réanimation 2025
PARIS 11-13 JUIN
Palais des Congrès de Paris - Porte Maillot

Evaluation de la recrutabilité

SRLF / SKR Juin 2025 Paris

H.U.B

Hôpital Erasme ULB

Frederic BONNIER HUB Erasme Bruxelles

5 - 15

Physiopathologie de la recrutabilité

- <u>Deux mécanismes coexistent :</u>
  - L'atélectasie par affaissement des alvéoles.
  - La consolidation inflammatoire avec comblement alvéolaire.

- La distinction entre SDRA d'origine intra/ extra pulmonaire essentielle, -> influence la réponse aux stratégies de recrutement*.

* Richard JC, Mercat A et al. Bedside assessment of alveolar recruitment Crit Care 2003 Oct 22;8(3):163–169

Evaluation de la recrutabilité

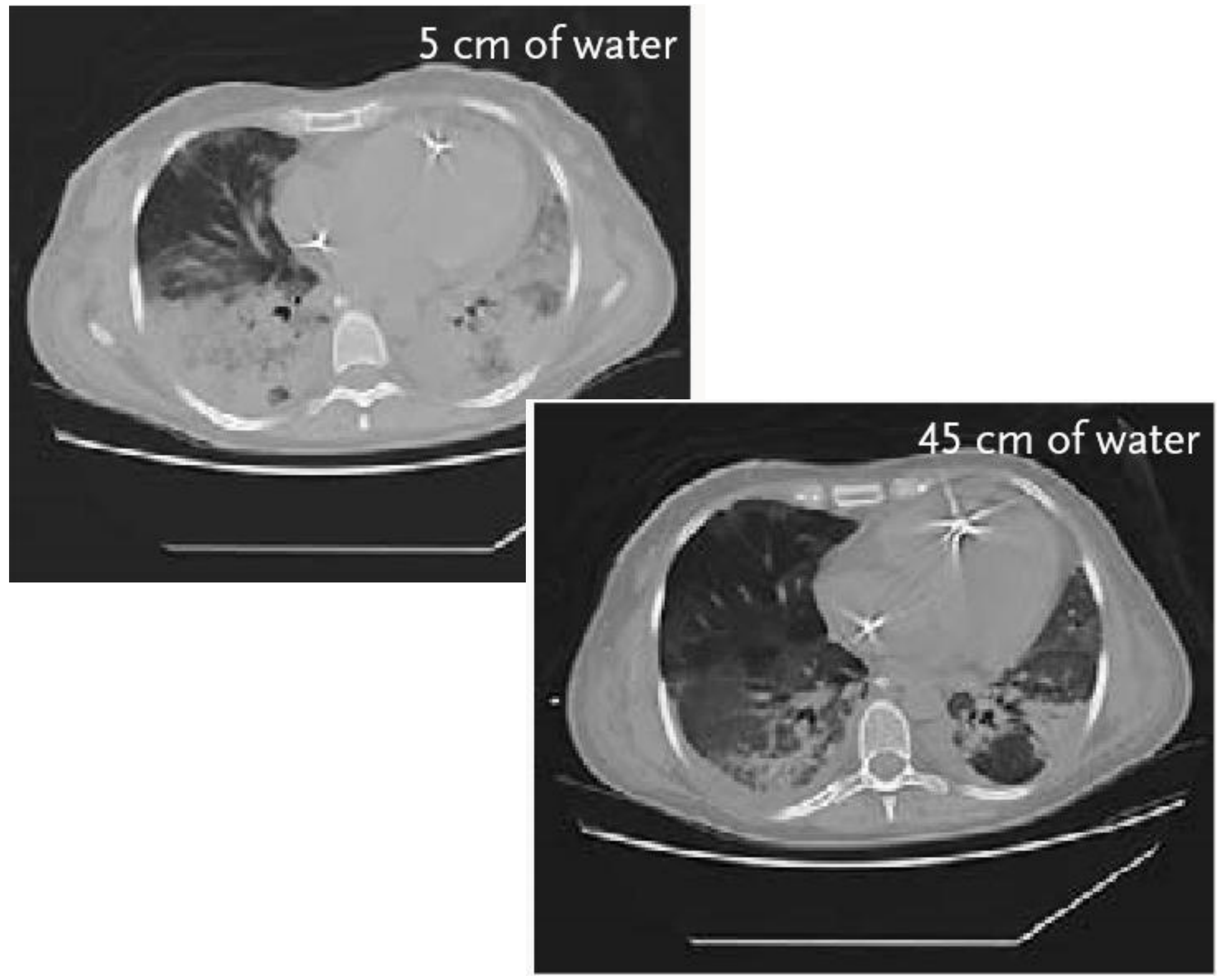
Méthodes:

- CT scan
- Echographie Pulmonaire
- EIT
- R/I ratio
- Comparaison des moyennes / distensibilité
- Dilution de l’Azote

Méthodes d'évaluation de la capacité de recrutement

Tomodensitométrie

- Référence absolue



Gattinoni L, et al. N Engl J Med 2006

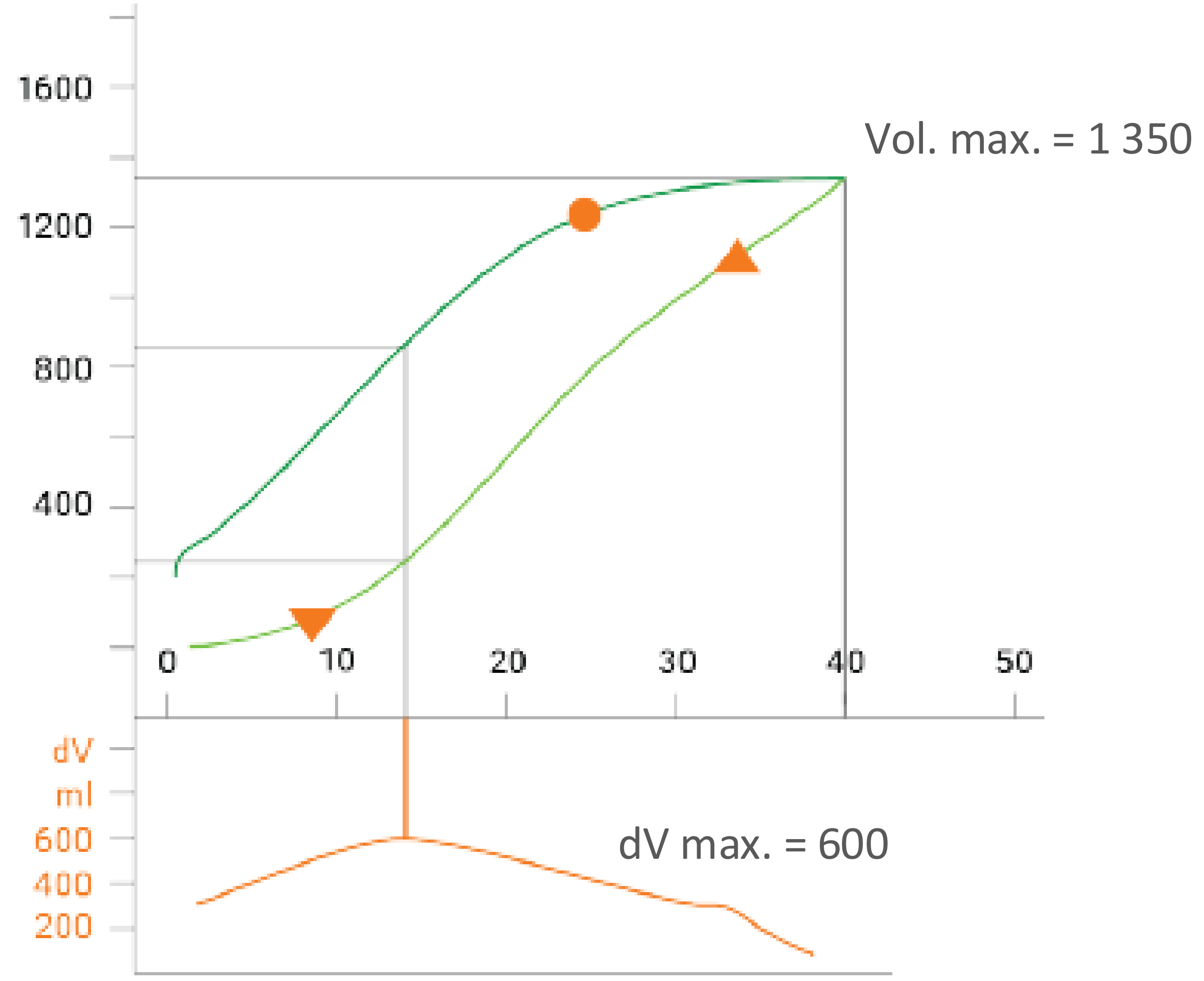
Autres méthodes d'imagerie

- Échographie pulmonaire
- Tomographie à impédance électrique (TEI)

Bouhemad. Am J Respir Crit Care Med 2011 / Bikker. Crit Care 2010

Méthode au chevet

- Courbe P/V à faible débit
- Dilution de l'Azote

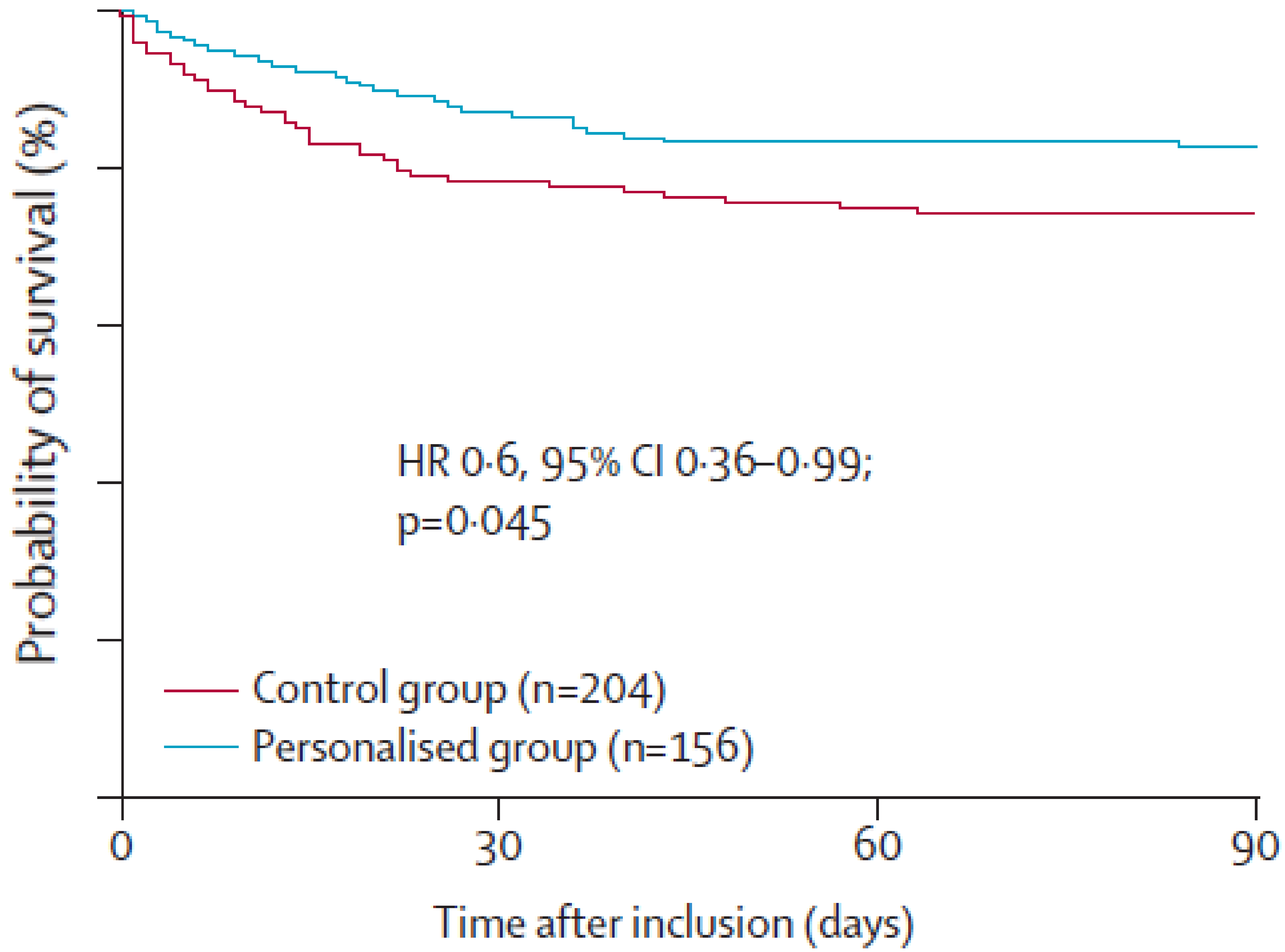


Chiumello, Davide, et al. Critical Care Medicine 2020 / Chen, Lu, et al. American journal of respiratory and critical care medicine 2020

Pourquoi?

Personnalisation de la ventilation mécanique basée sur la morphologie pulmonaire

- Lorsque la morphologie pulmonaire est correctement évaluée, la mortalité peut diminuer avec des stratégies personnalisées chez des patients souffrant de SDRA modéré à sévère.
- La mortalité augmente considérablement, suggérant un effet dommageable de la ventilation à poumons ouverts chez des patients sans recrutement alvéolaire.

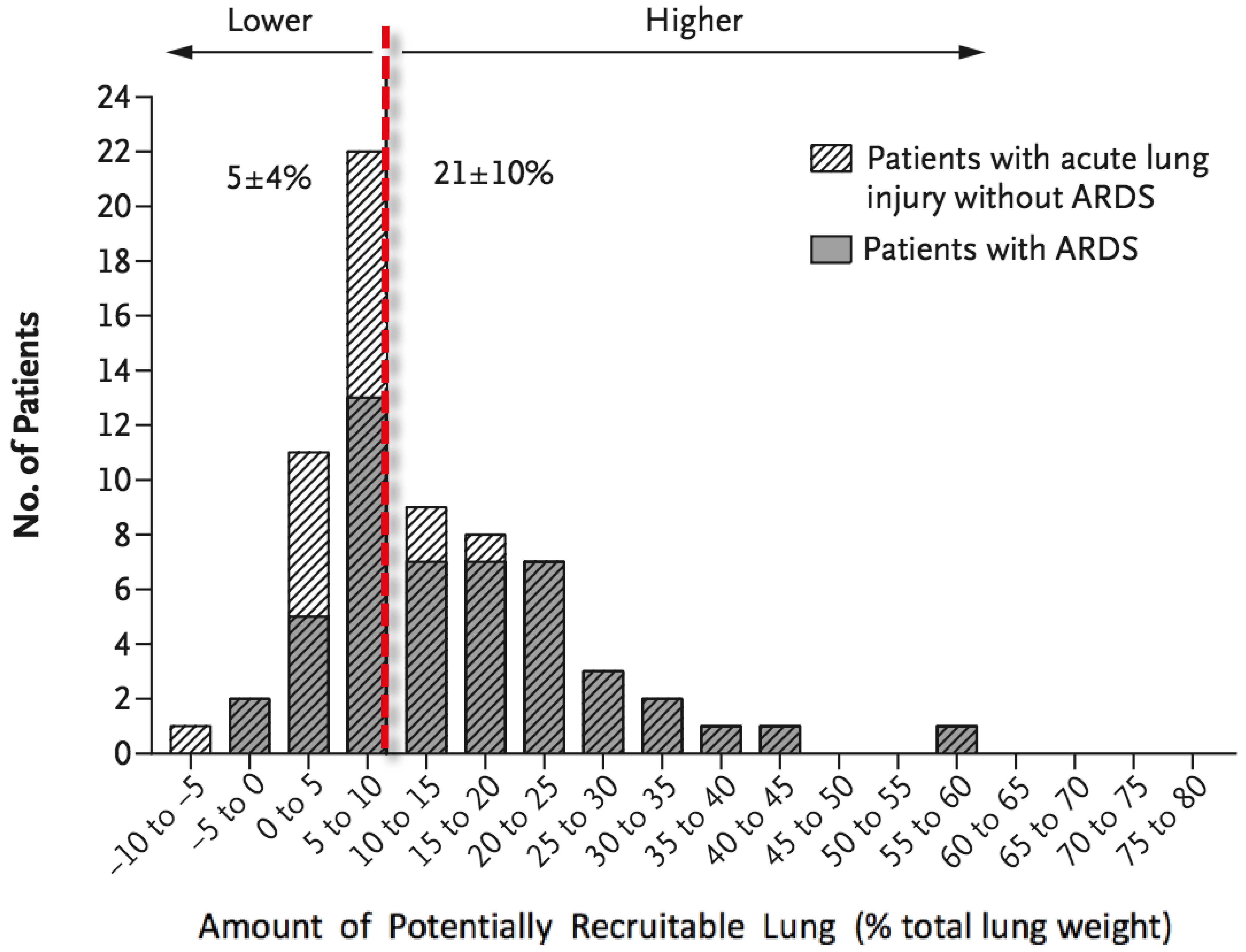


Constantin, JM. The Lancet Respiratory Medicine (2019)

Quand ?

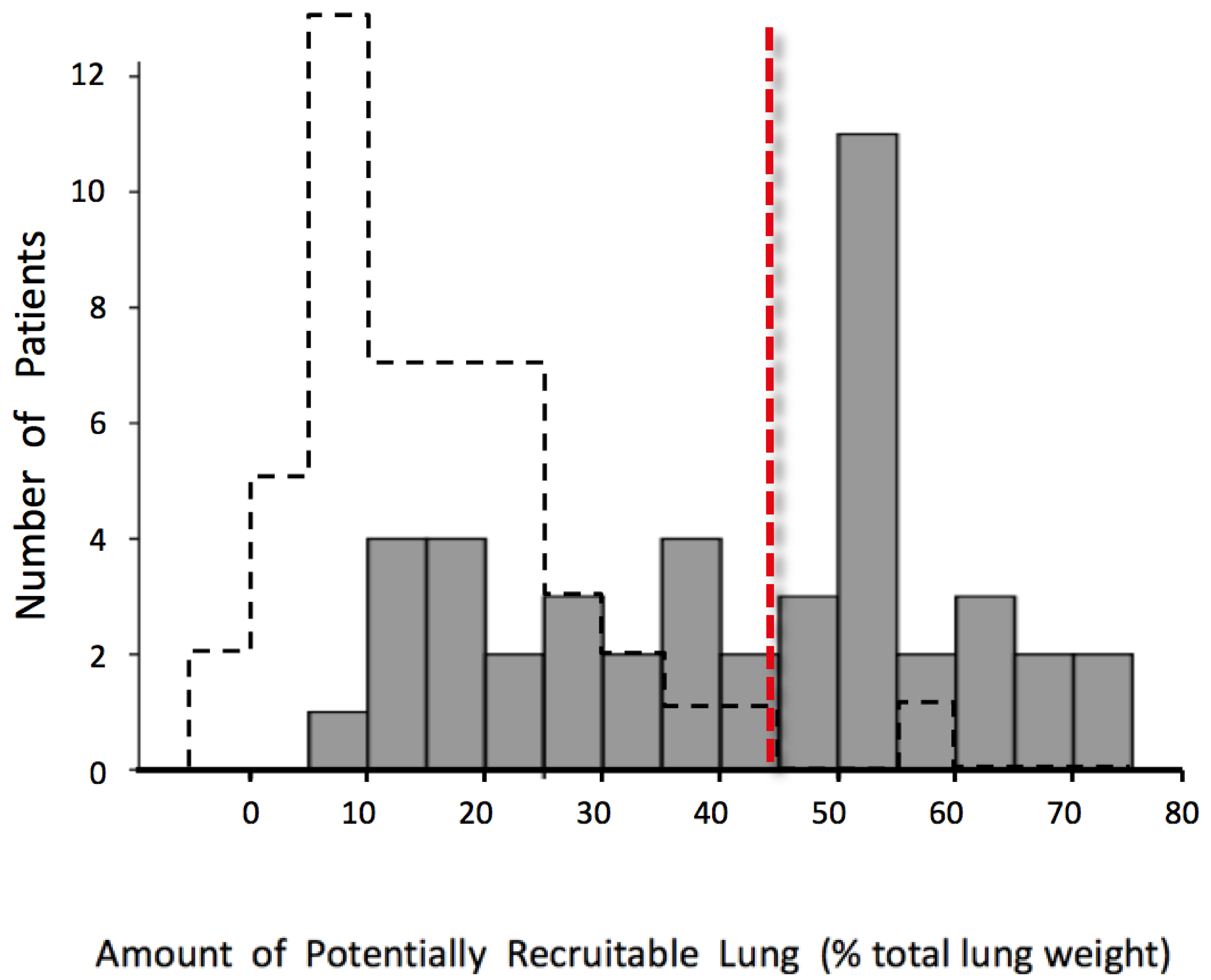
Critère temporel : un poumon SDRA peut-il être recruté ?

Patients ALI avec survenue tardive



de Matos et al. Critical Care 2012

Patients SDRA avec survenue précoce

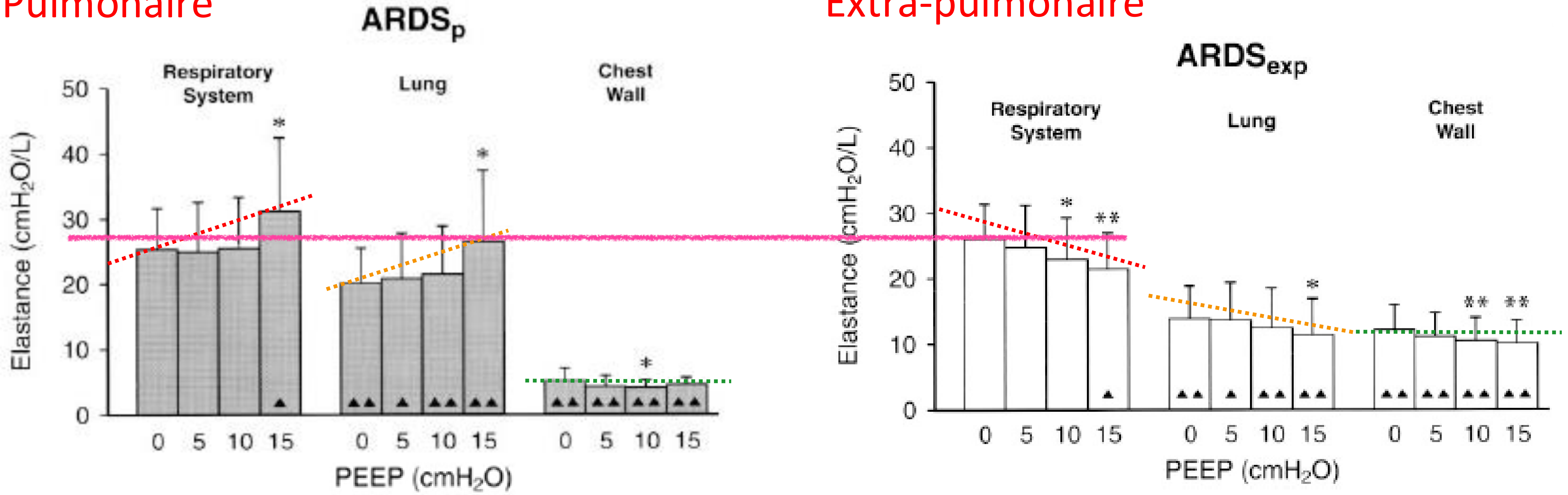


Cressoni M, Intensive Care Med. 2017 May

Type : les SDRA sont-ils tous identiques ?

Pulmonaire

Extra-pulmonaire



« …La voie de signalisation pathogénique prévalente n'a jamais été prise en compte dans les études cliniques sur le SDRA ; ***les patients présentant les deux types de SDRA sont généralement regroupés ensemble. Nos résultats suggèrent que cette différenciation pourrait être importante. »***

Gattinoni, L. American Journal of Respiratory and Critical Care Medicine 1998

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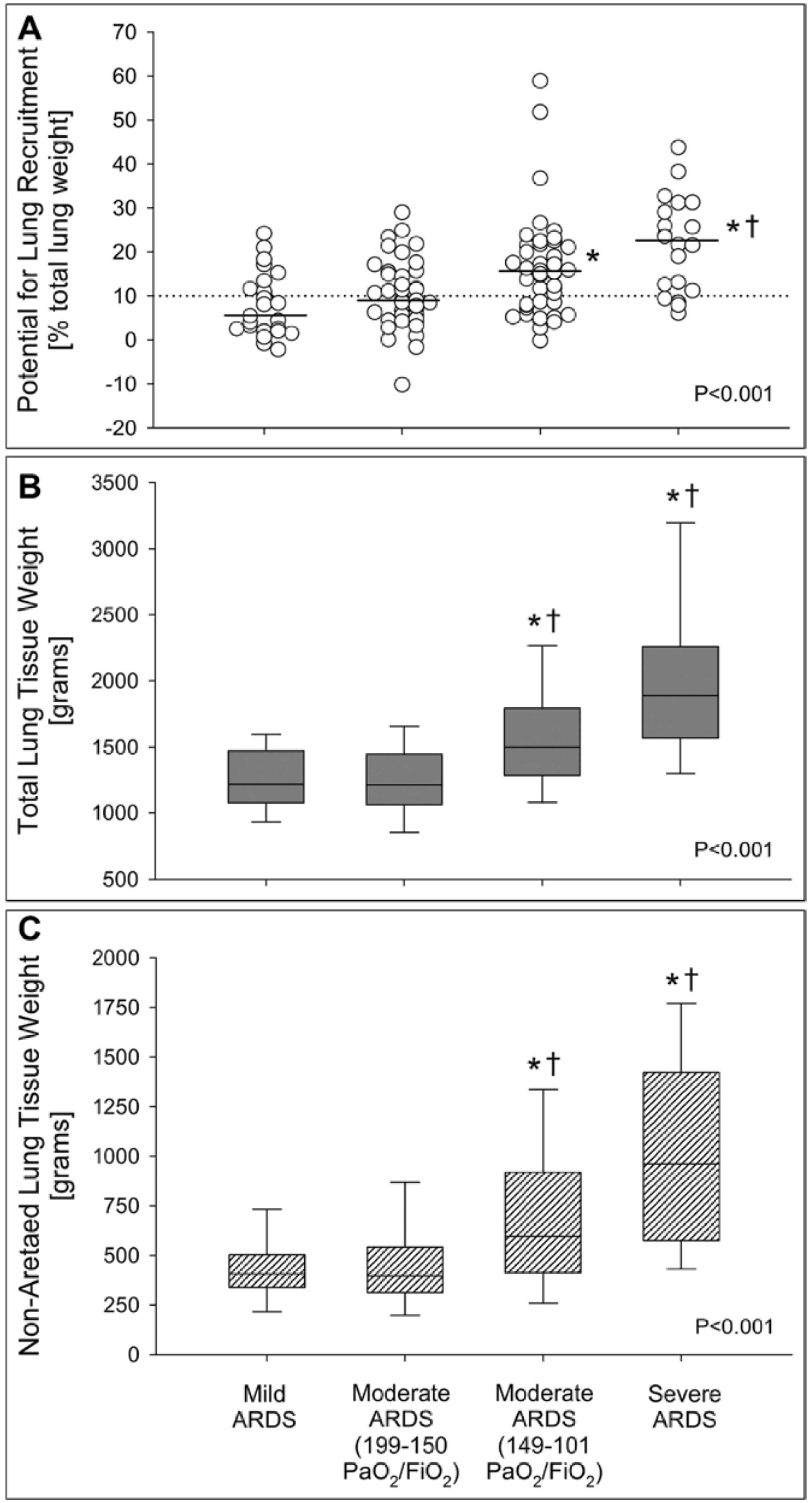
Lung recruitability and ICU mortality



