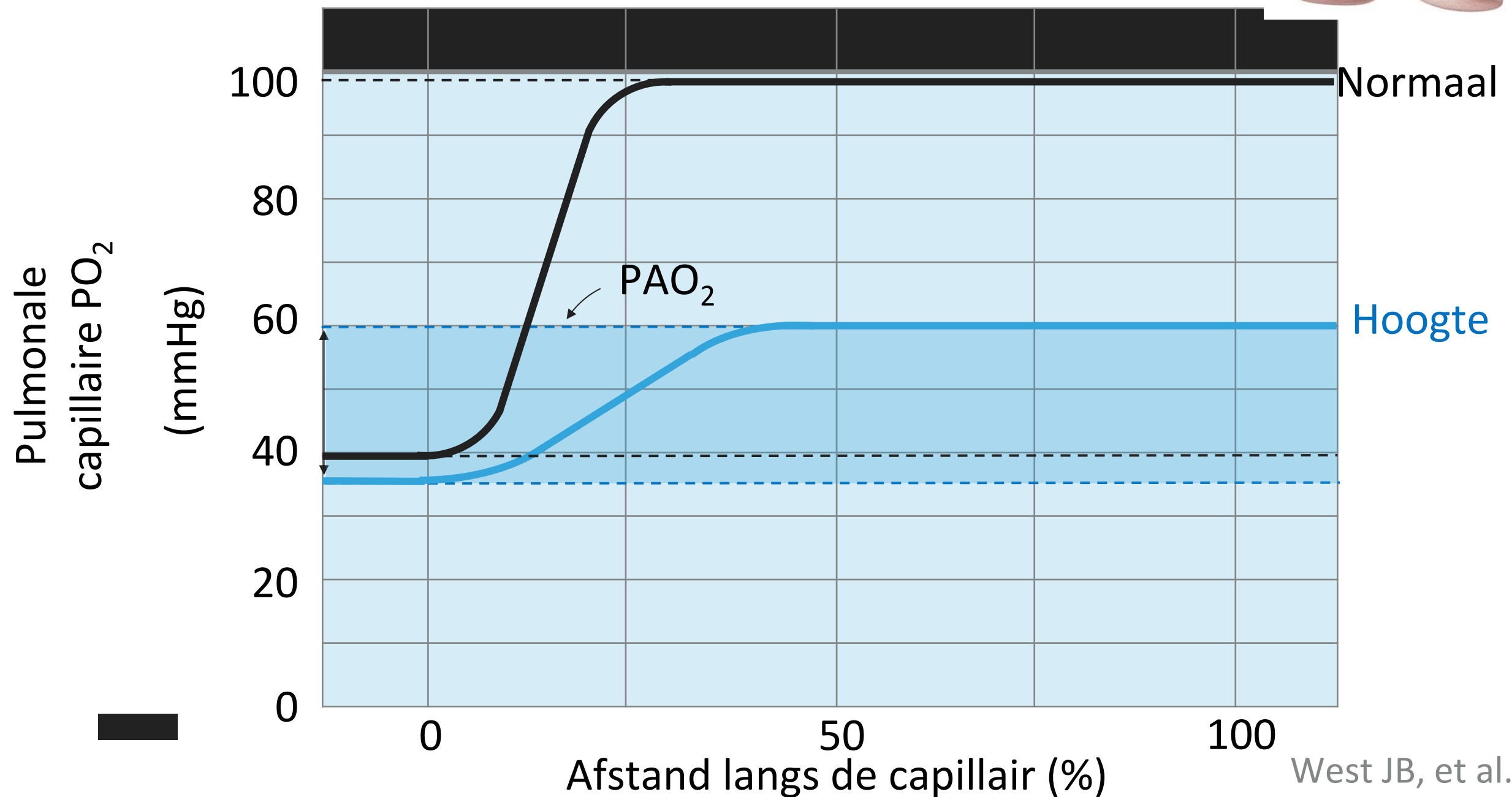
Diffusiebeperking



EFFECT VAN HOOGTE



Diffusiebeperking



EFFECT VAN HOOGTE



Diffusiebeperking