Caironi. Crit Care Med 2015

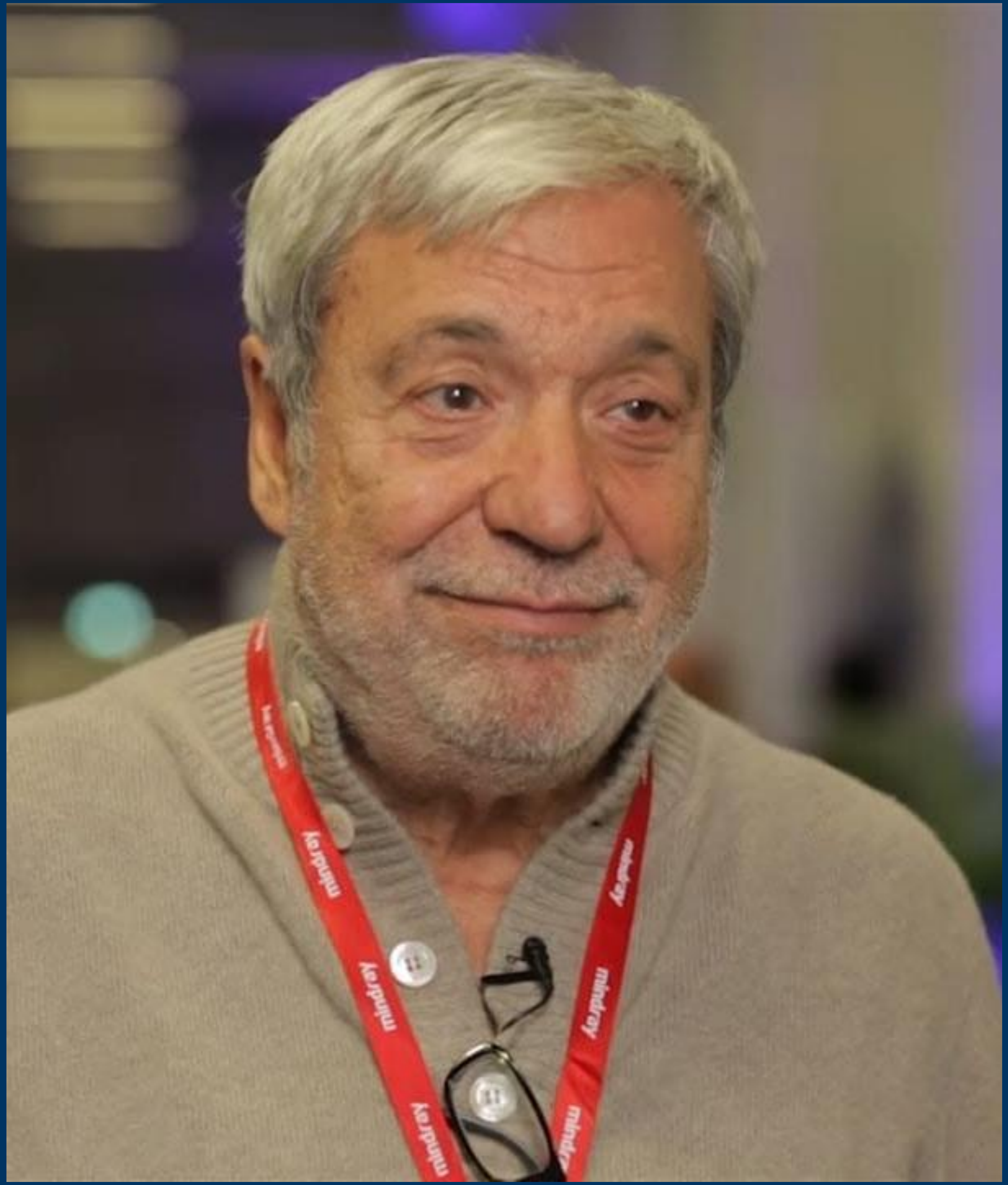
Lung recruitability and ICU mortality

5 cm H_2O; $p = 0.92$; and AUROC, 0.587; 95% CI, 0.498–0.676 at 15 cm H_2O; $p = 0.37$). When we considered CT-lung injury severity and Pao_2/Fio_2 as risk factors for mortality, the percentage of potentially recruitable lung was the only variable independently associated with a decreased ICU survival at both univariate and multivariable Cox proportional hazard

Characteristics	Univariate		Multivariable	
	HR	p^a	HR	p^a
Total lung tissue, g	1.00 (1.00–1.00)	0.66	1.00 (1.00–1.00)	0.47
Nonaerated lung tissue, g	1.00 (1.00–1.00)	0.24	1.00 (1.00–1.00)	0.73
Nonaerated lung tissue, %	1.01 (0.99–1.03)	0.29	1.01 (0.99–1.03)	0.32
Poorly aerated lung tissue, %	1.01 (0.99–1.03)	0.56	1.01 (0.98–1.03)	0.68
Normally aerated lung tissue, %	0.98 (0.96–1.00)	0.007	0.98 (0.95–1.01)	0.10
Hyperinflated lung tissue, %	1.14 (0.90–1.47)	0.27	1.13 (0.85–1.51)	0.39
Consolidated lung tissue, %	0.99 (0.96–1.01)	0.23	0.99 (0.96–1.01)	0.36
Potentially recruitable lung, %	1.04 (1.02–1.06)	0.002	1.04 (1.01–1.07)	0.007
Pao_2/Fio_2 at clinical PEEP, mm Hg	1.00 (0.99–1.00)	0.05	1.00 (0.99–1.00)	0.62
Pao_2/Fio_2 at 5 cm H_2O PEEP, mm Hg	0.99 (0.99–1.00)	0.07	1.00 (0.99–1.00)	0.38
Pao_2/Fio_2 at 15 cm H_2O PEEP, mm Hg	1.00 (0.99–1.00)	0.03	1.00 (0.99–1.00)	0.16

Caironi. Crit Care Med 2015

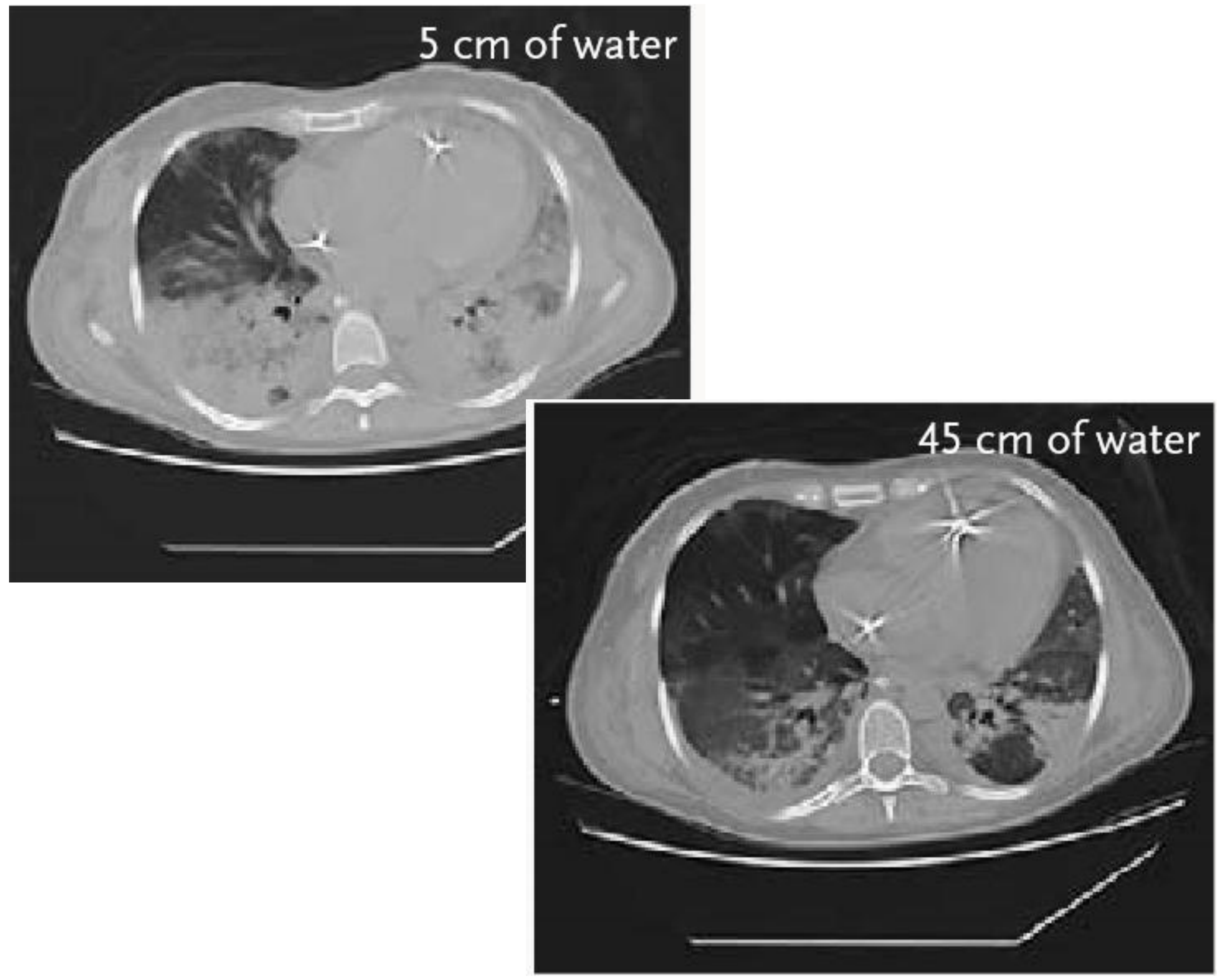
CT Scan assesment

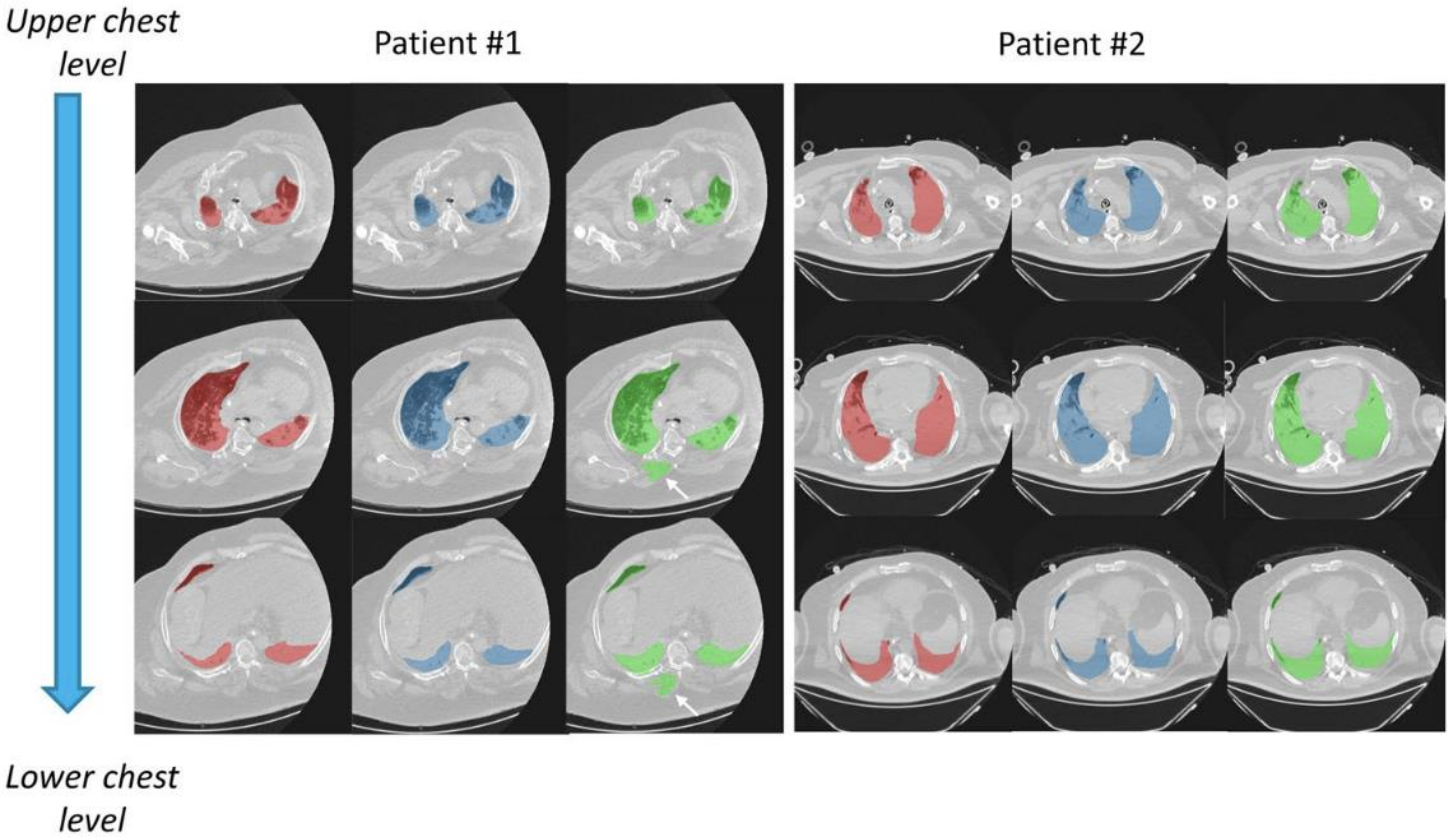


Méthodes d’évaluation de la capacité de recrutement

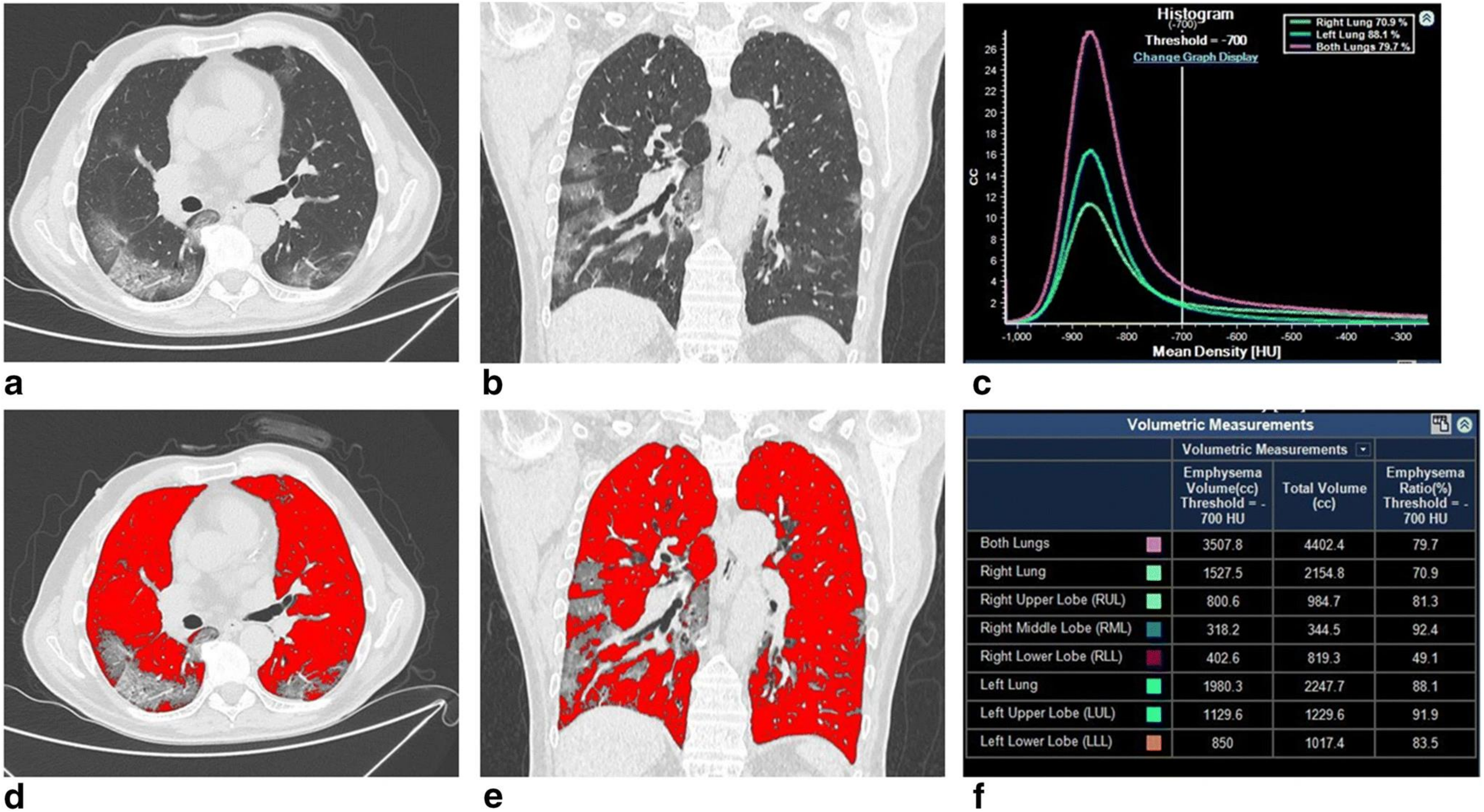
Tomodensitométrie

- Référence absolue





Gattinoni L, et al. N Engl J Med 2006



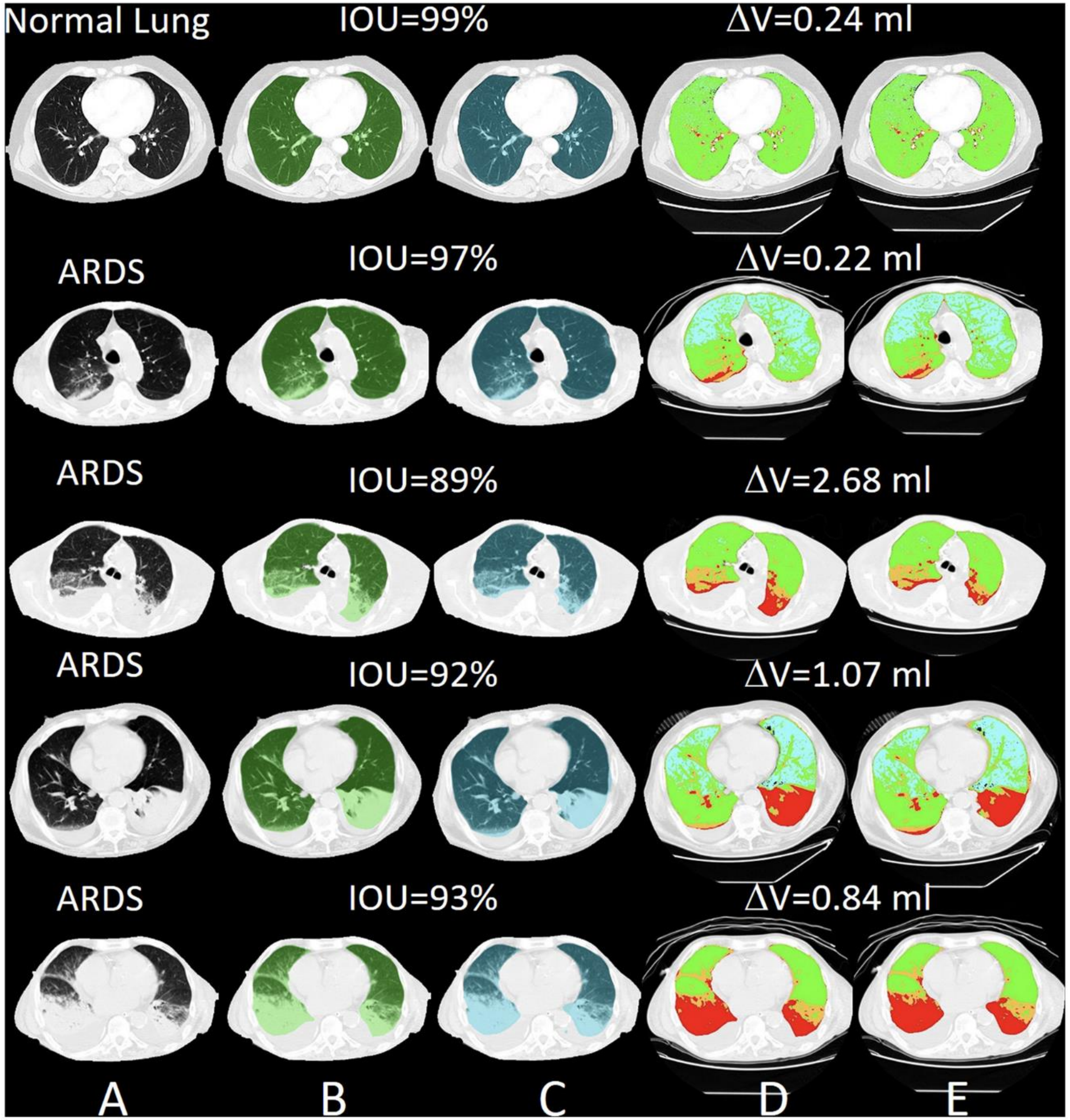
Volumetric Measurements			
	Volumetric Measurements		
	Emphysema Volume(cc) Threshold = -700 HU	Total Volume (cc)	Emphysema Ratio(%) Threshold = -700 HU
Both Lungs	3507.8	4402.4	79.7
Right Lung	1527.5	2154.8	70.9
Right Upper Lobe (RUL)	800.6	984.7	81.3
Right Middle Lobe (RML)	318.2	344.5	92.4
Right Lower Lobe (RLL)	402.6	819.3	49.1
Left Lung	1980.3	2247.7	88.1
Left Upper Lobe (LUL)	1129.6	1229.6	91.9
Left Lower Lobe (LLL)	850	1017.4	83.5

Using Artificial Intelligence for Automatic Segmentation of CT Lung Images in Acute Respiratory Distress Syndrome

Peter Herrmann[1], Mattia Busana[1], Massimo Cressoni[2], Joachim Lotz[3], Onnen Moerer[1], Leif Saager[1], Konrad Meissner[1], Michael Quintel[1,4] and Luciano Gattinoni[1]*

[1] Department of Anesthesiology, University Medical Center Göttingen, Göttingen, Germany, [2] Unit of Radiology, IRCCS Policlinico San Donato, Milan, Italy, [3] Institute for Diagnostic and Interventional Radiology, University Medical Center Göttingen, Göttingen, Germany, [4] Department of Anesthesiology, DONAUISAR Klinikum Deggendorf, Deggendorf, Germany

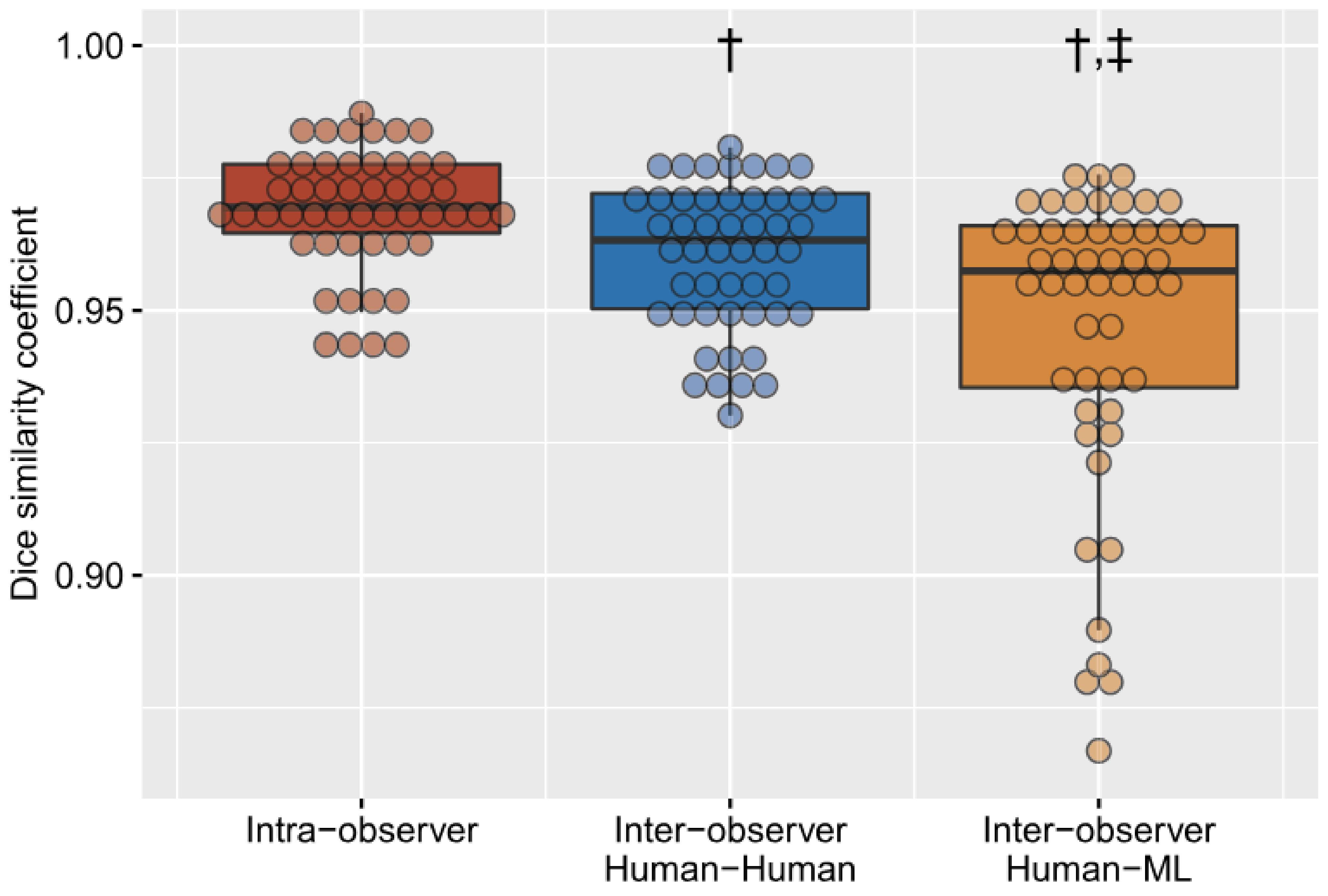
Cc in 2021 : « Due to the still poor performance, we plan to further improve the U-Net developed with LabVIEW and optimize it for the detection of differently damaged lung areas »

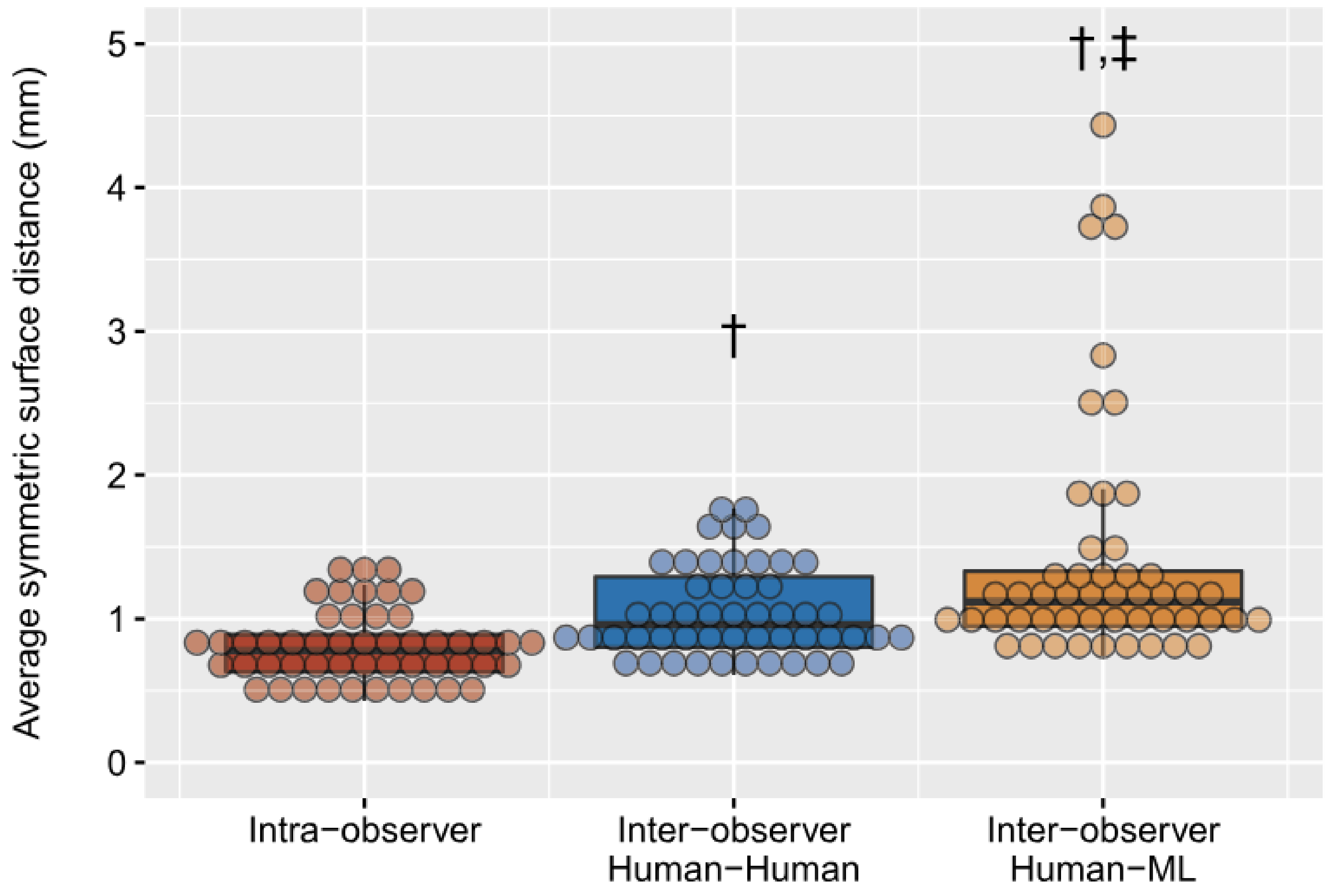


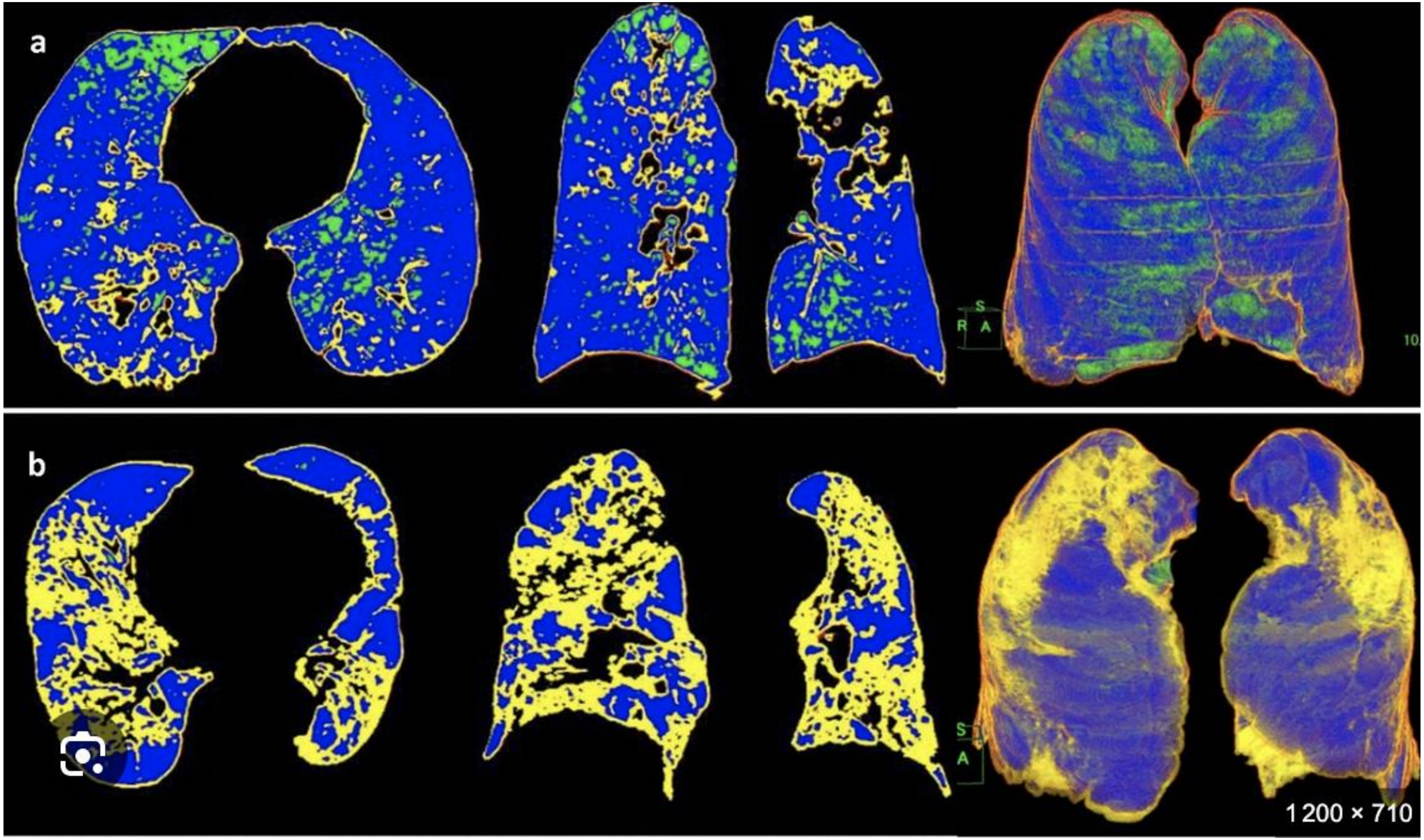
Precision of CT-derived alveolar recruitment assessed by human observers and a machine learning algorithm in moderate and severe ARDS

Penarrubia *et al.*
Intensive Care Medicine Experimental (2023) 11:8
https://doi.org/10.1186/s40635-023-00495-6

Ludmilla Penarrubia[1†], Aude Verstraete[2†], Maciej Orkisz[1], Eduardo Davila[1], Loic Boussel[1,3], Hodane Yonis[2], Mehdi Mezidi[2], Francois Dhelft[2,4], William Danjou[2], Alwin Bazzani[2], Florian Sigaud[5], Sam Bayat[6,7], Nicolas Terzi[8,9,10], Mehdi Girard[2], Laurent Bitker[1,2], Emmanuel Roux[1] and Jean-Christophe Richard[1,2*]






a
b
S
R
A
S
A
1 200 × 710

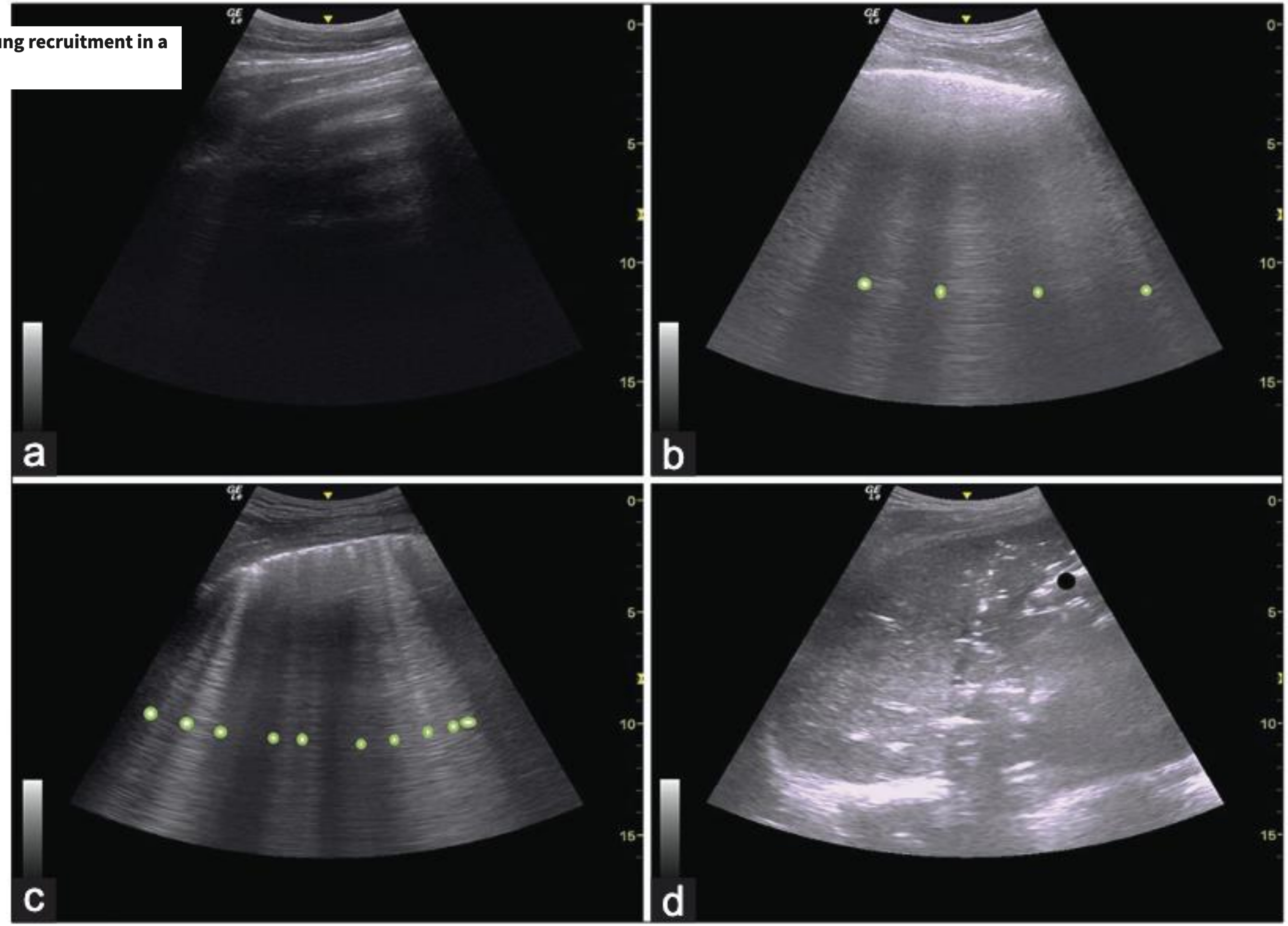
Méthodes « au chevet du patient »

Ultrasonographie

Ultrasonographie Pulmonaire

- Facilement disponible
- Non invasive
- Pas de radiations
- Pas onéreux
- Opérateur formé
- Même en ventilation spont.

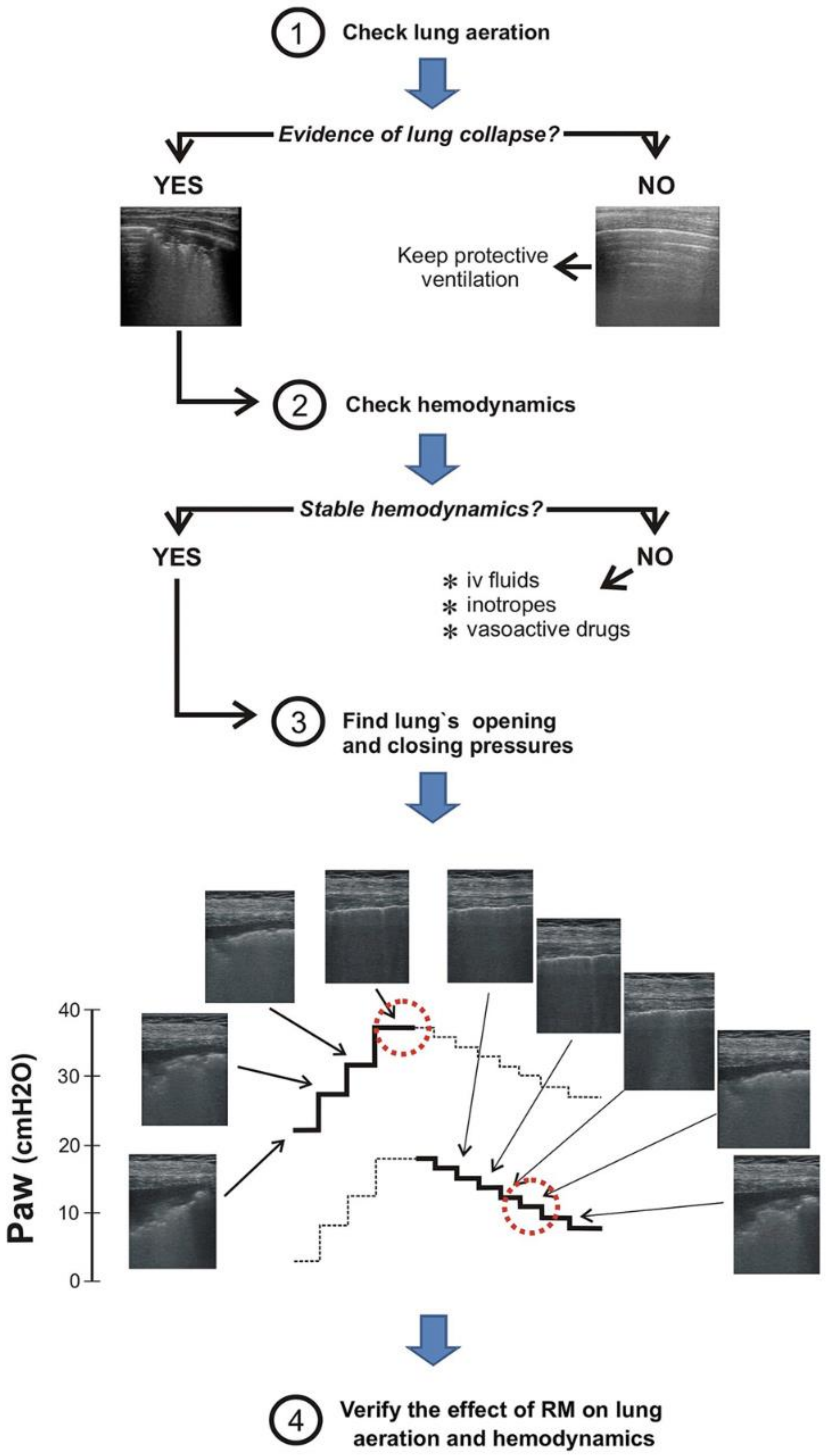
Utility of bedside lung ultrasound for assessment of lung recruitment in a case of acute respiratory distress syndrome



Lung India. 2019 Sep-Oct;36(5):451–456.

Ultrasonography for the assessment of lung recruitment maneuvers

Gerardo Tusman*, Cecilia M. Acosta and Mauro Costantini



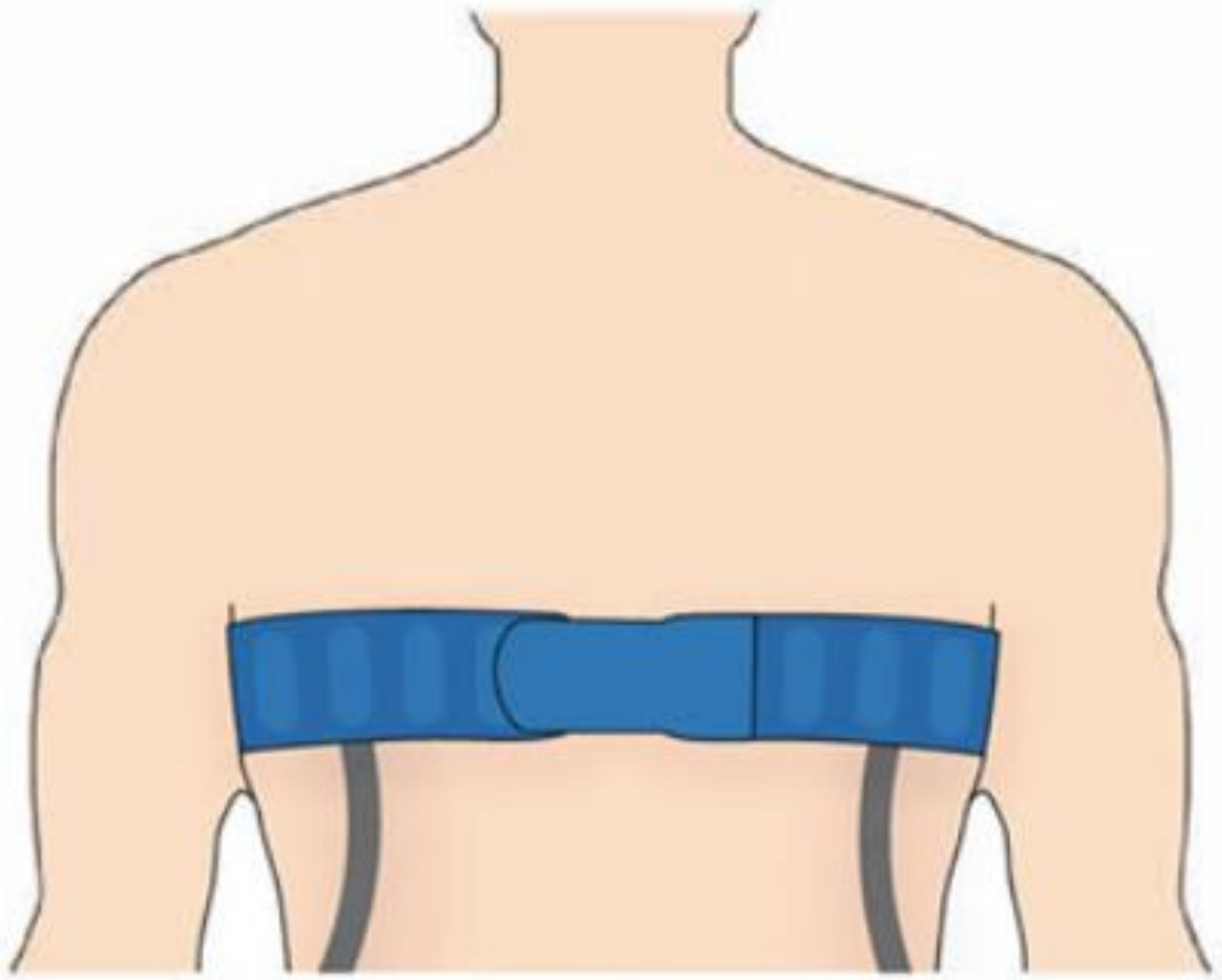
Tusman *et al. Crit Ultrasound J (2016) 8:8*
DOI 10.1186/s13089-016-0045-9

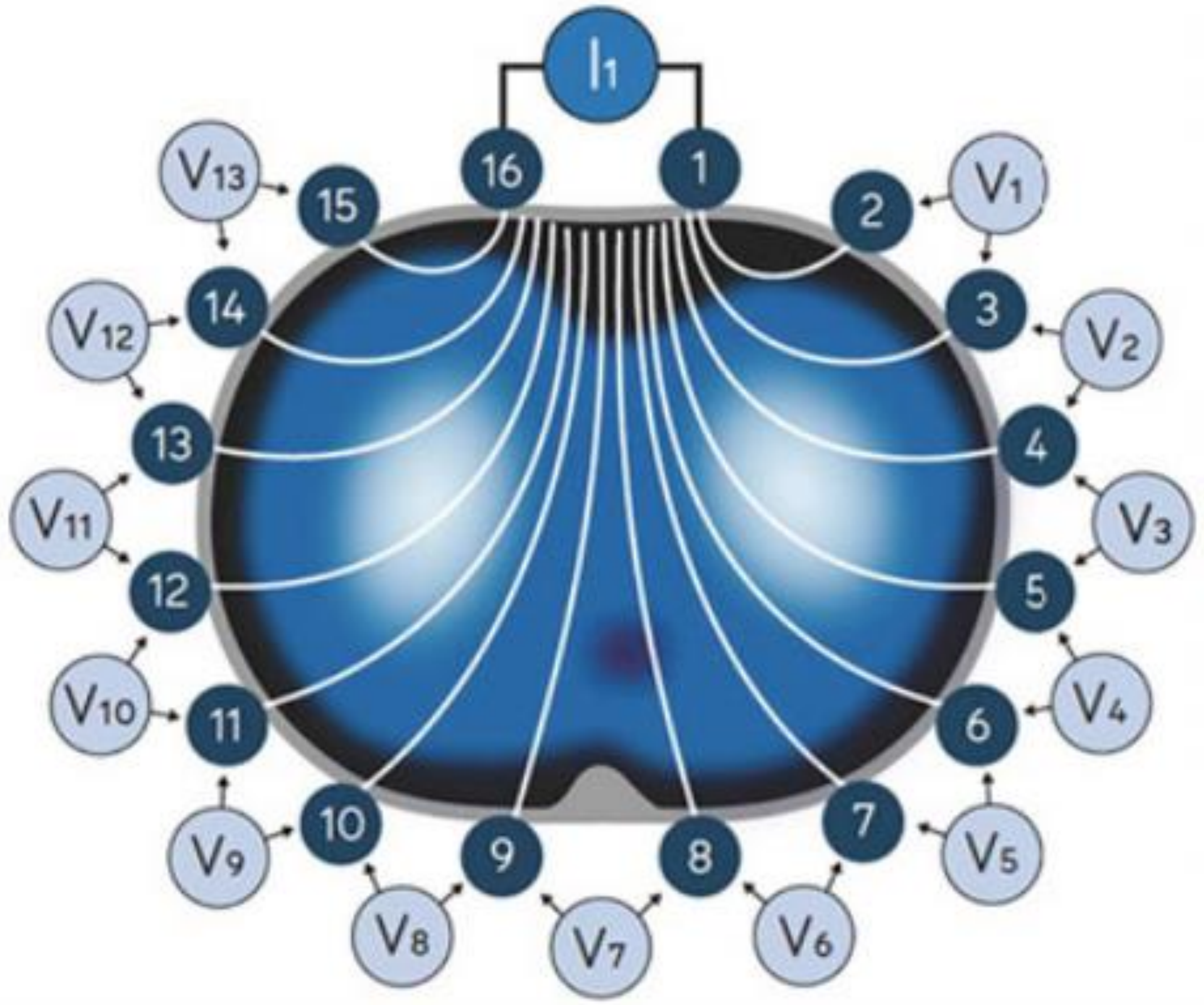
Ultrasonographie Pulmonaire

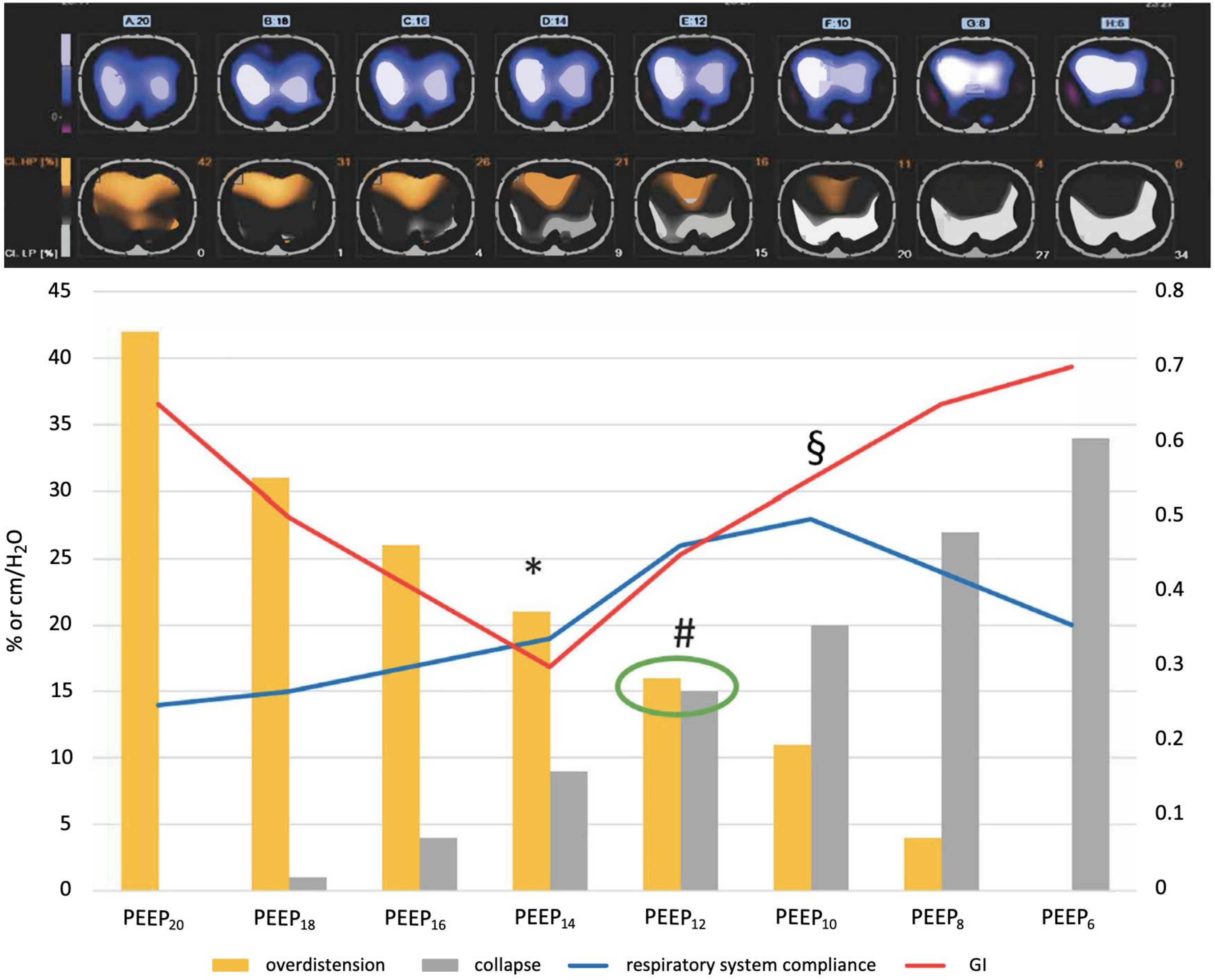
- Limites techniques de l'US
- Reproductibilité?
- Qualitatif plus que quantitatif

Impédence Eléctrique (EIT)

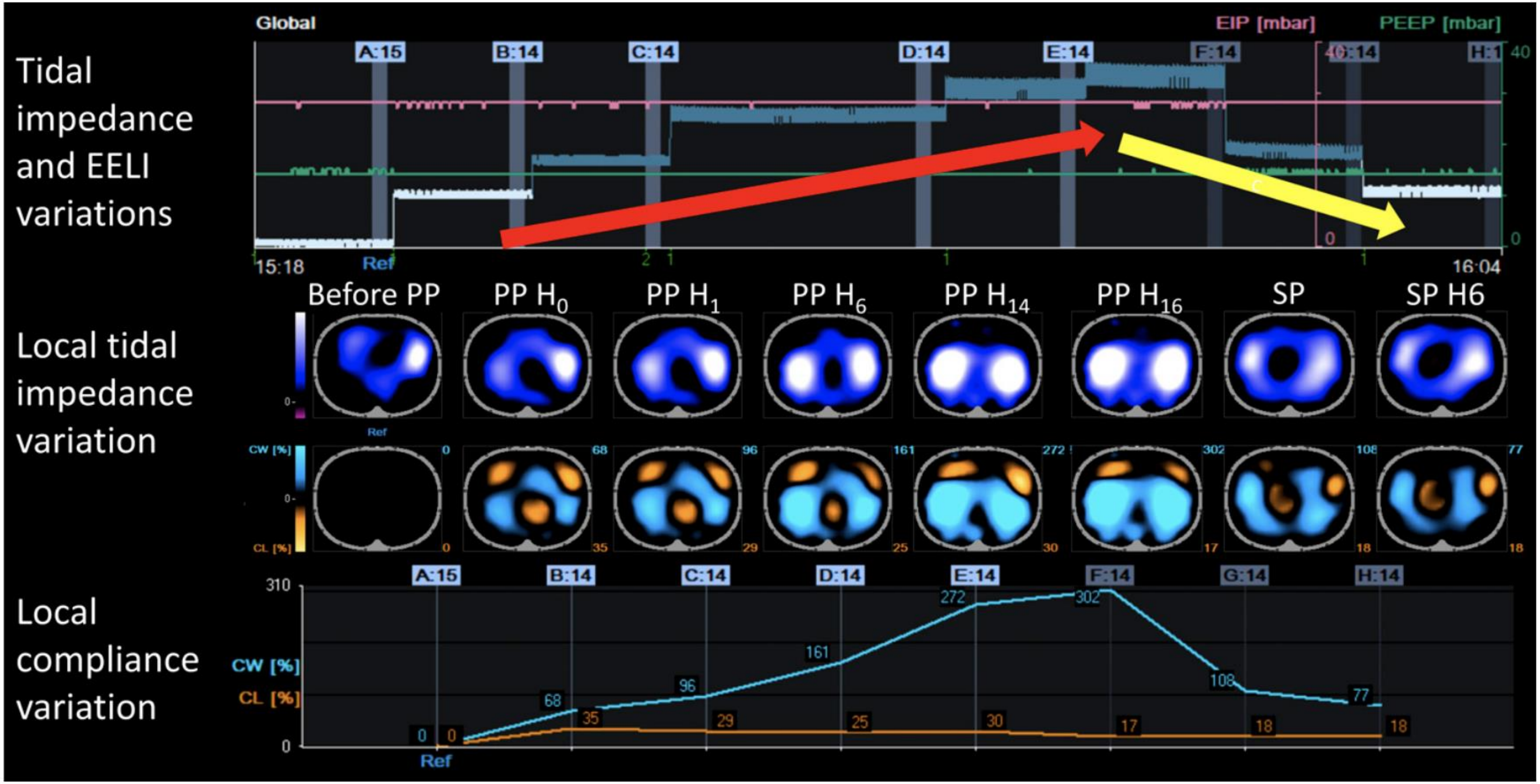
Impédence électrique:







A:20
B:18
C:16
D:14
E:12
F:10
G:8
H:6
CL HP [%]
CL LP [%]
42
31
26
21
16
11
4
0
0
1
4
9
15
20
27
34
45
40
35
30
25
20
15
10
5
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
% or cm/H2O
*
#
§
PEEP20
PEEP18
PEEP16
PEEP14
PEEP12
PEEP10
PEEP8
PEEP6
overdistension
collapse
respiratory system compliance
GI



Tidal impedance and EELI variations
Local tidal impedance variation
Local compliance variation
Global
EIP [mbar]
PEEP [mbar]
A:15
B:14
C:14
D:14
E:14
F:14
G:14
15:18
Ref
16:04
Before PP
PP H0
PP H1
PP H6
PP H14
PP H16
SP
SP H6
CW [%]
CL [%]
310
0
68
96
161
272
302
108
77
35
29
25
30
17
18
H:14

CONCISE CLINICAL REVIEW

Electrical Impedance Tomography to Monitor Hypoxemic Respiratory Failure

Guillaume Franchineau[1], Annemijn H. Jonkman[2], Lise Piquilloud[3], Takeshi Yoshida[4], Eduardo Costa[5], Hadrien Rozé[6,7], Luigi Camporota[8], Thomas Piraino[9,10], Elena Spinelli[11], Alain Combes[12], Glasiele C. Alcala[5], Marcelo Amato[5], Tommaso Mauri[11,13], Inéz Frerichs[14], Laurent J. Brochard[9,15], and Matthieu Schmidt[12]; for the Pleural Pressure Working Group (PLUG)

Population	Severity of the Population	Mean PEEP in the EIT group	Mean PEEP in the control group	Results
24 patients with ARDS vs. 31 historical patients (26)	APACHE II score 23.5	Based on overdistension and collapse: 18 cm H_2O	2 cm H_2O above inflection point of pressure–volume curve: 14 cm H_2O	- Higher compliance in EIT-based PEEP group: 26 vs. 20 ml/cm H_2O - No difference in clinical outcomes
117 patients with ARDS (83)	19.7% severe ARDS, 45.3% moderate ARDS, APACHE II score 19	Based on overdistension and collapse: 8 cm H_2O	Based on PEEP/$F_{I_{O_2}}$ table: 8 cm H_2O	- Nonsignificant 28-d mortality in EIT group: 21% vs. 27% - ICU length of stay: 13 vs. 10 d - Ventilator-free days: 14 vs 23 d
87 patients with ARDS (81)	75.9% severe ARDS, inclusion ≤24 h after intubation	Based on overdistension and collapse: 16.2 cm H_2O	Based on pressure–volume curve: 17.4 cm H_2O	- Lower hospital mortality in EIT group: 44.4% vs 69.0% - Lower ΔP in EIT group: 10.9 vs. 12.4 cm H_2O
12 patients with ARDS with a cross-over protocol (84)	$Pa_{O_2}/F_{I_{O_2}}$, 130; MV duration at inclusion, 0.6 d; SAPS II, 38	EIT-selected PEEP was lower: mean difference of change, −2 cm H_2O		- Lower mechanical power in EIT group: 11.42 J/min, with lower ΔP and higher static respiratory system compliance

Evaluation via respirateur

Pré- requis

- Patient passif : sédation profonde ± paralysie
- Condition hémodynamique stable cardiaque / neuro
- Ballonnet surgonflé (pour éviter les fuites)

R/I Ratio

Pression : un poumon SDRA
peut-il être recruté ?

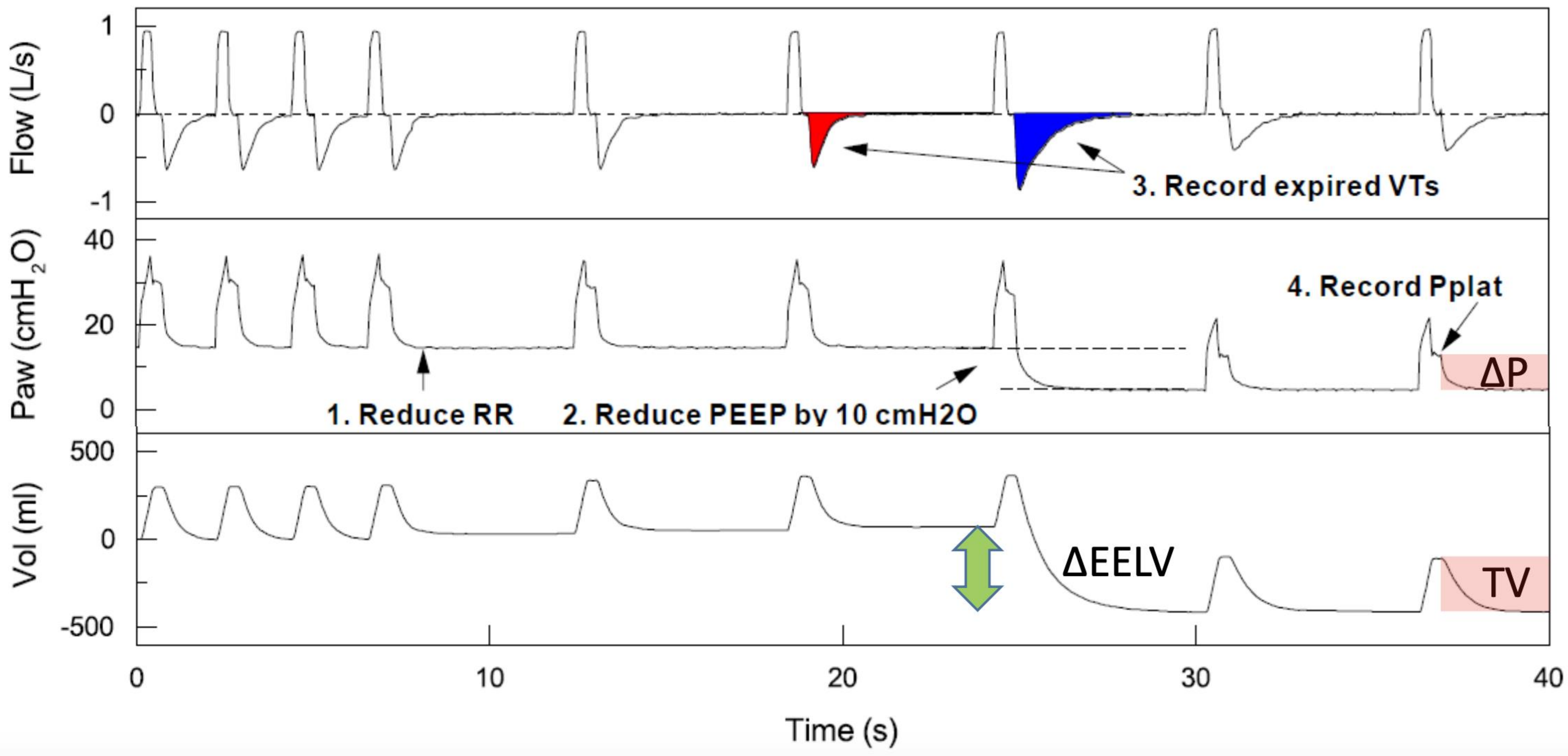
R/I Ratio

Potential for Lung Recruitment Estimated by the Recruitment-to-Inflation Ratio in Acute Respiratory Distress Syndrome

A Clinical Trial

Vrec = ΔEELV – ΔPEEP * TV / ΔP

$$\text{R/I ratio} = \frac{\text{Vrec}}{\Delta\text{PEEP}} \times \frac{\Delta P}{\text{TV}}$$



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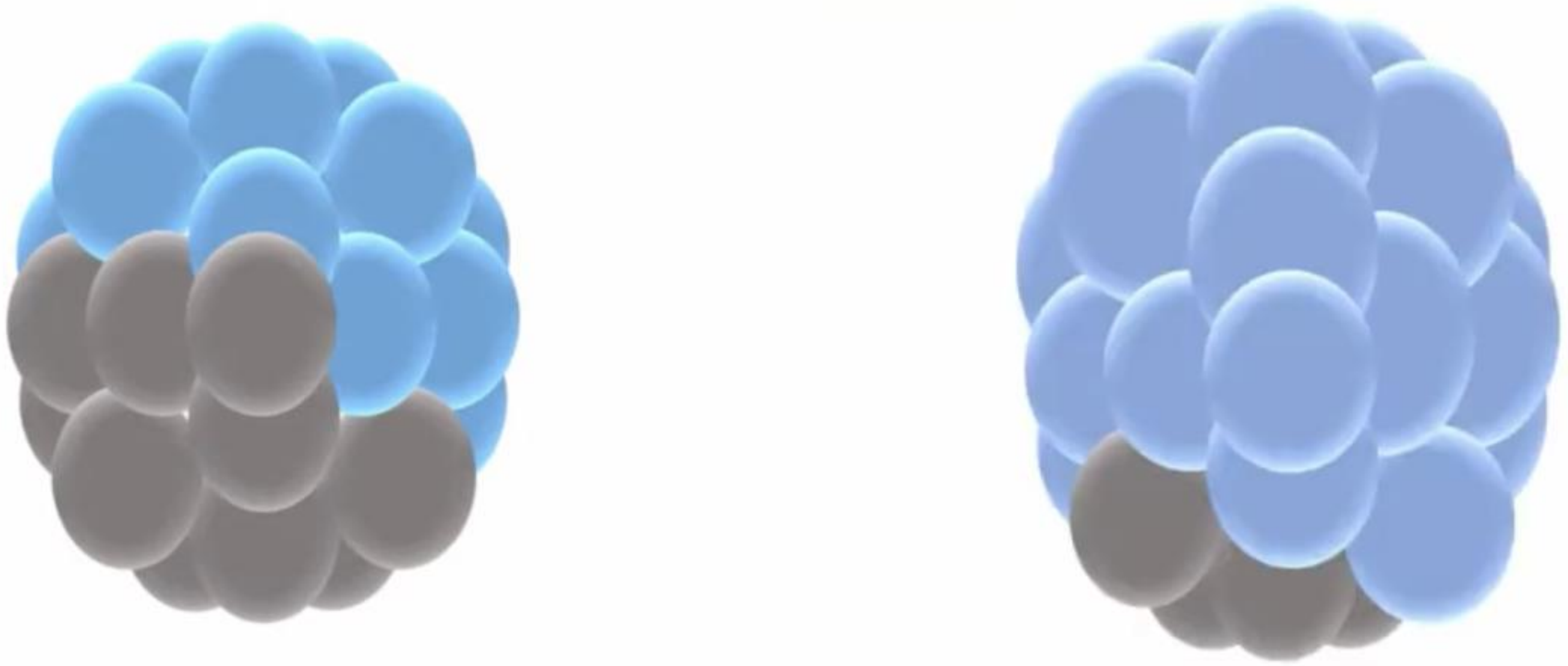
R/I Ratio



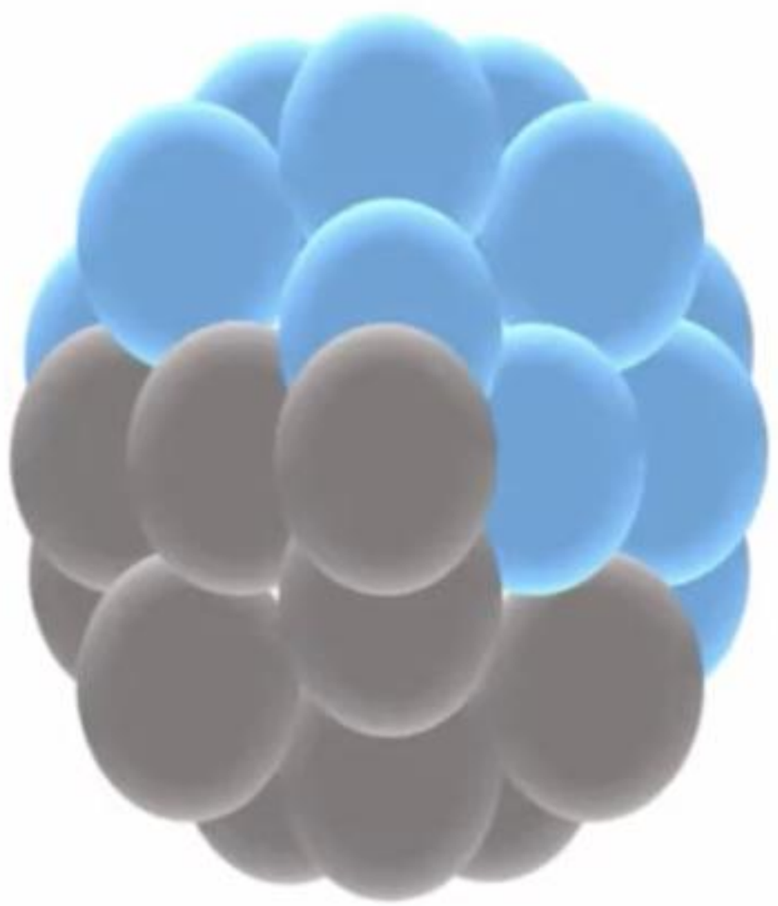
C = 30 ml/cm H_2O

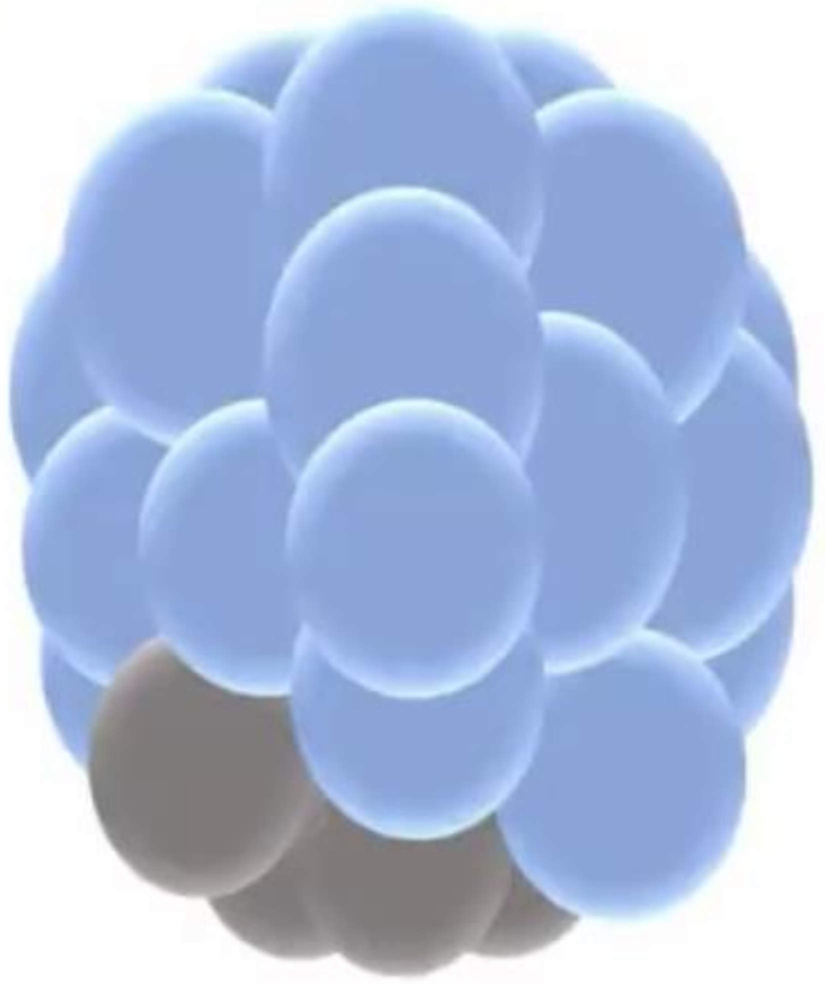
PEP = 5 cm H_2O → PEP = 15 cm H_2O

EELV = 600 ml EELV = ?

d'après G.Carteaux . CHU Créteil

R/I Ratio





C = 30 ml/cm H_2O

PEP = 5 cm H_2O → PEP = 15 cm H_2O

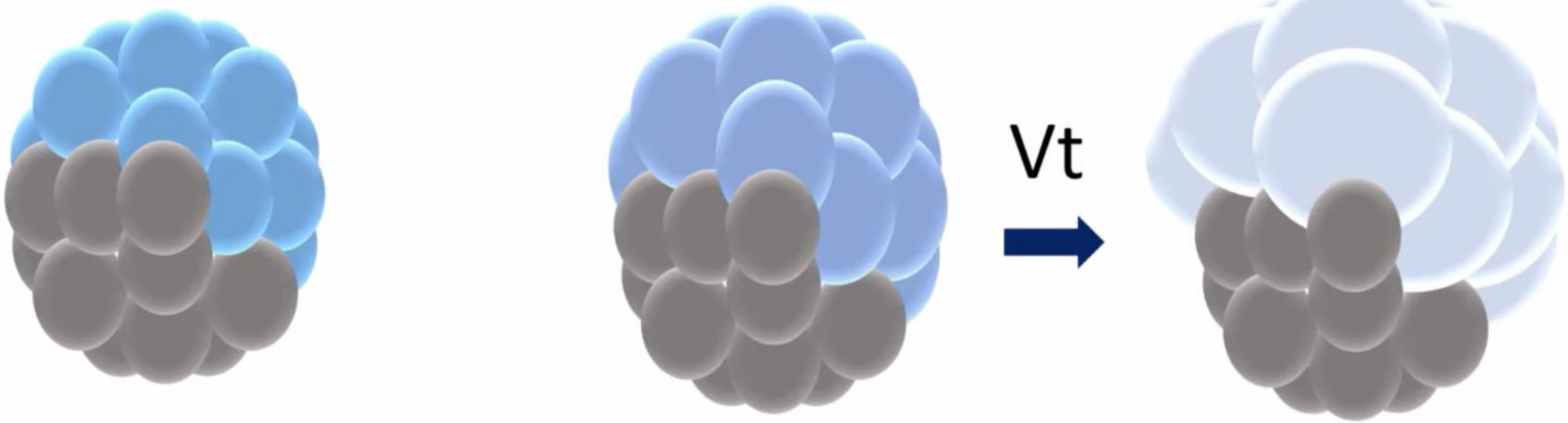
EELV = 600 ml EELV = 900 ml

d'après G.Carteaux . CHU Créteil

Pression : un poumon SDRA
peut-il être recruté ?

R/I Ratio

Patient non recruteur



$C = 30$ ml/cm H_2O

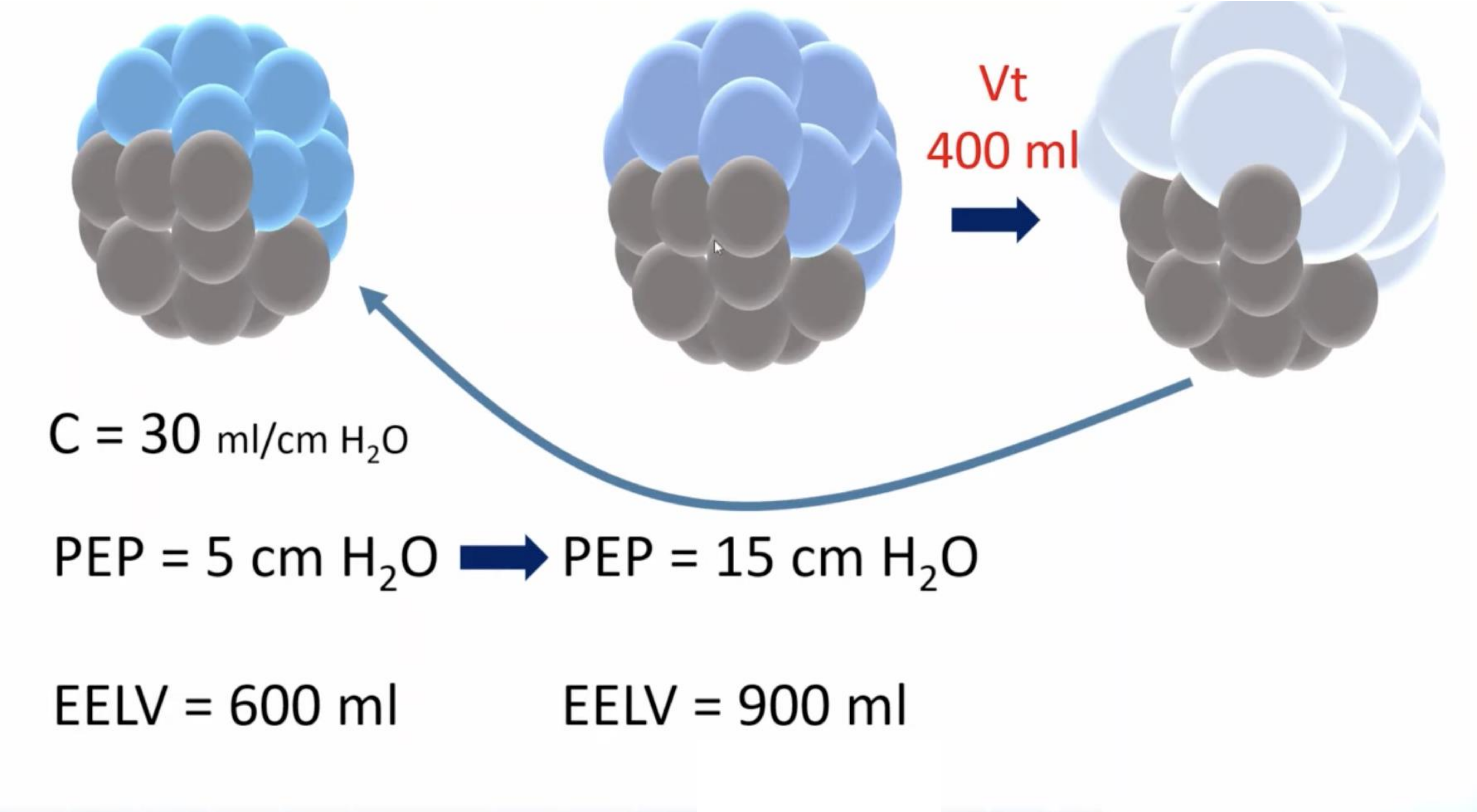
PEP = 5 cm H_2O ➡ PEP = 15 cm H_2O

EELV = 600 ml EELV = 900 ml

d'après G.Carteaux . CHU Créteil

R/I Ratio

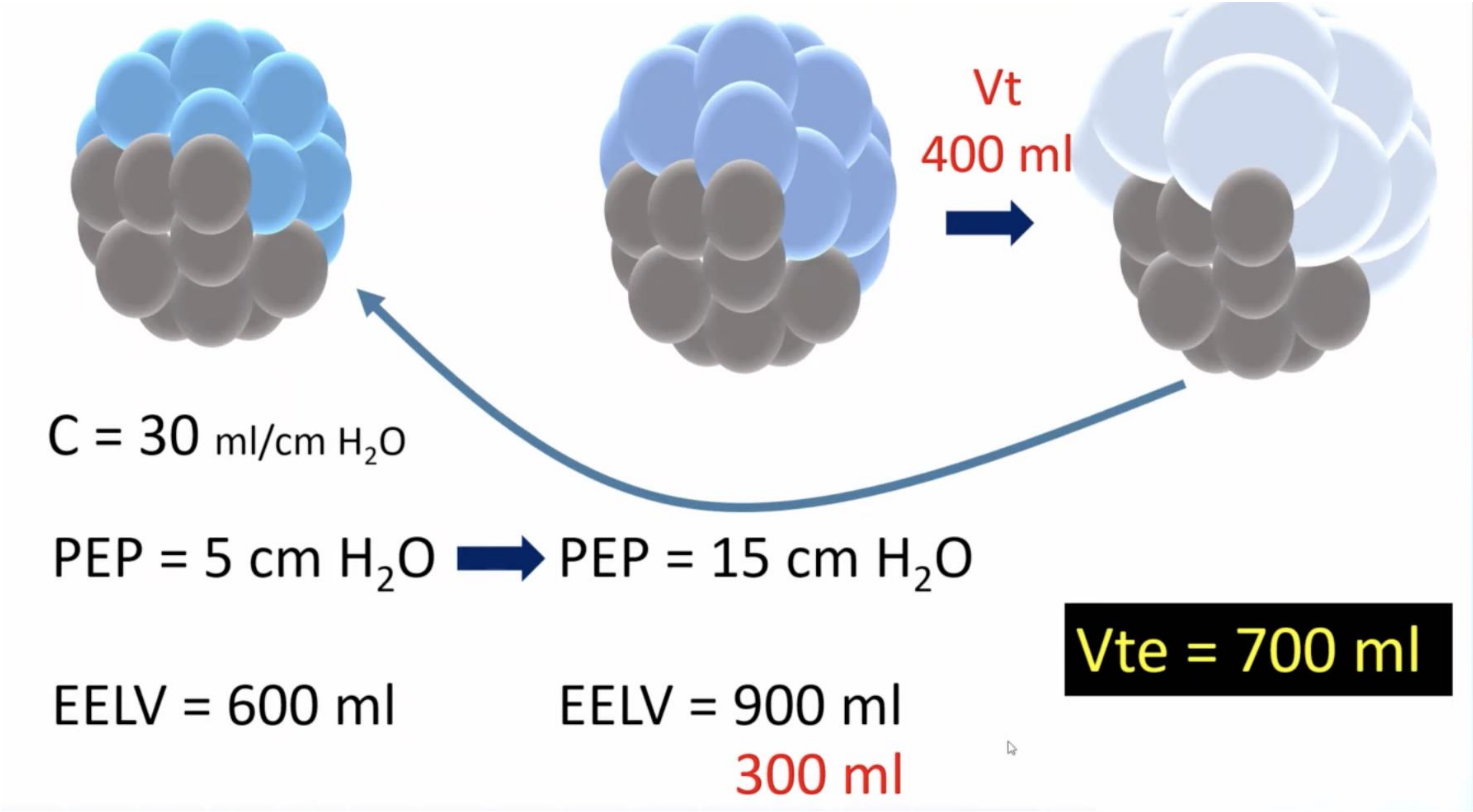
Patient non recruteur



d'après G.Carteaux . CHU Créteil

R/I Ratio

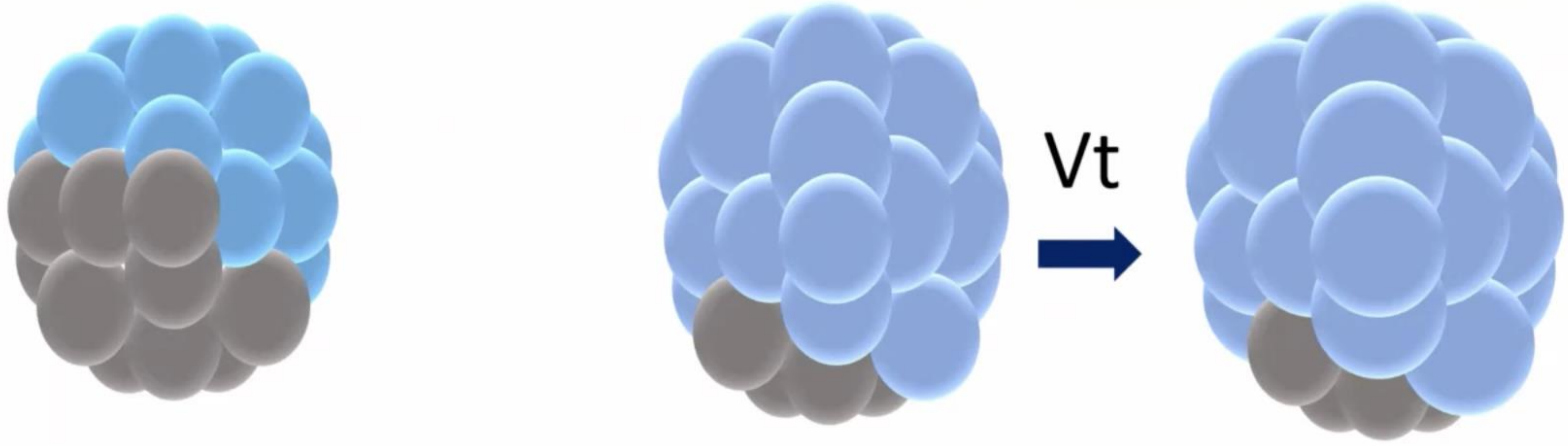
Patient non recruteur



d'après G.Carteaux . CHU Créteil

R/I Ratio

Patient recruteur



$C = 30$ ml/cm H_2O

PEP = 5 cm H_2O → PEP = 15 cm H_2O

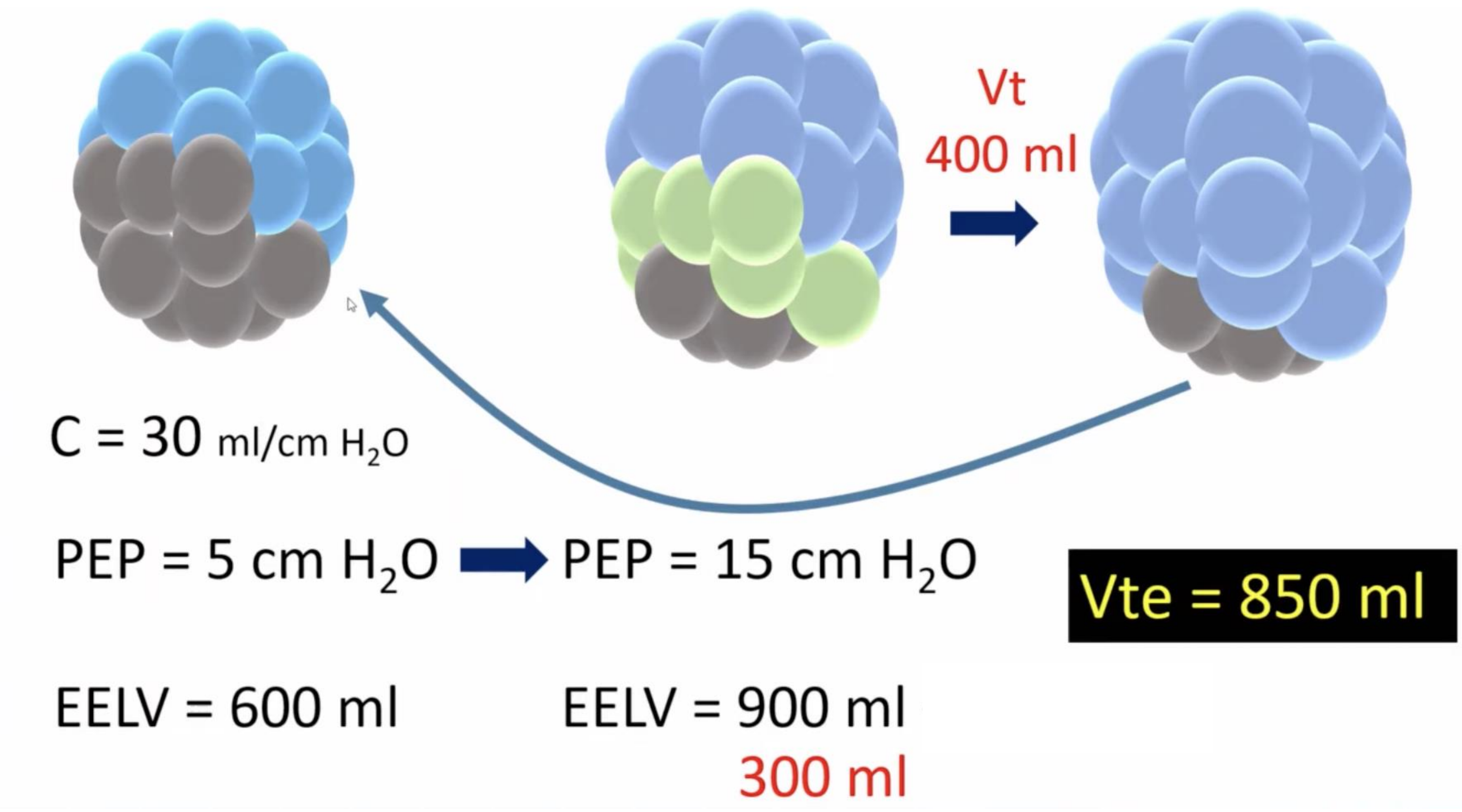
EELV = 600 ml

EELV = 900 ml + Vrec

d'après G.Carteaux . CHU Créteil

R/I Ratio

Patient recruteur

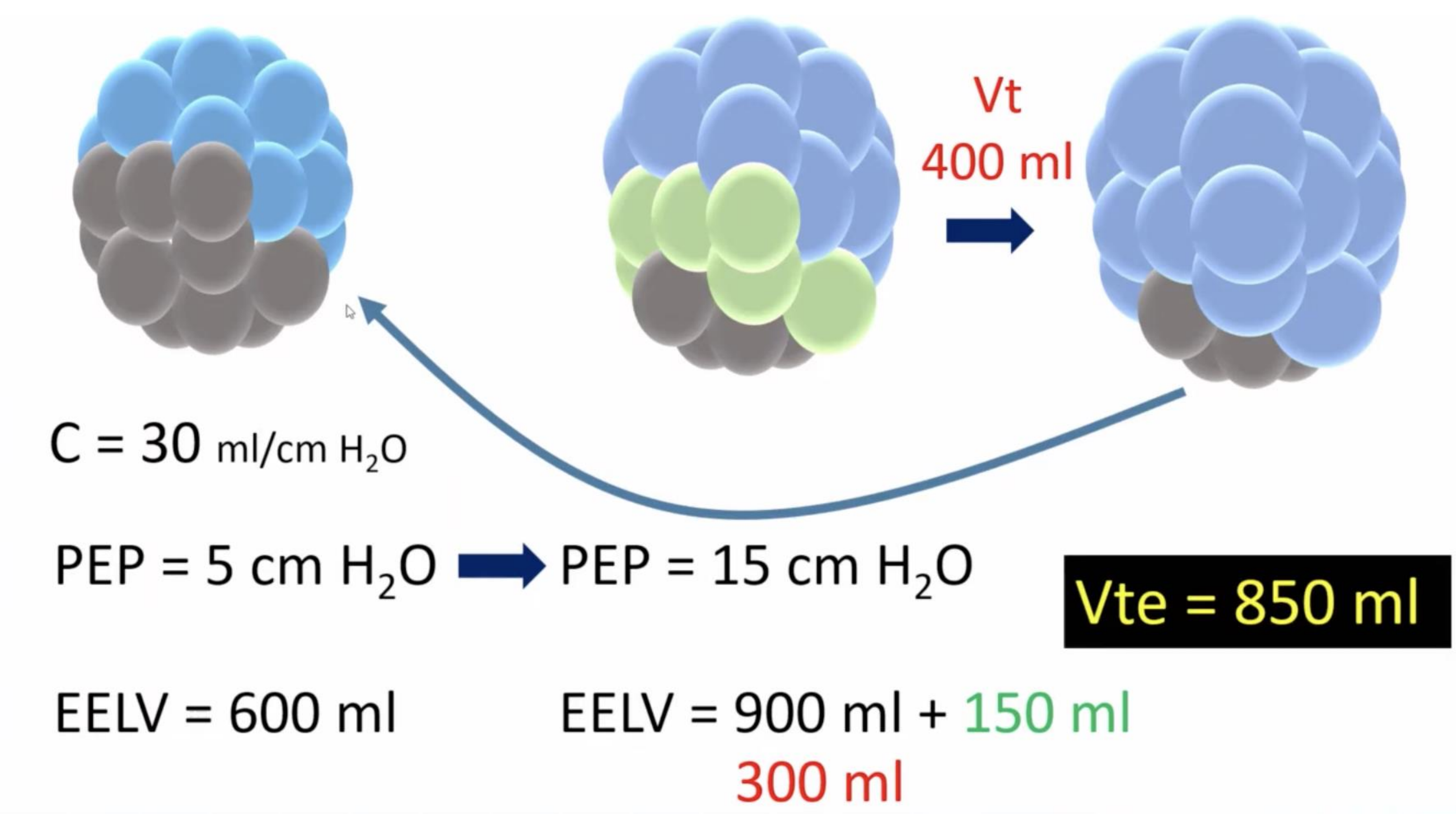


d'après G.Carteaux . CHU Créteil

Pression : un poumon SDRA
peut-il être recruté ?

R/I Ratio

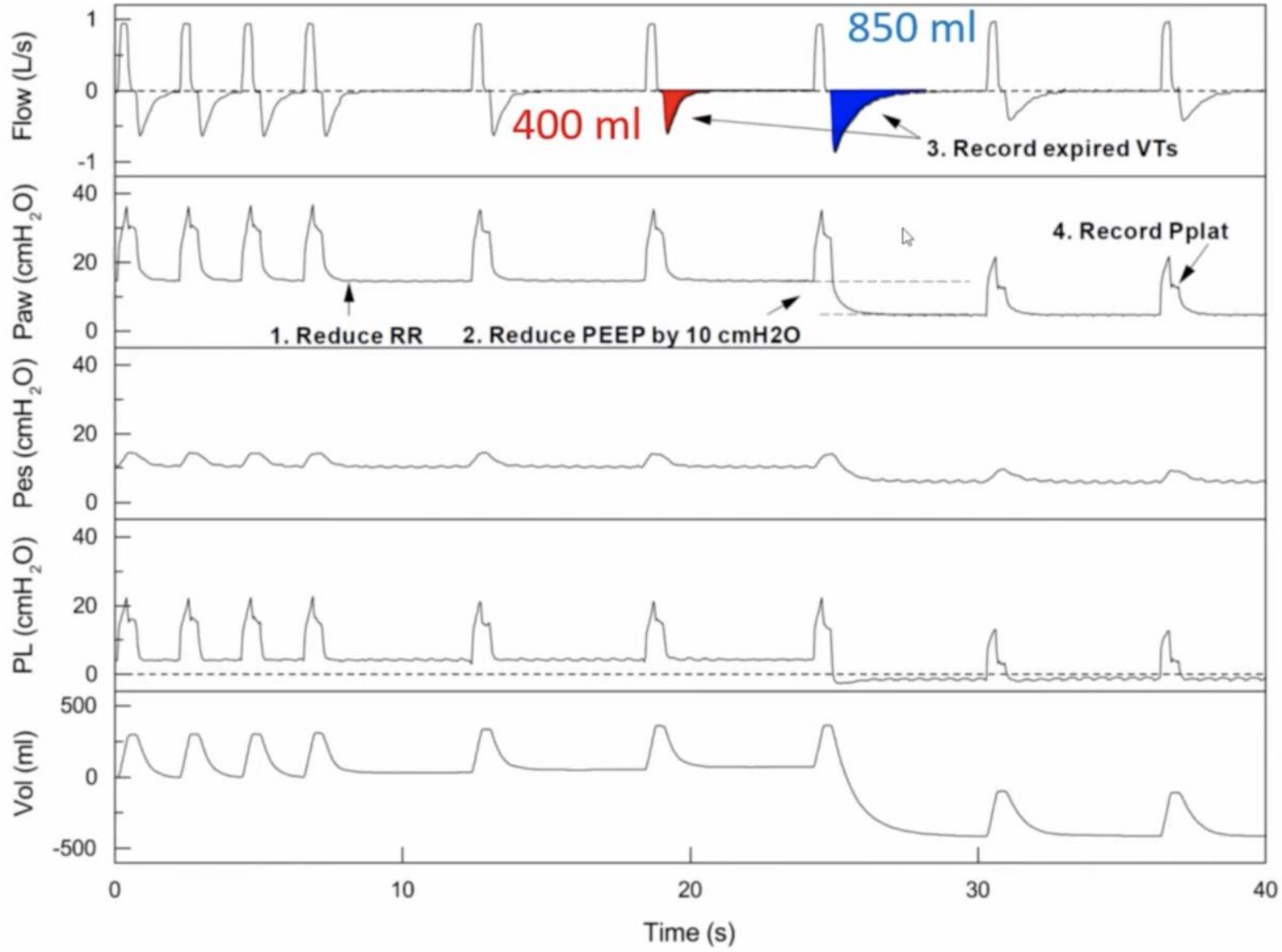
Patient recruteur



d'après G.Carteaux . CHU Créteil

Pression : un poumon SDRA
peut-il être recruté ?

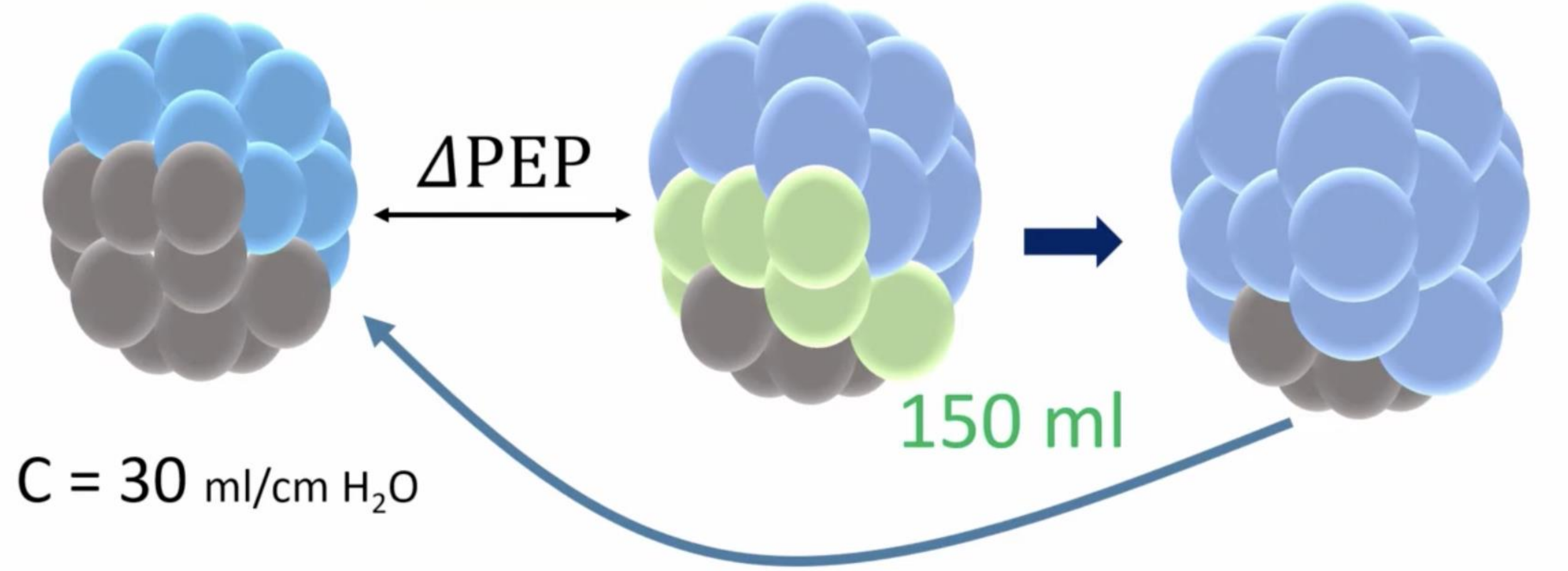
R/I Ratio



$C_{basse\text{-}PEP}$ =
30 ml/cmH_2O

Chen L *et al.* AJRCCM 2020;2:178-187

R/I Ratio

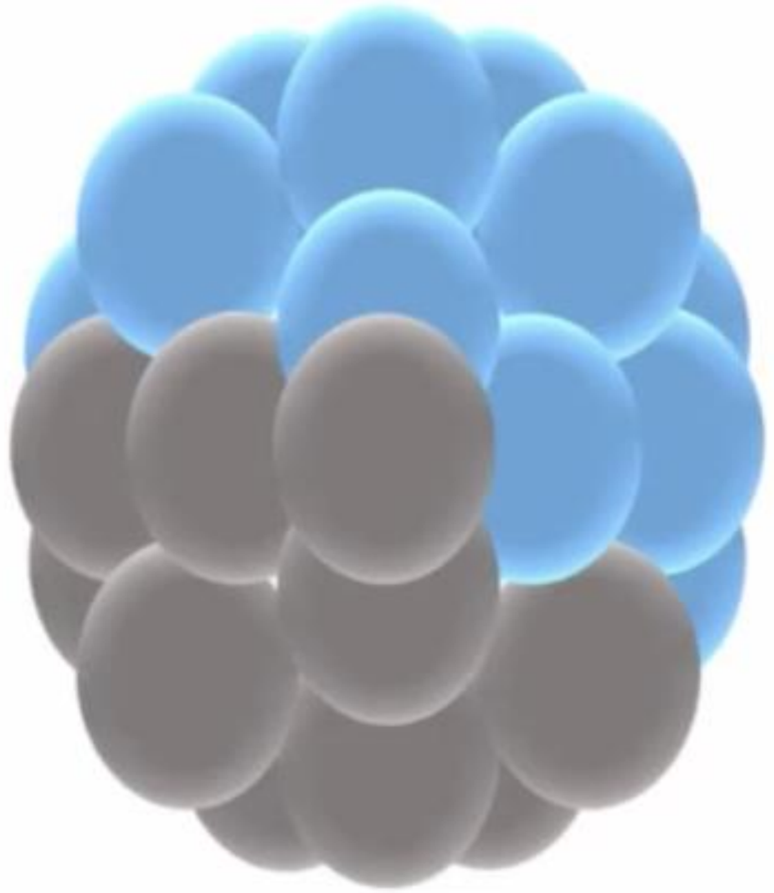


$$V_{REC} = V_{expiré} - Vt_{réglé} - C_{basse\text{-}PEP} \times \Delta PEP$$

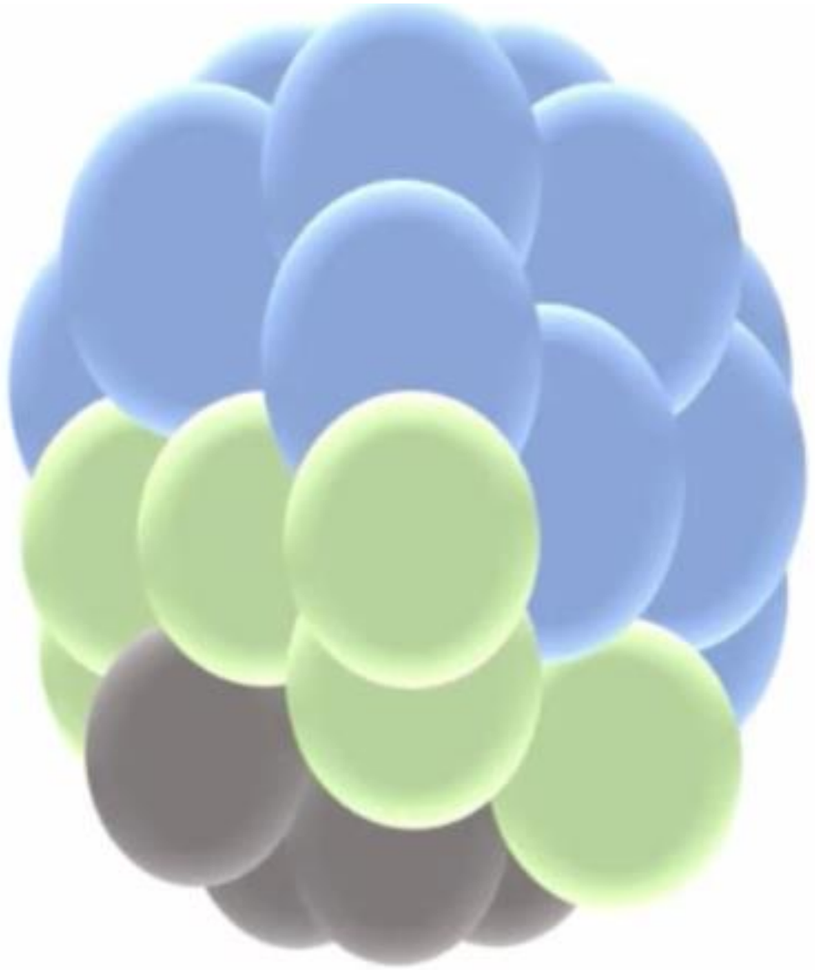
$$V_{REC} = 850 - 400 - 300$$

d'après G.Carteaux . CHU Créteil

R/I Ratio



PEP = 5 cm H_20



PEP = 15 cm H_20

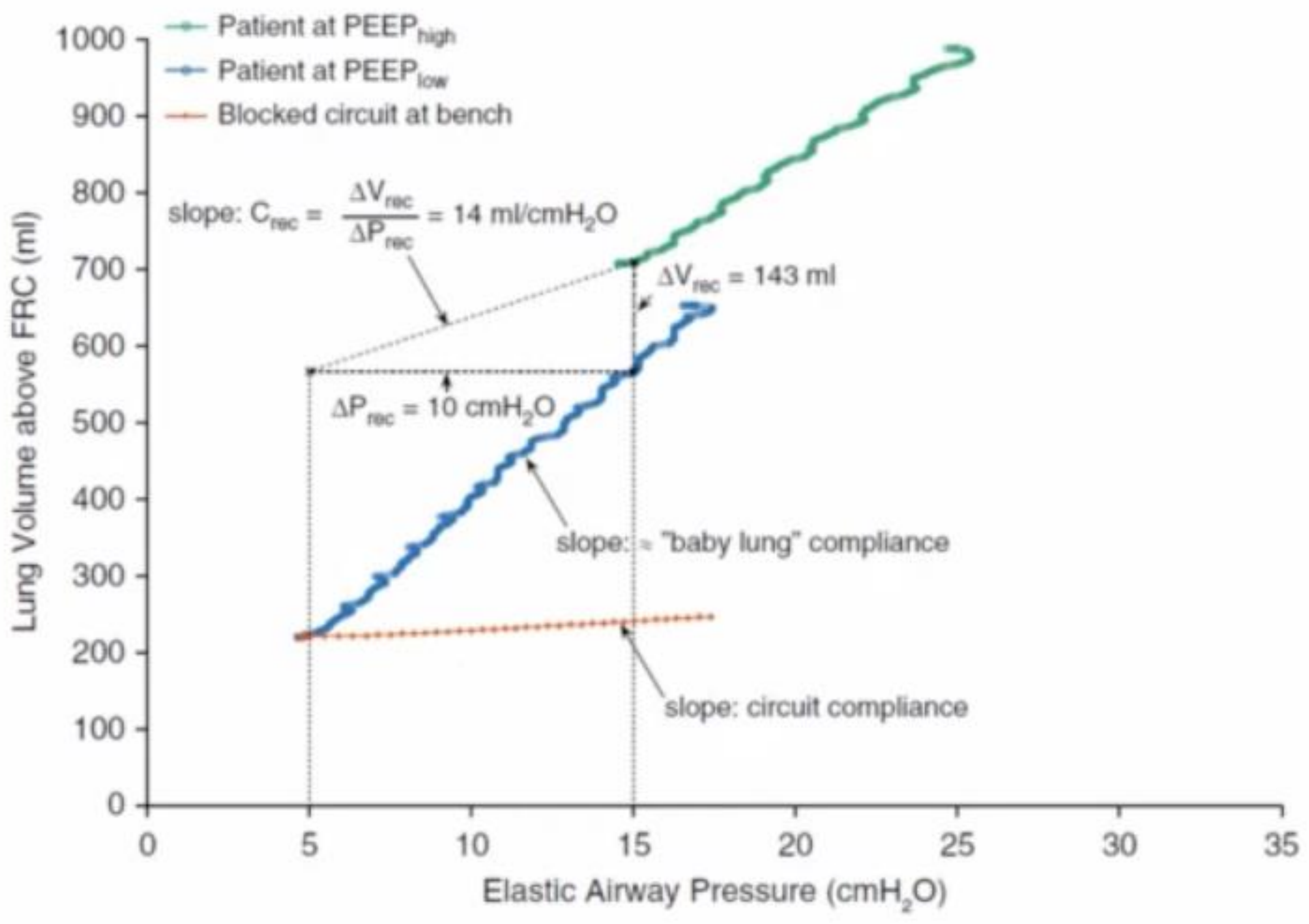
$C_{basse\text{-}PEP}$ = 30 ml/cm H_2O

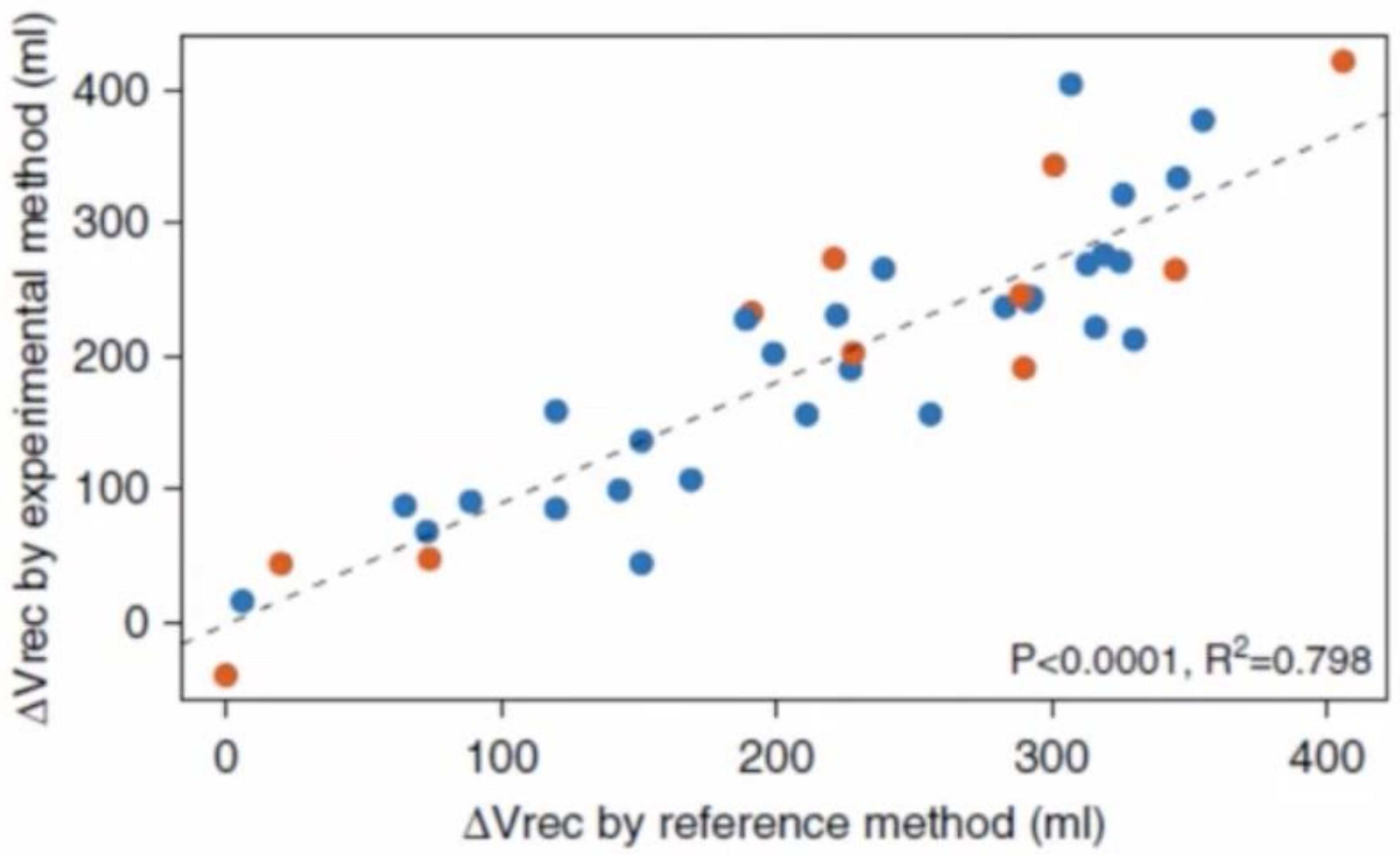
C_{REC} = 150 ml / 10 cm H20
= 15 ml/cm H_2O

$$\frac{R}{I} = \frac{C_{REC}}{C_{basse-PEP}}$$

d'après G.Carteaux . CHU Créteil

R/I Ratio





R/I
Médiane

Faible potentiel de recrutement ← 0,5 → Haut potentiel de recrutement

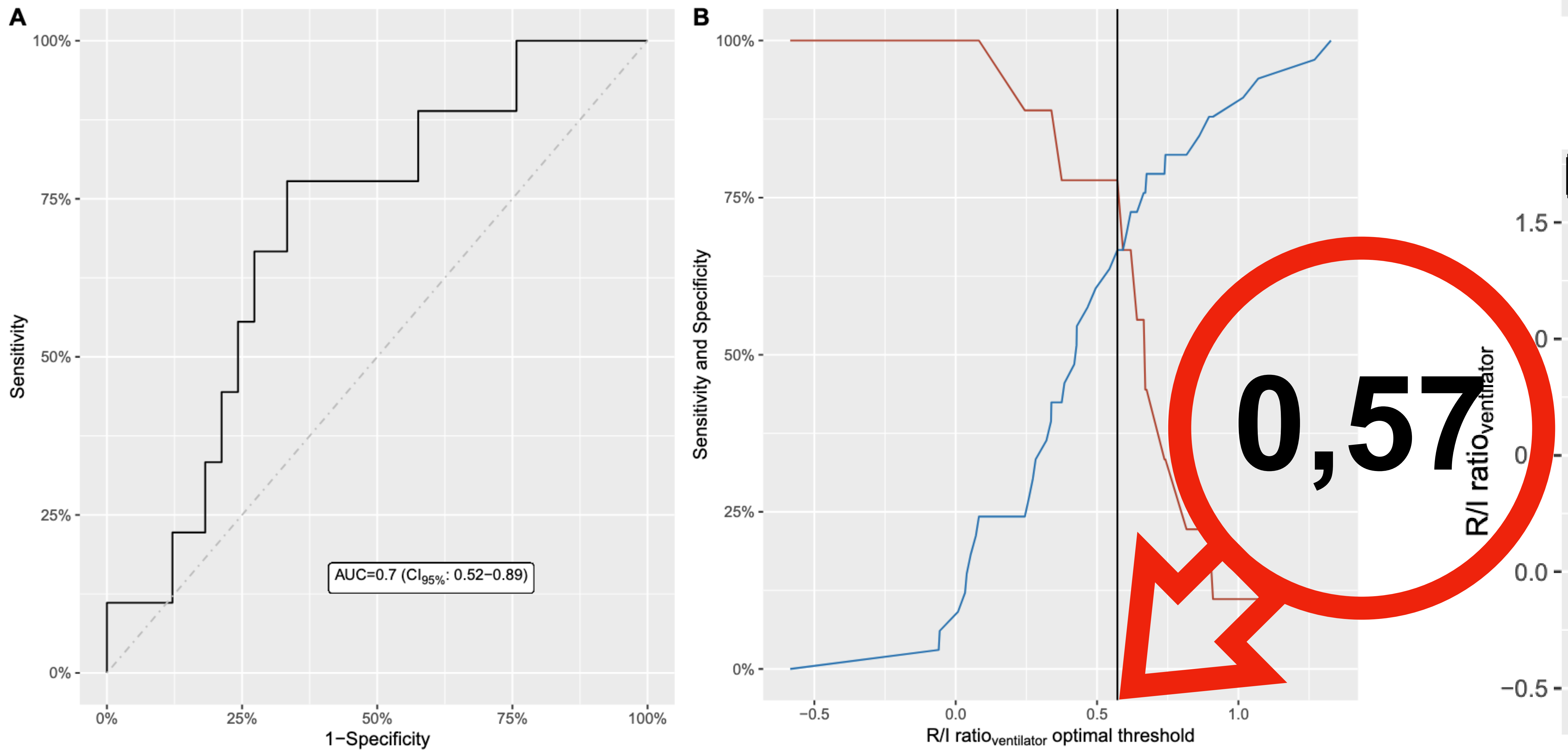
Chen L *et al.* AJRCCM 2020;2:178-187

d'après G.Carteaux . CHU Créteil

RESEARCH Open Access

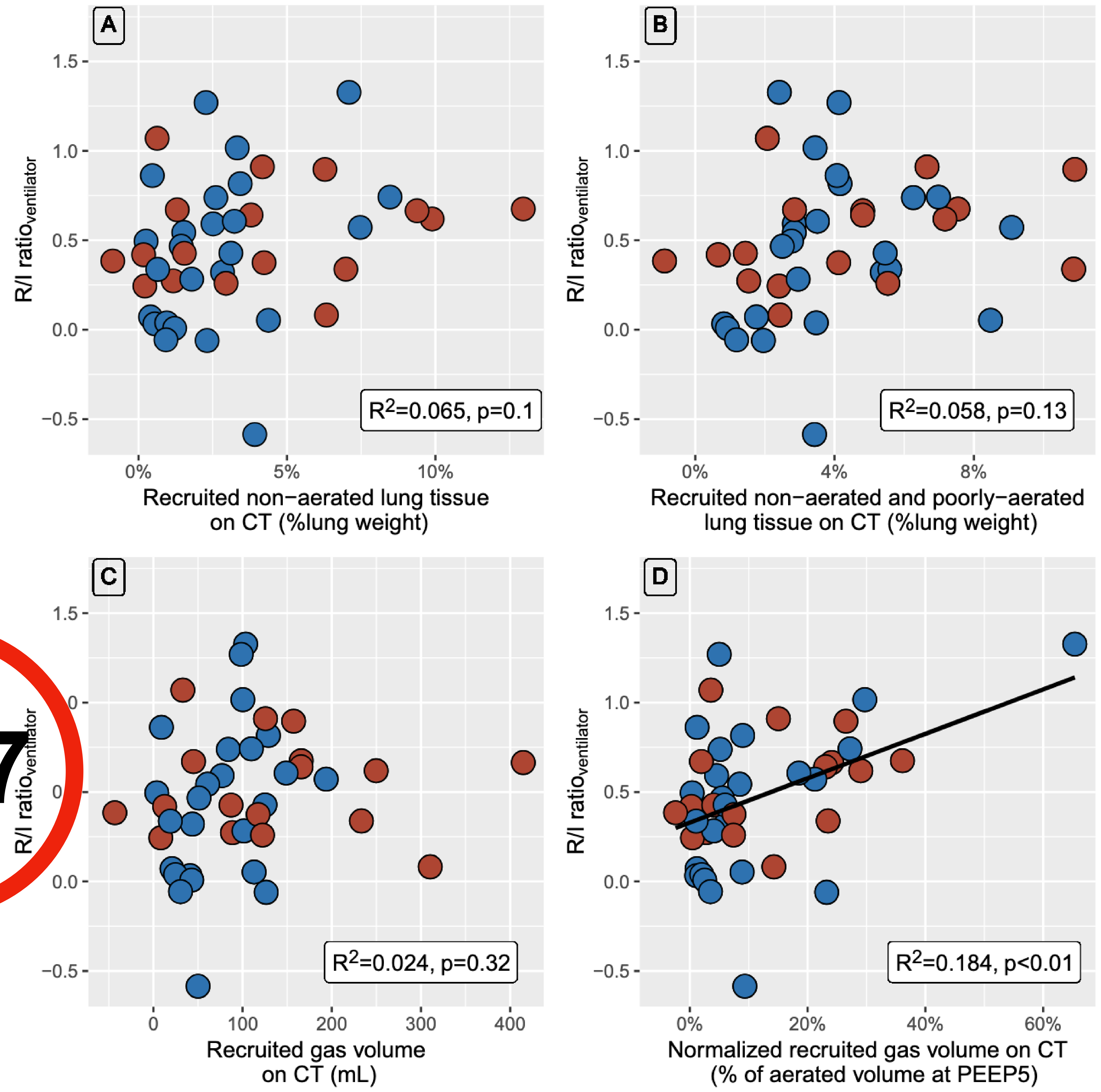
Diagnostic performance of the recruitment-to-inflation ratio to assess lung recruitability by PEEP in ARDS. a computed tomography study

Jean-Christophe Richard[1,2,3*], Francois Dhelft[1,2], Guillaume Deniel[1,2,3], Emmanuel Roux[3], Hodane Yonis[1], Mehdi Mezidi[1], Louis Chauvelot[1], Maxime Gaillet[1,2], Ines Noirot[1], Eduardo Davila[3], Rosalie Schoux[1], Yorick Rodriguez[1,2], Florent Baudin[4,5], Ludmilla Penarrubia[3], Loic Boussel[2,3,6], Maciej Orkisz[3] and Laurent Bitker[1,2,3]



C

Optimal threshold [CI_{95}%]	Sensitivity [CI_{95}%]	Specificity [CI_{95}%]	PLR [CI_{95}%]	NLR [CI_{95}%]
0.57 [0.06−0.67]	0.78 [0.44−1]	0.67 [0.52−0.82]	2.33 [1.2−4.33]	0.33 [0−0.84]



Séquence complète :

Recruitment-to-inflation ratio

- PV curve 5-15: look for airway opening pressure
- Set PEEP at 15 cmH2O or AOP + 10 cmH2O
- Drop PEEP to 5 cmH2O or AOP and measure expired volume
- Calculate the ΔEELV as expired volume –VT
- Calculate volume recruited as ΔEELV – (10x Cstat at low PEEP)
- Calculate the compliance of the volume recruited as volume recruited /10
- Calculate the compliance at 5 cmH2O or AOP
- R/I ratio: Recruitment compliance / compliance at PEEP 5 or AOP

- **Chen. Am J Respir Crit Care Med 2019**

SDRApps

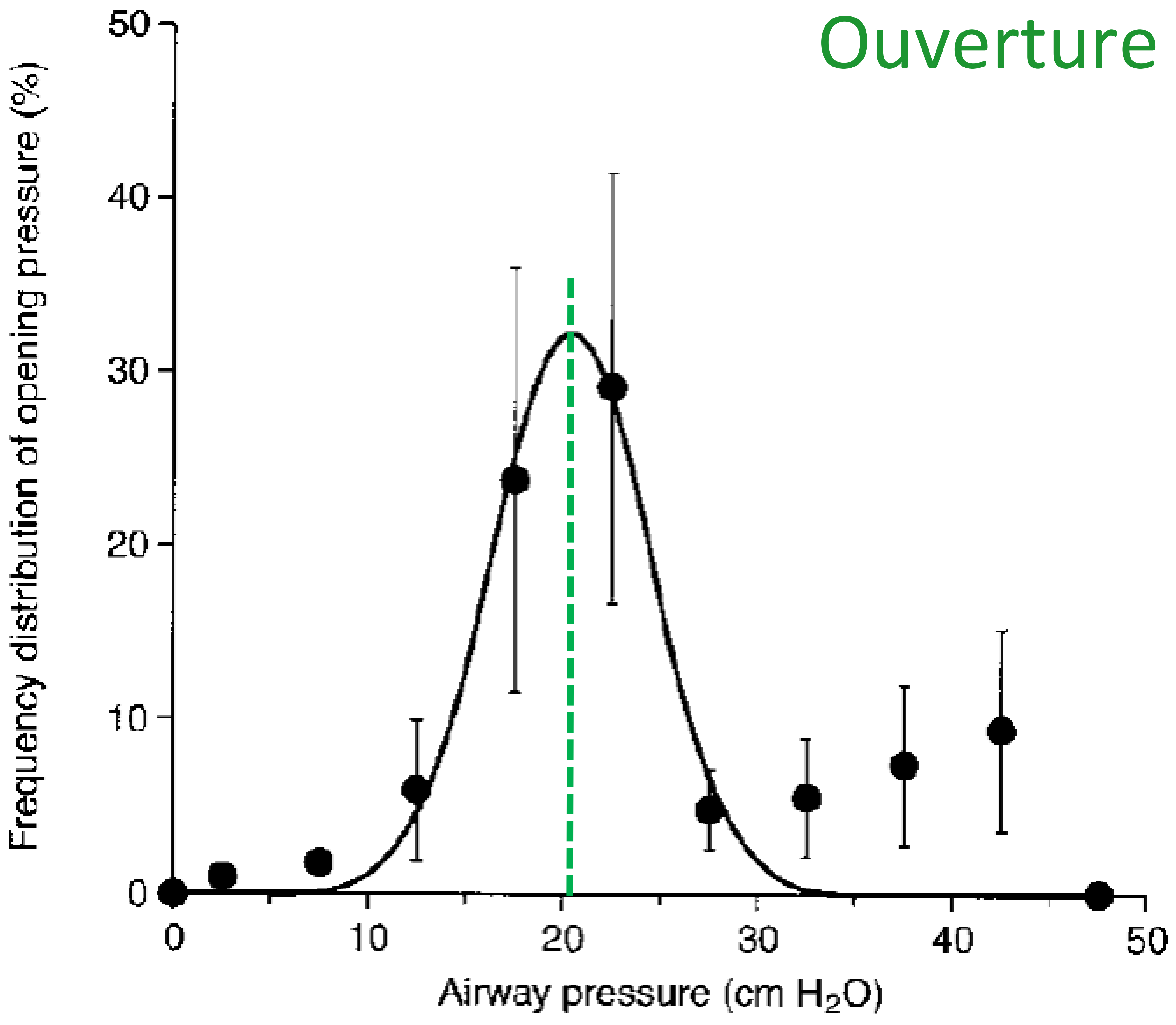
SDRApps est une application d'aide à la prise en charge du syndrome de détresse respiratoire aiguë

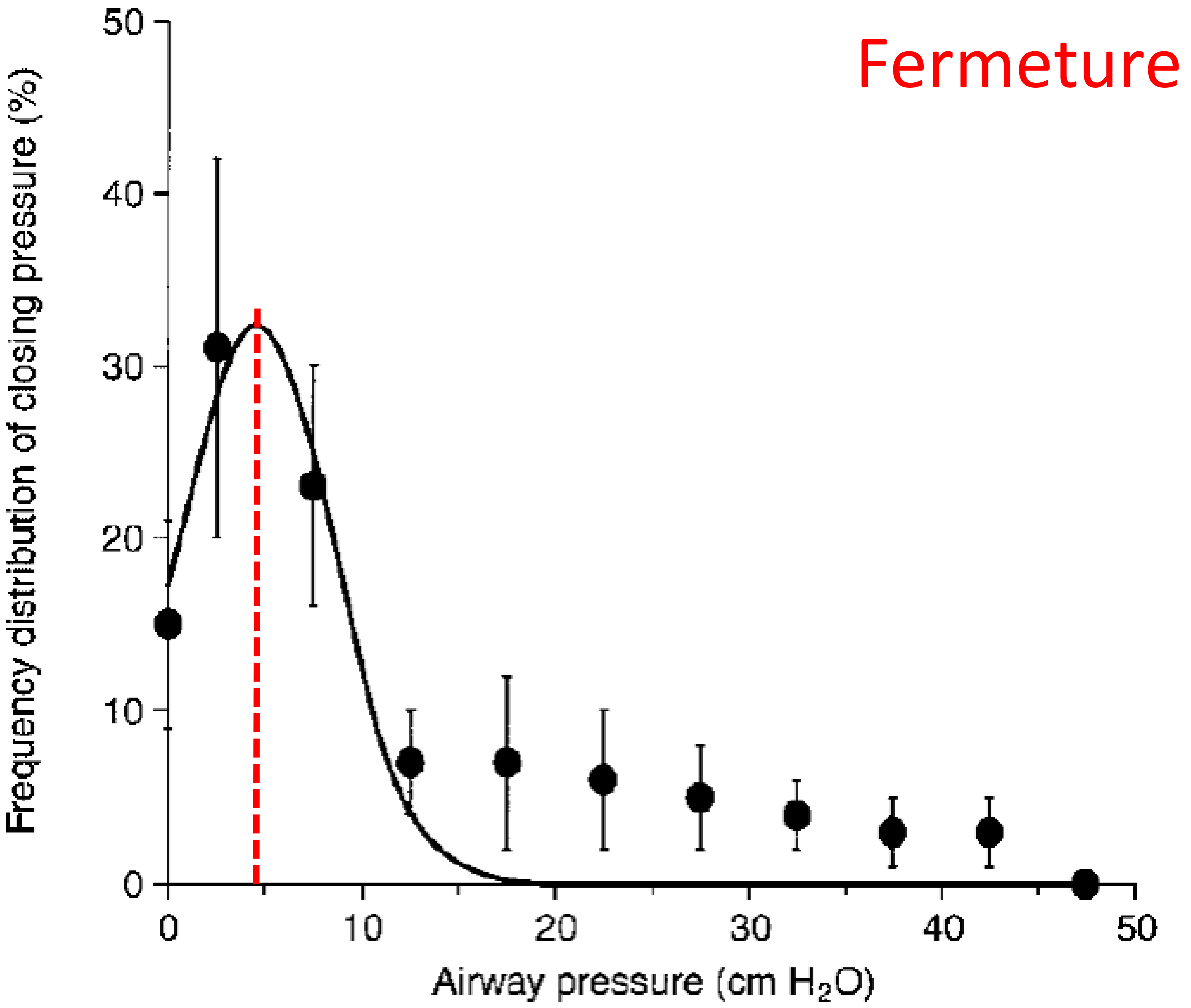
Accéder à l'application


R/I RATIO
Paramètres affichés
Vt
mL
PEP haute
cmH_2O
PEP basse
cmH_2O
Paramètres mesurés
Vt expiré à haute PEP
mL
Vt expiré à basse PEP
mL
Pplat à basse PEP
cmH_2O
Effacer les données
Terminer

TEST DE RUCRUTABILITE PAR DISTANCE MAXIMALE NORMALISEE (DMN)

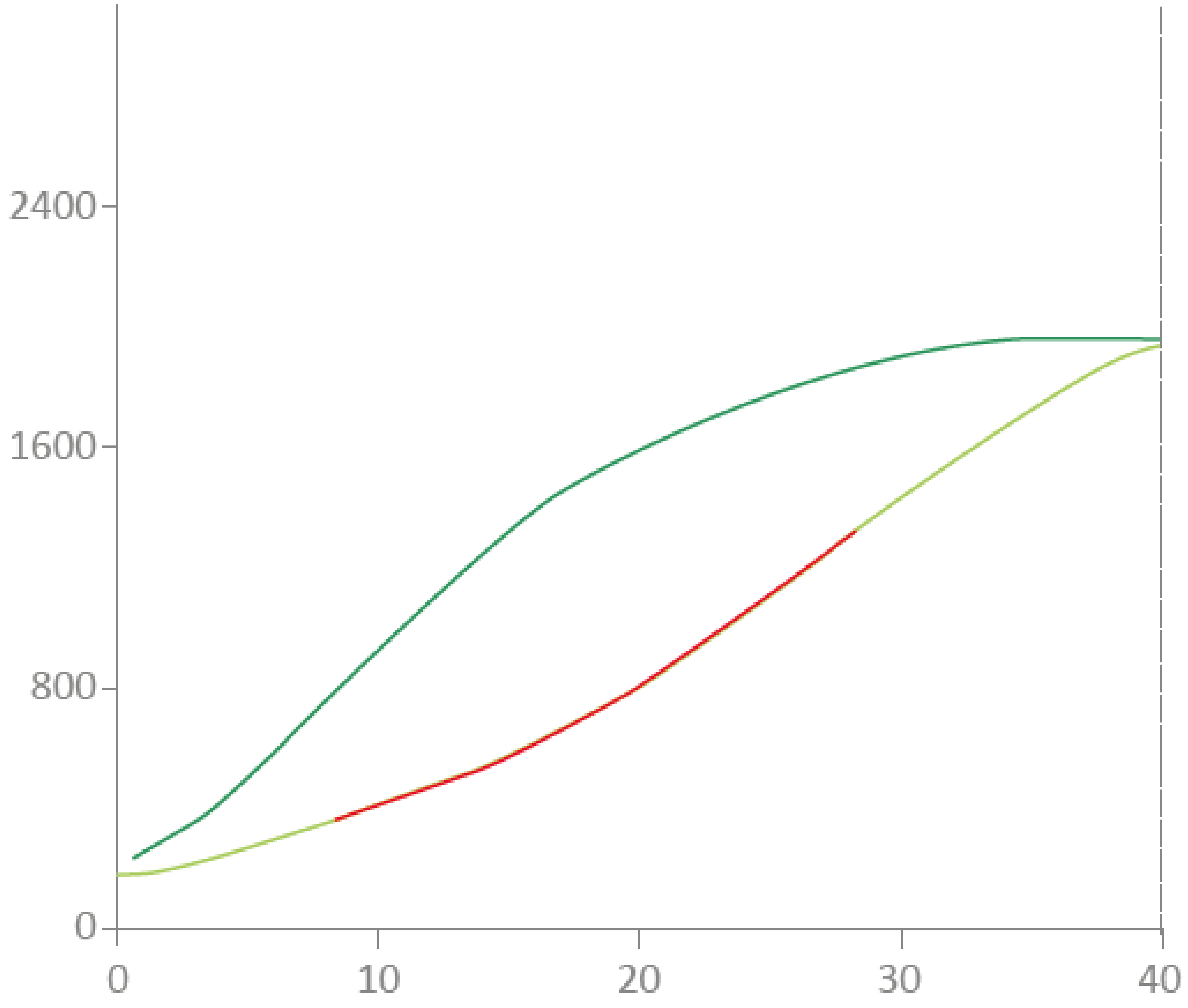
Hystérésis - Pression d'ouverture et de fermeture chez des patients SDRA

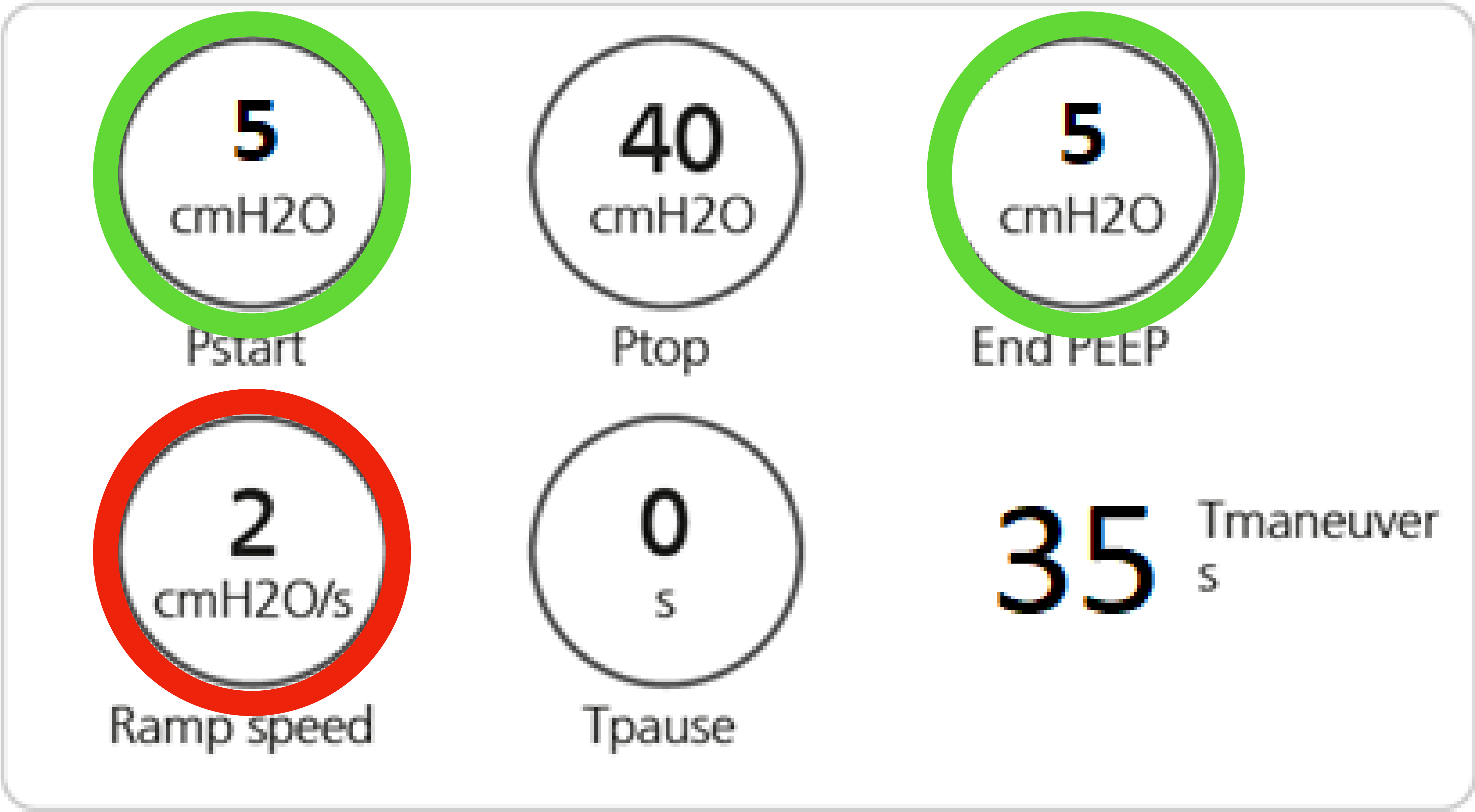




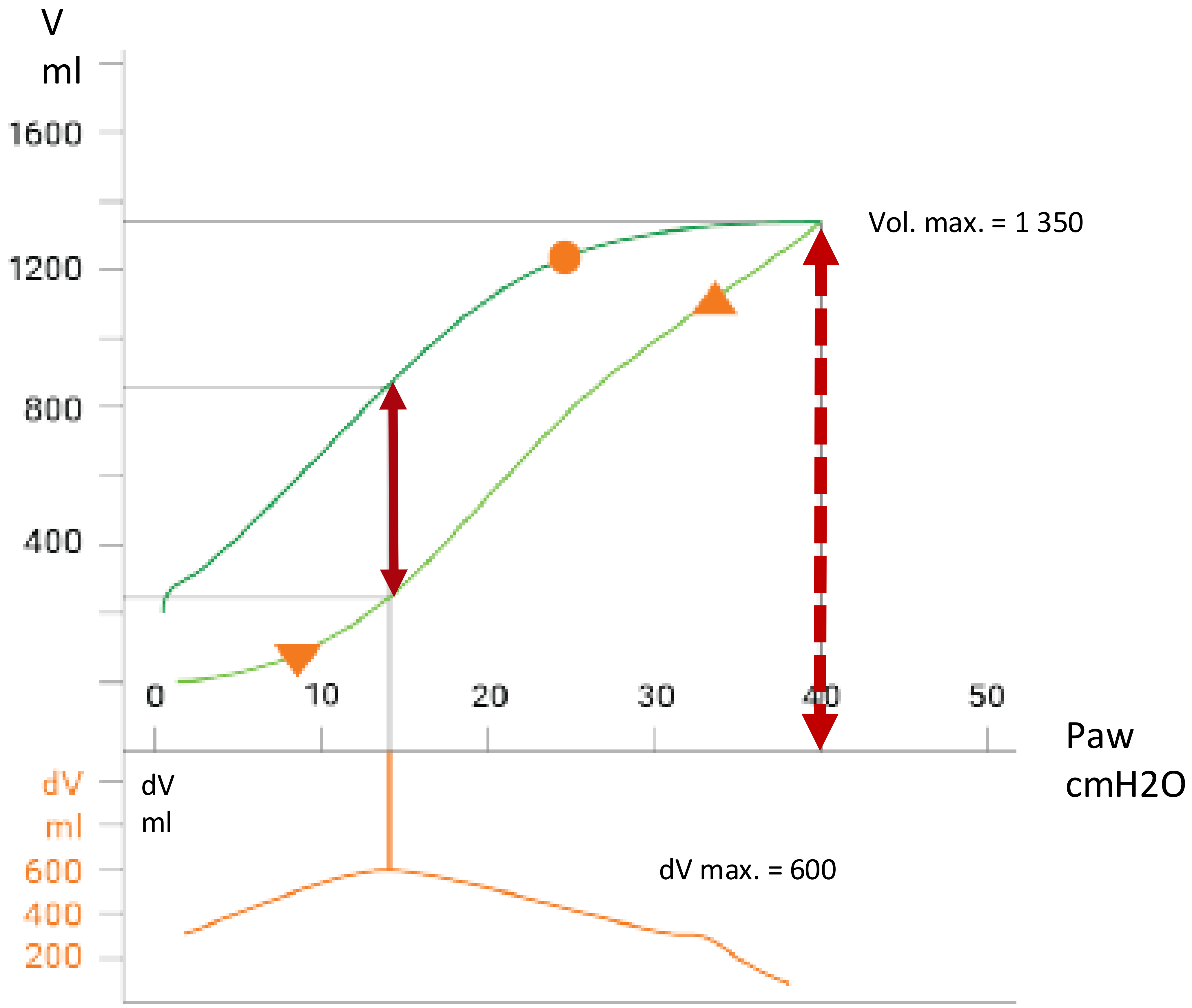
Crotti. Am J Respir Crit Care Med Vol 164. pp 131–140, 2001

Initiation : générer une courbe P/V à faible débit et à pression contrôlée





Analyse de la courbe P/V



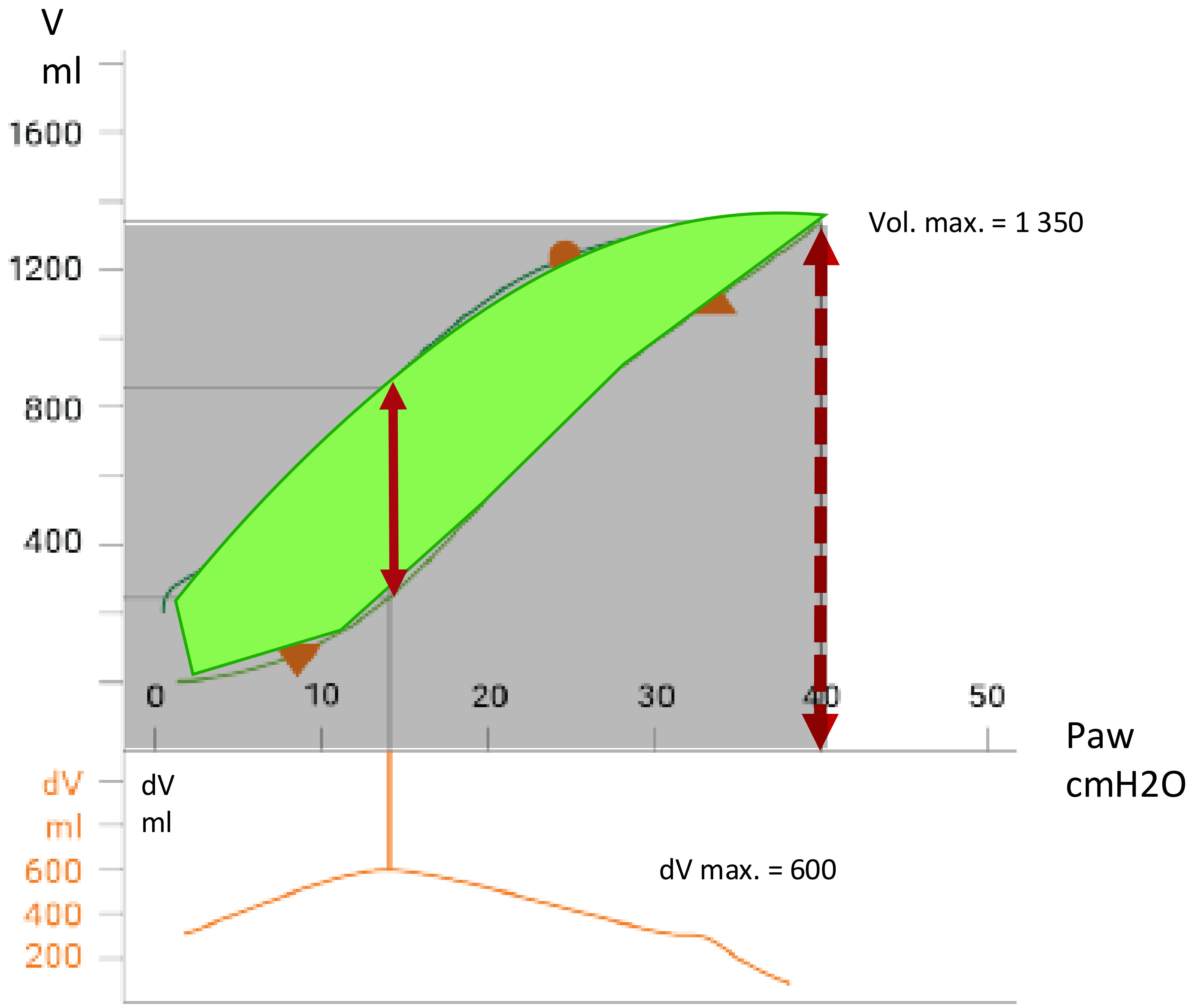
Distance maximale entre l'insufflation et l'expiration (ml)

Volume maximal (ml)

Distance maximale normalisée (%) =

Chiumello. Crit Care Med 2020

Analyse de la courbe P/V



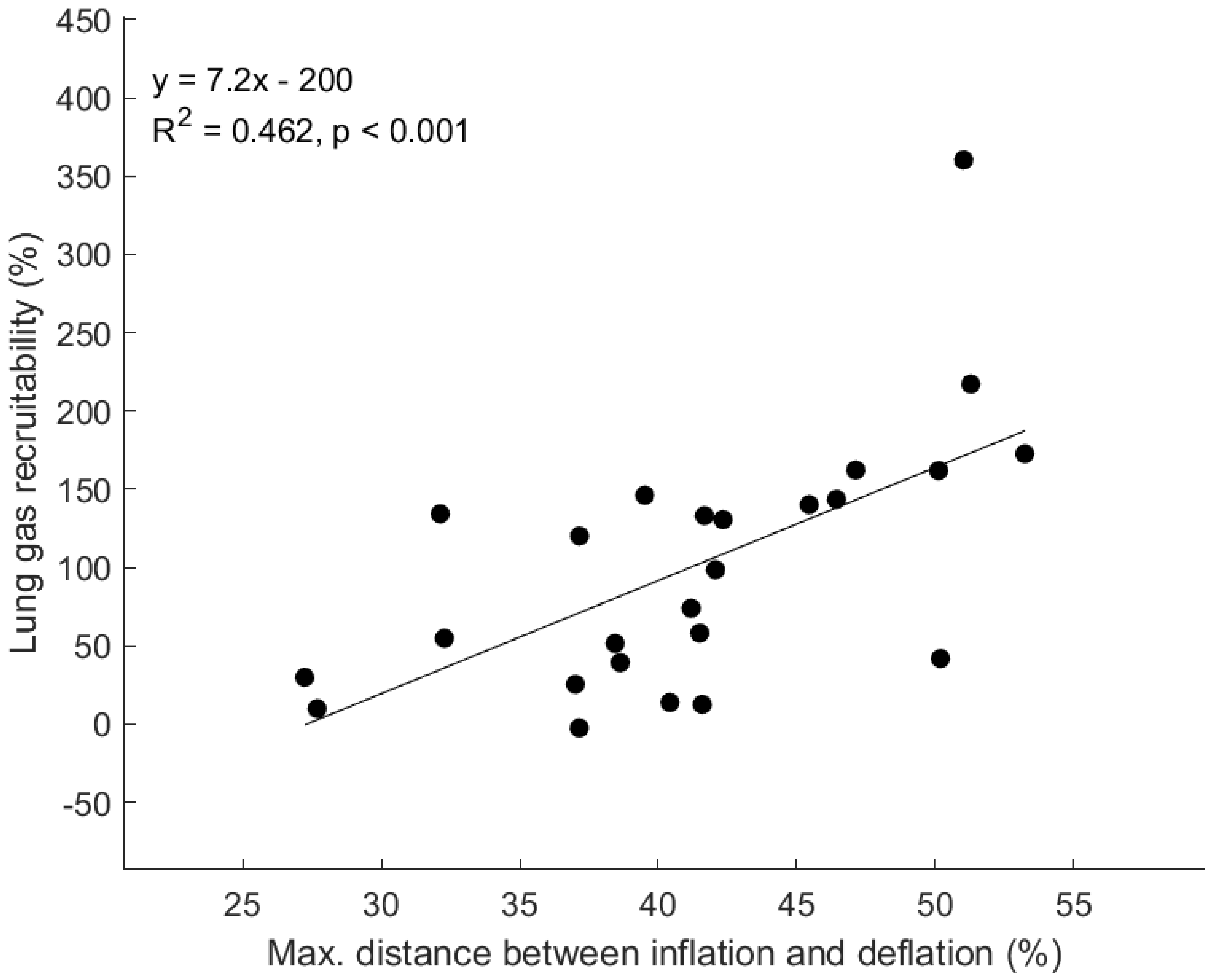
Distance maximale entre l'insufflation et l'expiration (ml)

Volume maximal (ml)

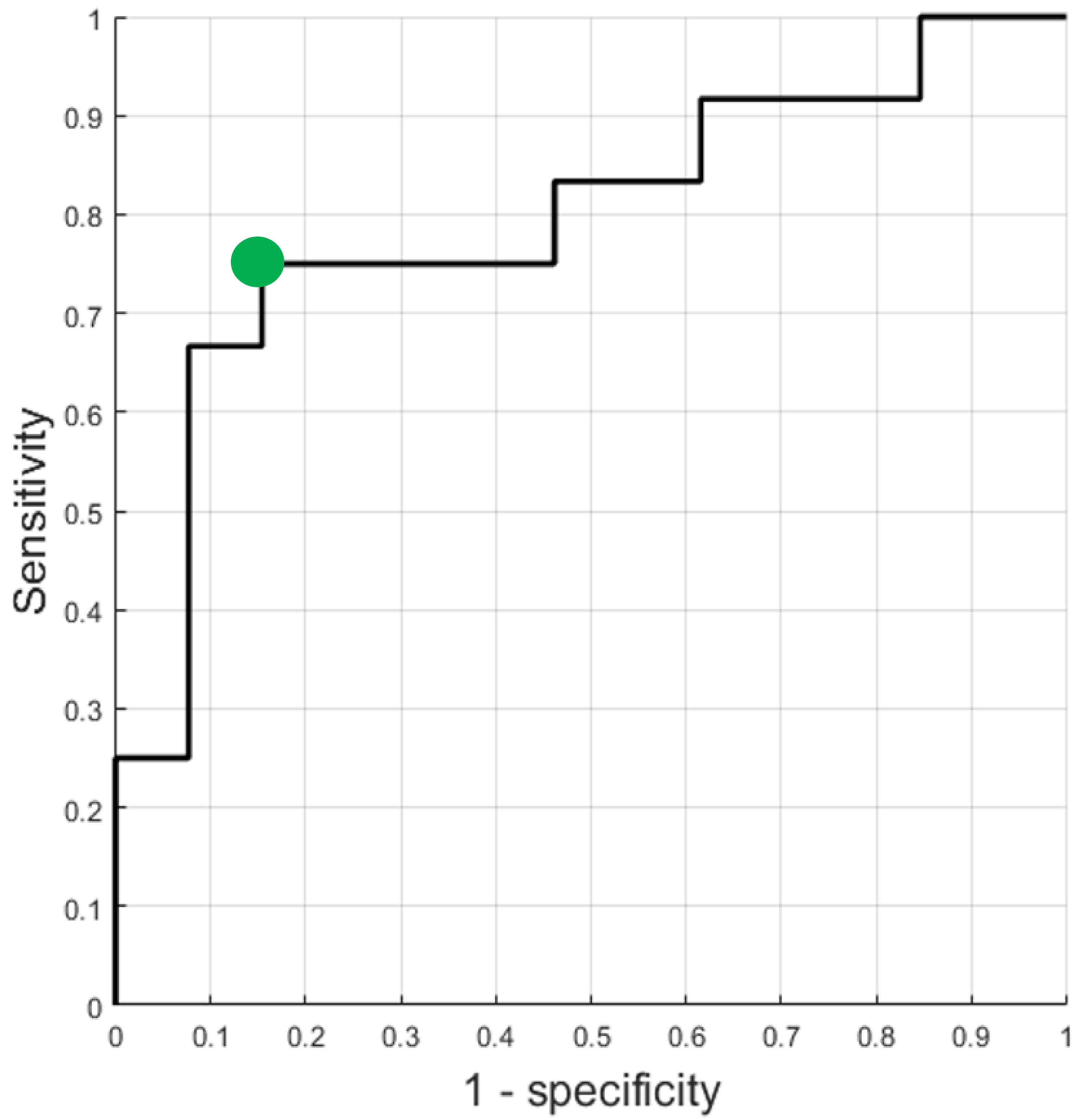
Distance maximale normalisée (%) =

Chiumello. Crit Care Med 2020

P/V vs tomodensitométrie : distance maximale normalisée



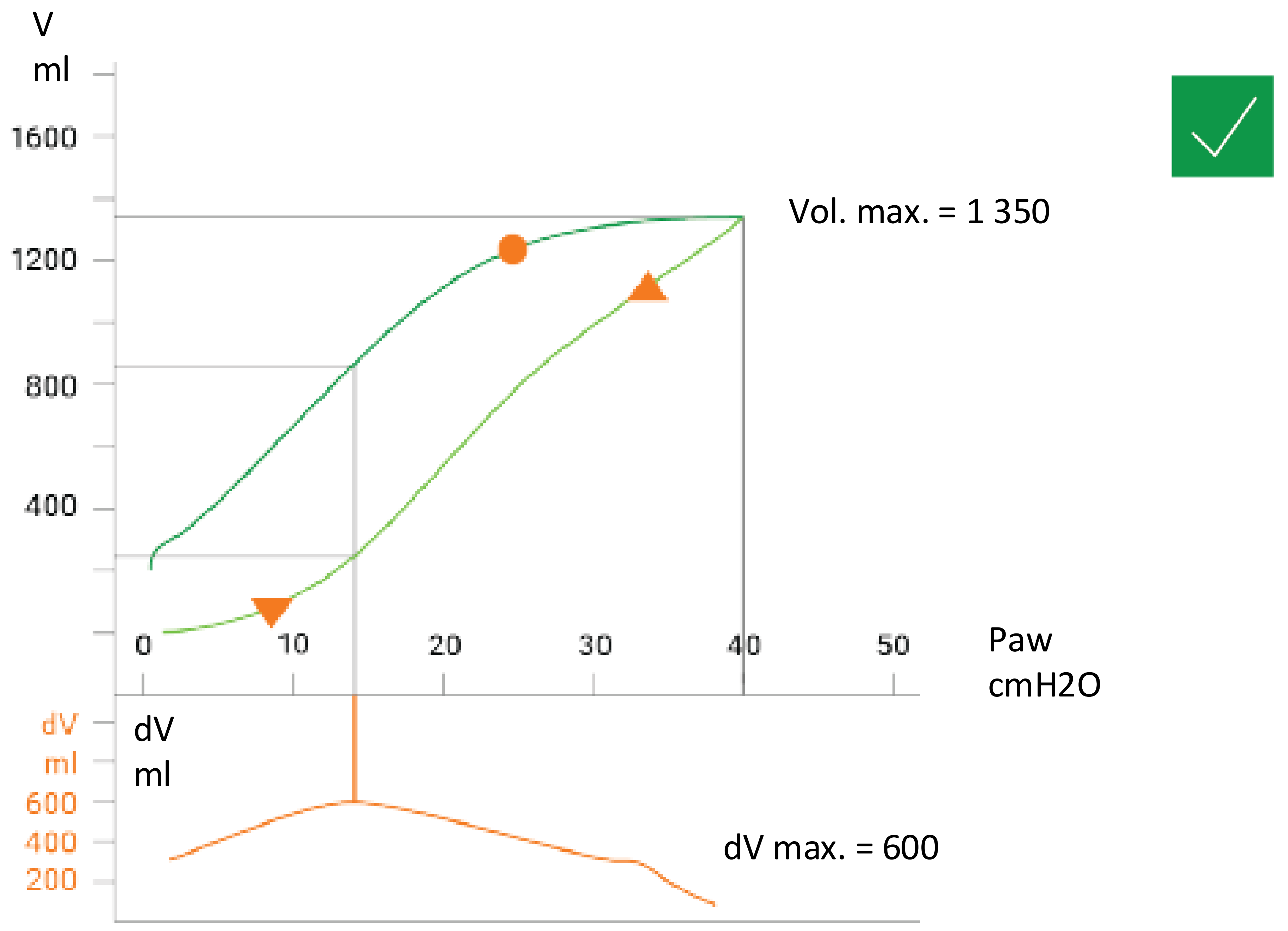
Max. distance between inflation and deflation (%)

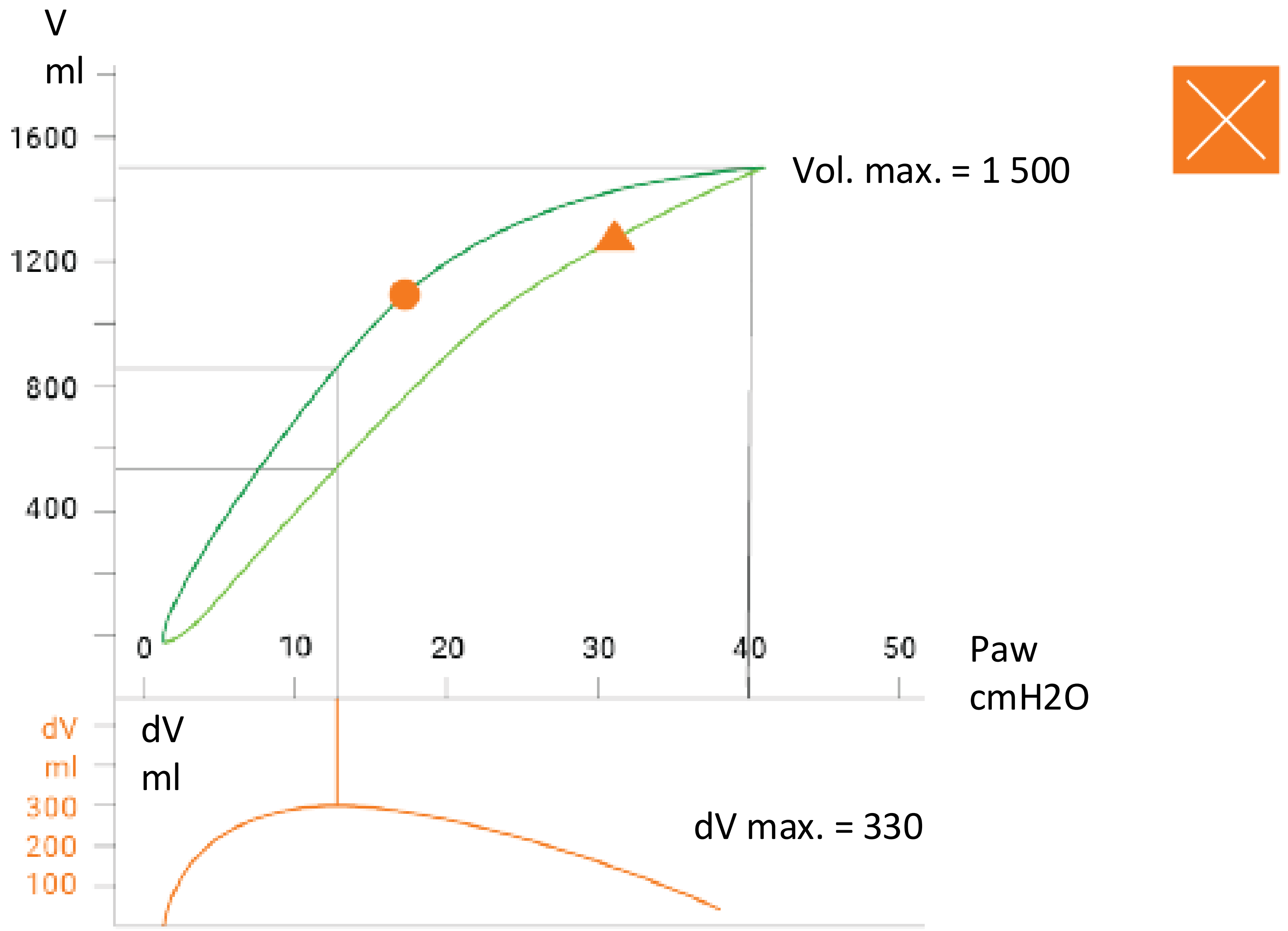


Seuil : distance maximale = 41 %

Chiumello. Crit Care Med 2020

Évaluation : DMN % >< 41 % ?



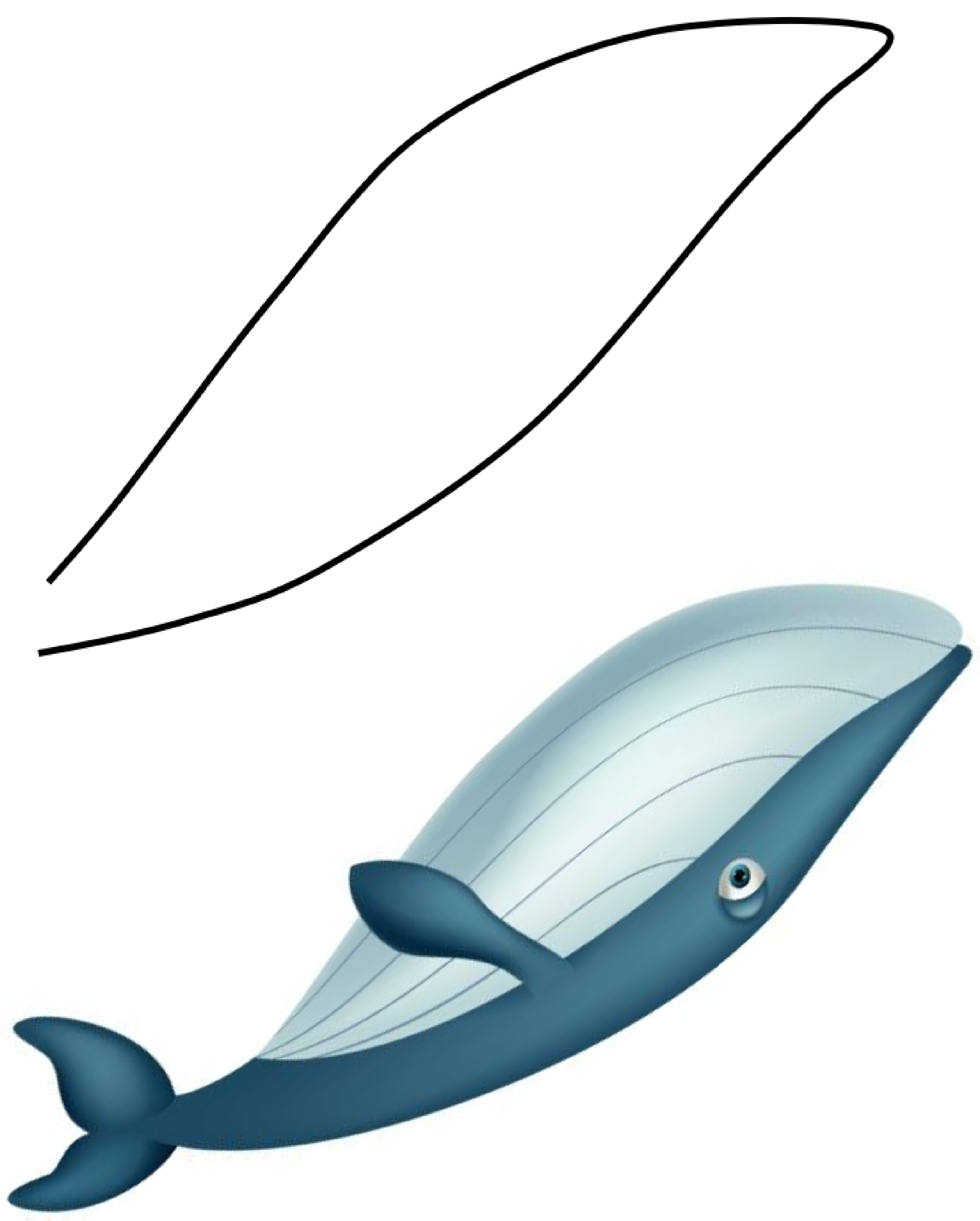


$$\text{DMN \%} = \frac{\text{Distance maximale entre l'insufflation et l'expiration}}{\text{Volume maximal}} = \frac{600}{1\,350}$$

DMN % = 44 % = Fort potentiel de recrutement

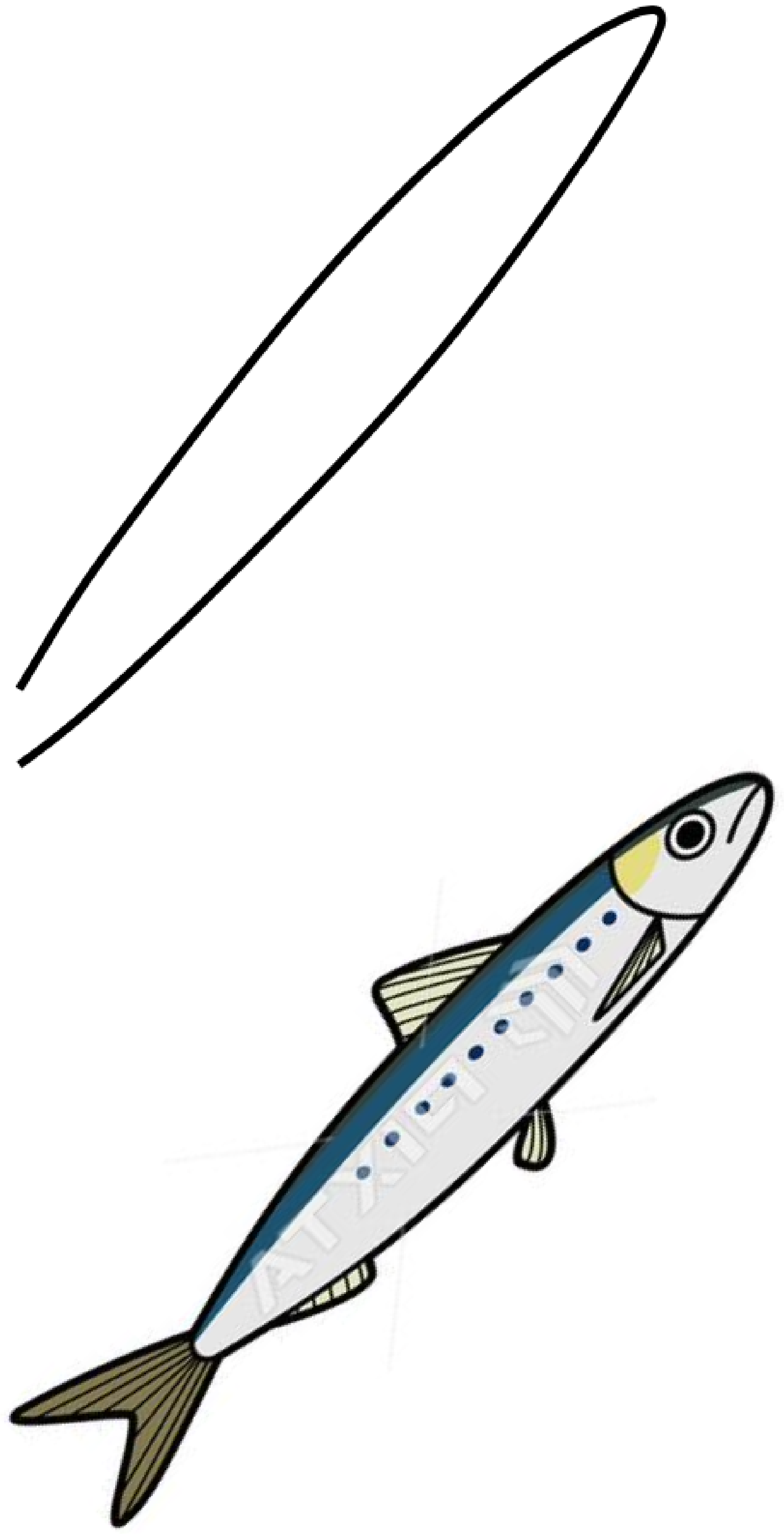
$$\text{DMN \%} = \frac{\text{Distance maximale entre l'insufflation et l'expiration}}{\text{Volume maximal}} = \frac{330}{1\,500}$$

DMN % = 22 % = Faible potentiel de recrutement high recruitability



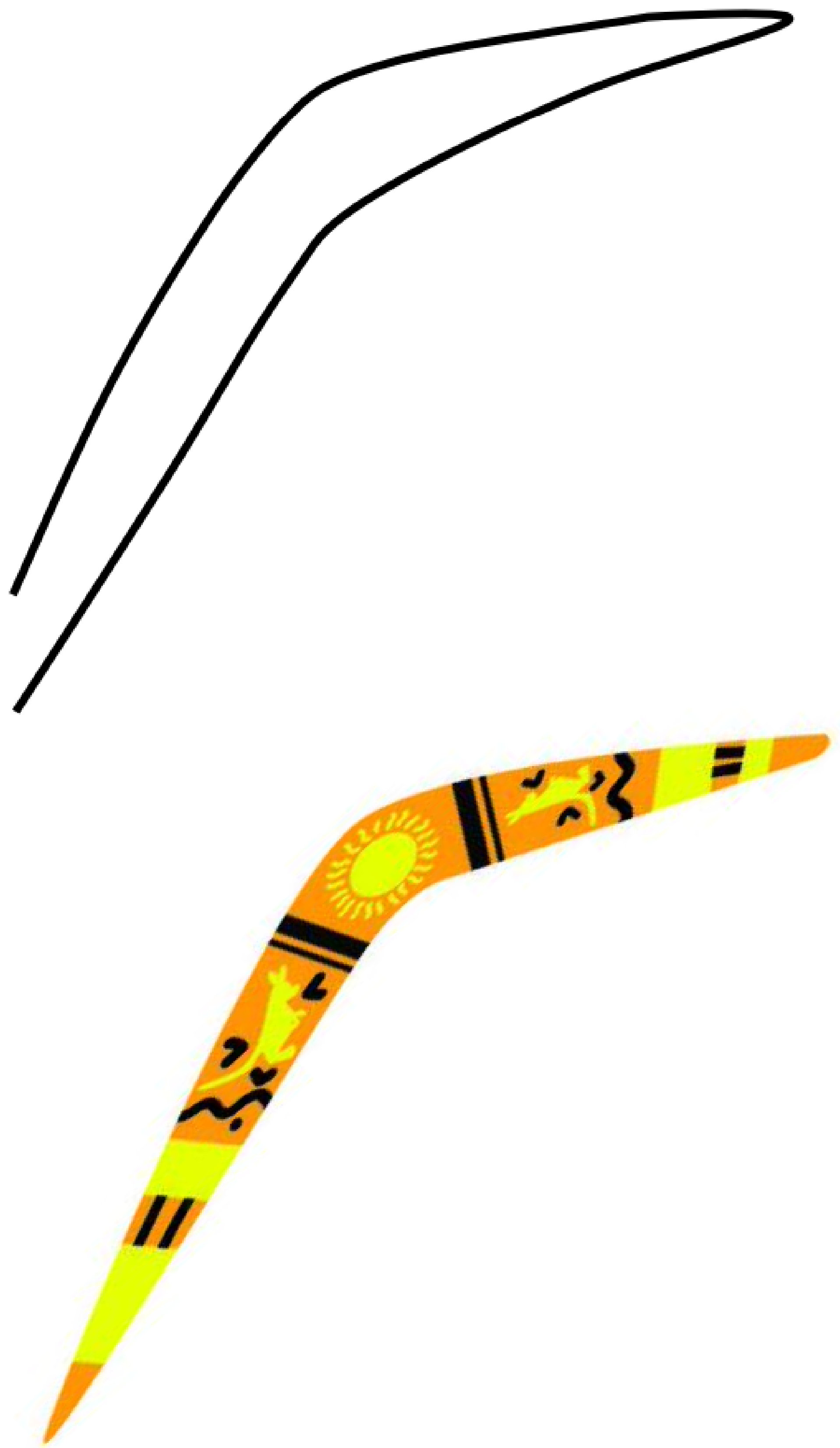
the Whale

low recruitability



the Sardine

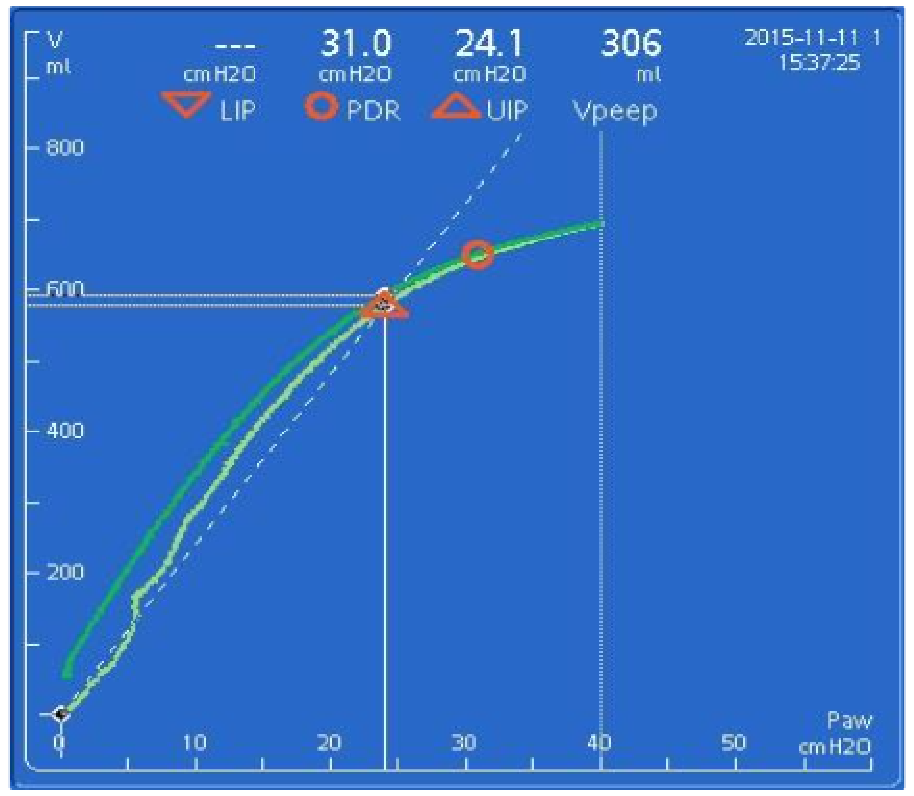
lung overdistention



the Boomerang

With courtesy of F.Mojoli

asses recruitability



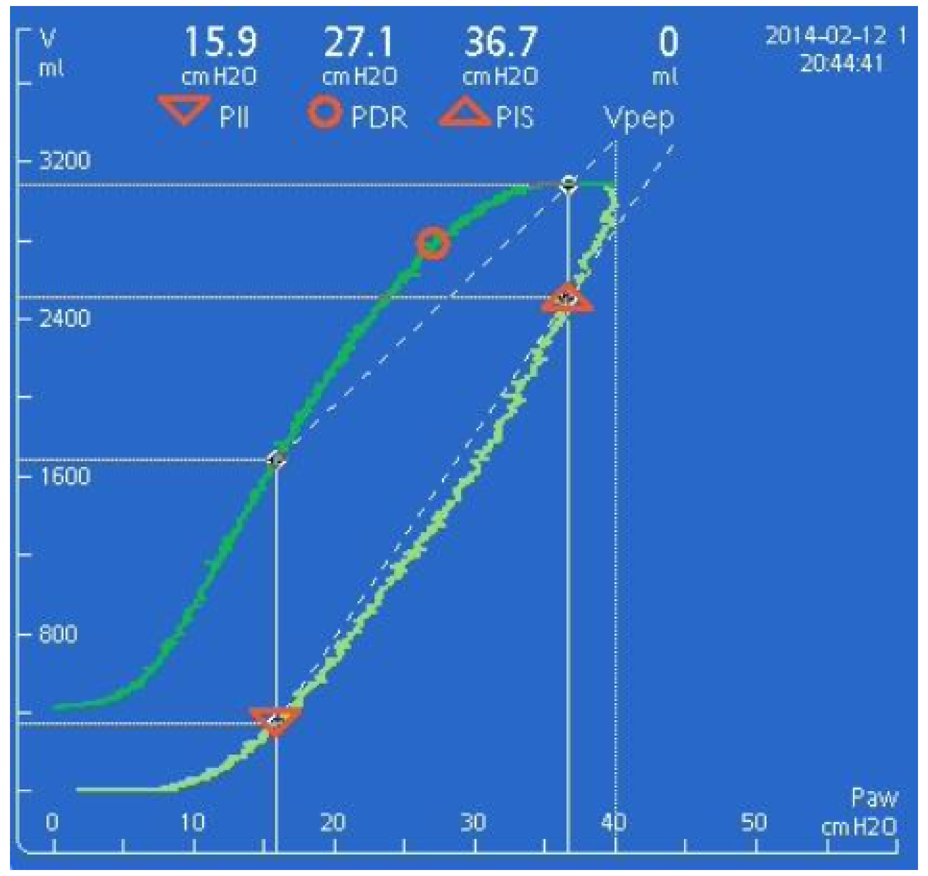
low potential

NO recruitment maneuver

set PEEP = 5-8 cmH_2O

high potential

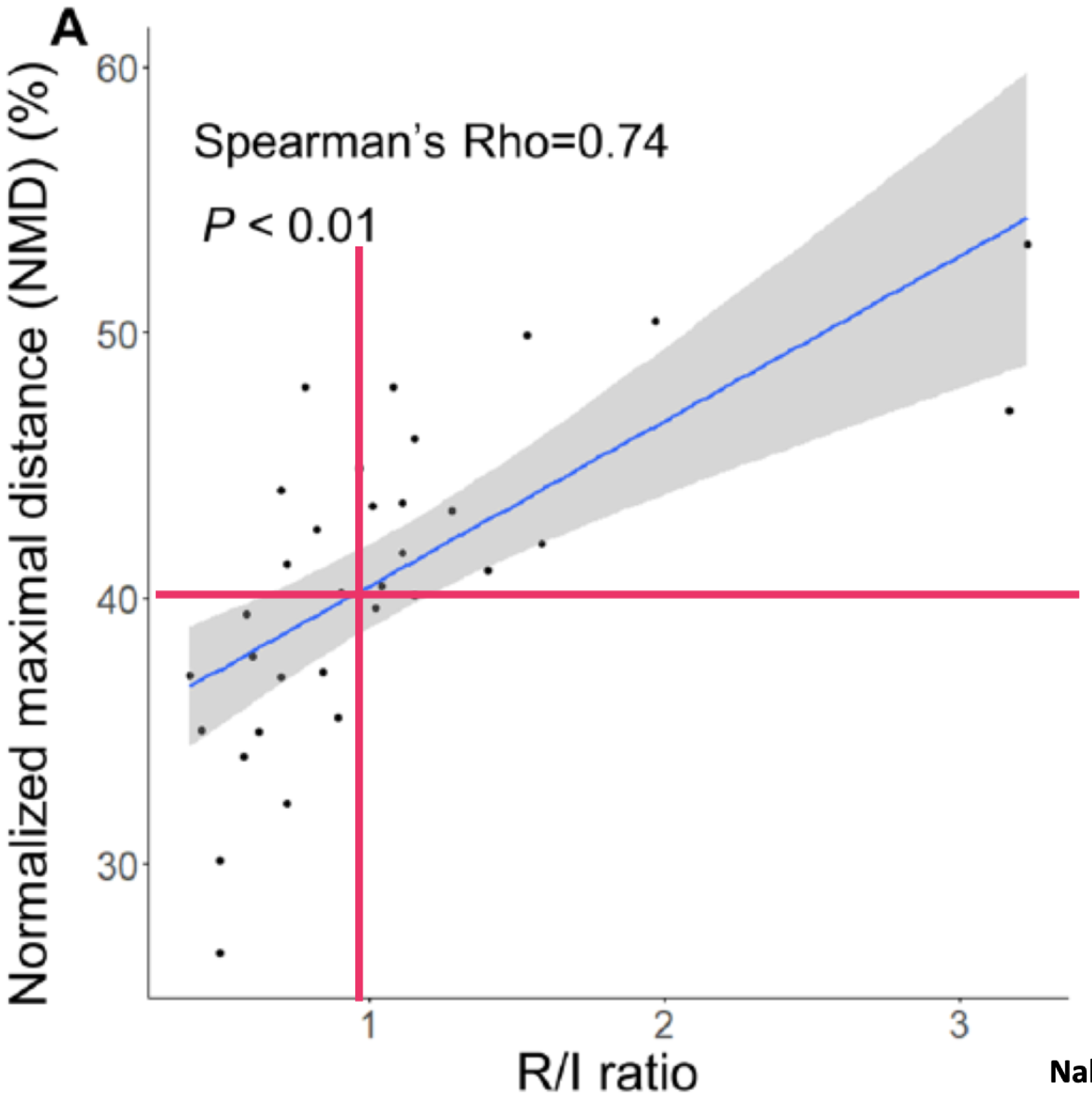
recruitment maneuver + PEEP titration



5 -15

Recruitment-to-inflation ratio and hysteresis

33 severe COVID-19 ARDS patients



Nakayama. Annals of Intensive Care 2022

Méthode par dilution de l’Azote (multiple-breaths nitrogen washin–washout MBNW)

RESEARCH ARTICLES Open Access

Validation of a novel system to assess end-expiratory lung volume and alveolar recruitment in an ARDS model

Laurent Bitker[1,2], Nadja Cristinne Carvalho[3], Sascha Reidt[3], Christoph Schranz[3], Dominik Novotni[3], Maciej Orkisz[2], Eduardo Davila Serrano[2], Jean-Pierre Revelly[3] and Jean-Christophe Richard[1,2*]

$$EELV_{MBNW} = \frac{\text{Cumulative}\Delta\text{N2volume}}{\Delta\text{N2fraction}}.$$

VS

$$Vrec_{CT} = \frac{Vtis_{PEEPn} - Vtis_{PEEPn+1}}{1 - Fgas_{PEEPn}} \bullet Fgas_{PEEPn},$$

Bitker *et al. ICMx* (2021) 9:46
https://doi.org/10.1186/s40635-021-00410-x

Intensive Care Medicine Experimental

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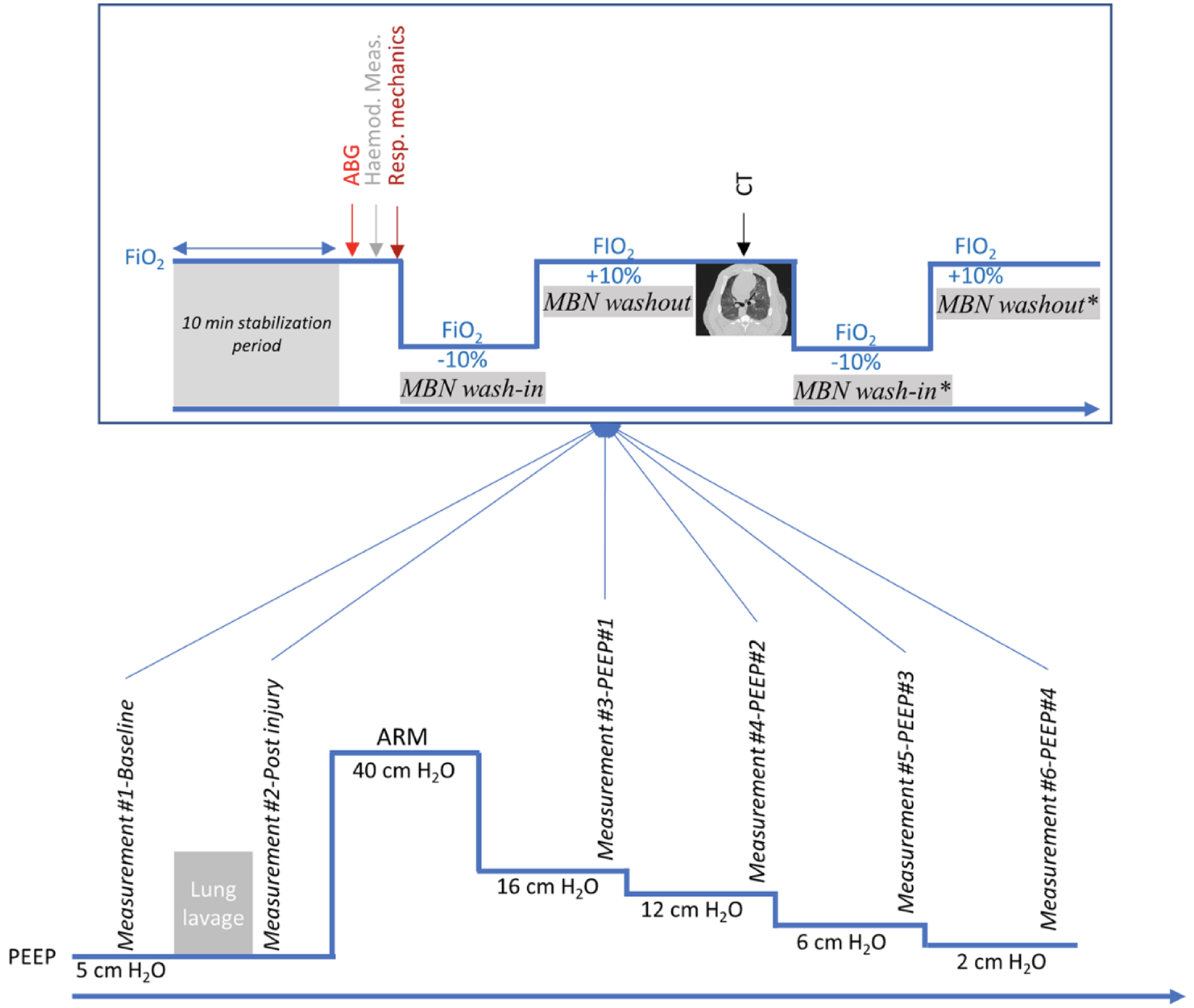

Fig. 1 Experimental protocol. *ABG* arterial blood gas, *ARM* alveolar recruitment maneuver, *CT* computed tomography, *FiO$_2$* fraction of inspired oxygen, *Hemod. Meas.* hemodynamic measurements, *MBN* multiple breath nitrogen, *PEEP* positive end-expiratory pressure; *Resp. mechanics* respiratory mechanics measurements. * refers to MBNW replicates performed in all experimental conditions on 5 pigs of the study

Bitker *et al. ICMx* (2021) 9:46
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Intensive Care Medicine Experimental

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Maciej Orkisz[2], Eduardo Davila Serrano[2], Jean-Pierre Revelly[3] and Jean-Christoph

- **Biais non constant entre les méthodes. Tendance à des valeurs plus négatives à mesure que la EELV augmentait avec la PEEP.**

- **Biais entre les méthodes ± 86 mL**
- **Erreur entre les deux méthodes 13,7 %.**

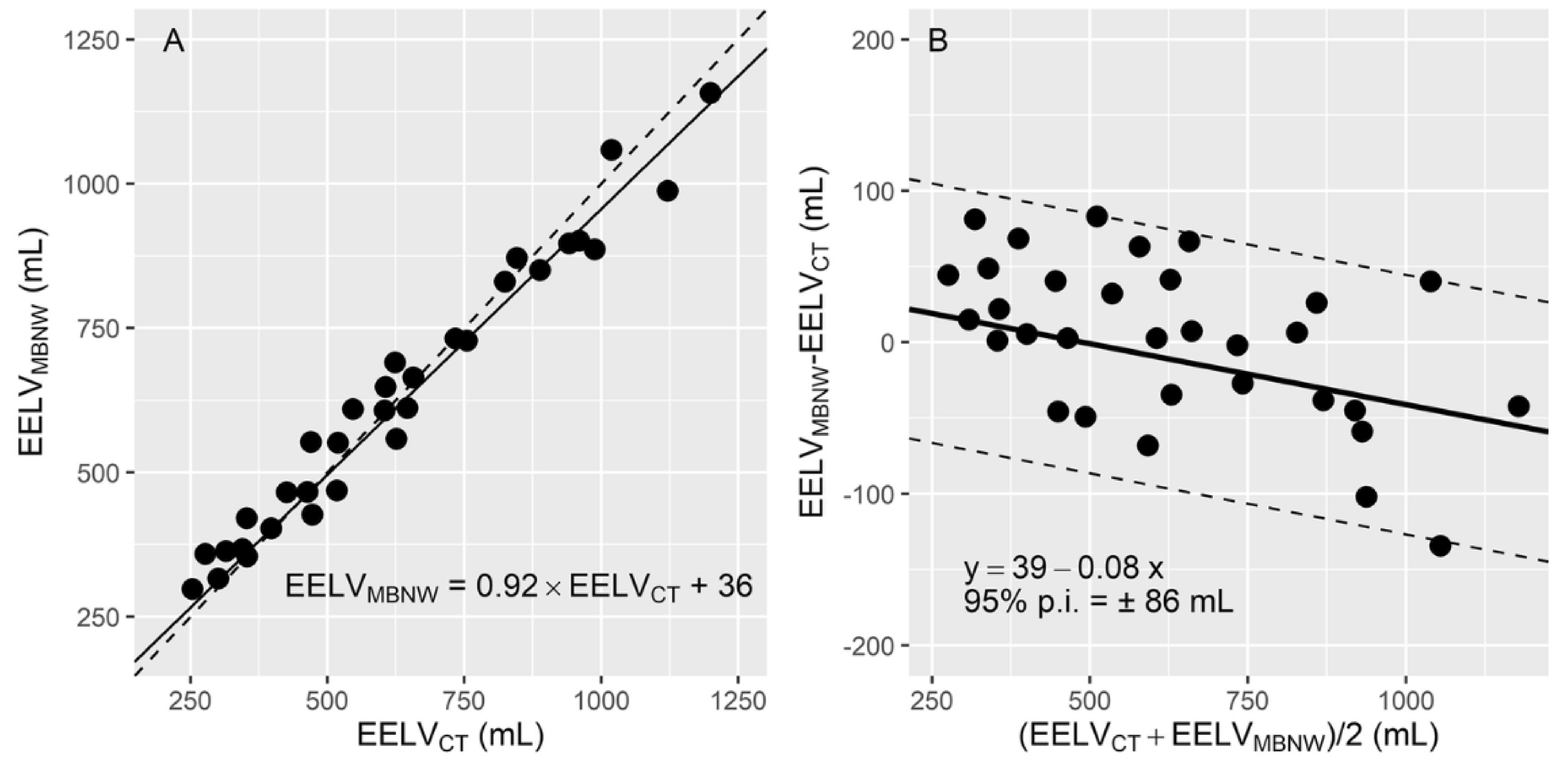

Fig. 2 Correlation between $EELV_{MBNW}$ and $EELV_{CT}$ (**A**) and corresponding Bland and Altman plot (**B**). Each symbol represents a concomitant measurement of end-expiratory lung volume assessed with the multi-breath nitrogen washin–washout technique ($EELV_{MBNW}$) and computed tomography ($EELV_{CT}$). **A** Solid line is regression line. Dashed line is line of identity. **B** continuous line and the 2 broken lines are the mean bias and 95% prediction interval limits of the bias between methods, respectively. 95% p.i. = 95% prediction interval of the bias between methods

Bitker *et al. ICMx* *(2021) 9:46*
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Intensive Care Medicine Experimental

Conclusions:

- CT méthode de référence
- Avec respirateur + « accessible »
- Limites

Merci

Conclusions:

- CT méthode de référence
- Avec respirateur + « accessible »
- Limites