

Electrical Impedance Tomography ; New Marker for Lung Protective Strategy in ARDS?

Department of Intensive Care Medicine

Department of Pulmonology

Dong Hyun, LEE

Conflict of Interest



- Drager Korea
 - Pulmovista 500: Free demonstration (2 months)
 - EIT analysis software (EIT analysis tool 6.3)
 - Savina 300 Ventilator: Free demonstration (2 months)
- Planned to equip additional mechanical ventilator (4)

Electrical Impedance Tomography



전기

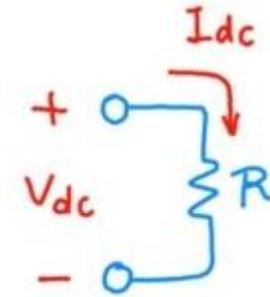
임피던스?

단층촬영

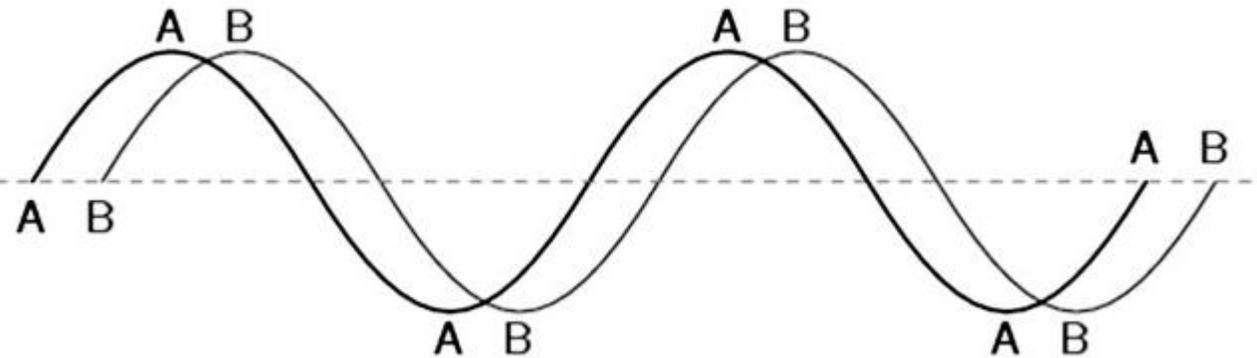
온저항(impedance 임피던스)은 회로에서 전압이 가해졌을 때 전류의 흐름을 방해하는 값이다. 임피던스의 값은 교류 회로의 전압과 전류의 비로 나타낼 수 있으며, 일반적으로 교류 전압의 진동수에 의존한다. 교류 회로에서 임피던스는 저항 개념의 확장인데, 크기값만 갖는 저항과 달리 크기와 위상의 값을 갖는다. 직류 회로에서는 임피던스와 저항이 같은데, 이는 임피던스의 위상각이 0이라 생각하면 된다. 전기 회로망에서 교류 회로를 분석할 때 임피던스가 자주 사용되는데, 임피던스를 이용하면 삼각함수의 형태를 갖는 전압과 전류의 관계를 직선으로 나타낼 수 있기 때문이다.

임피던스는 복소수로 표시되며, 국제단위계에서 단위는 옴(Ω)이다. 임피던스의 기호는 보통 Z 로 나타내며, 크기와 위상각을 함께 나타낼 때에는 $|Z| \angle \theta$ 의 형태로 나타낼 수 있다. 보통 복소평면에 나타내는 바버이 히르르 브서하 때 가자 마이 쓰인다. 직류회로의 전기저항과는 달리 온항이 크다고 단정지을 수는 없다. 서로 온항을 같게 해주는 것이 원칙이다.

임피던스의 역수는 어드미턴스로, 국제단



$$R = \frac{V_{dc}}{I_{dc}}$$



Electrical Impedance Tomography



전기

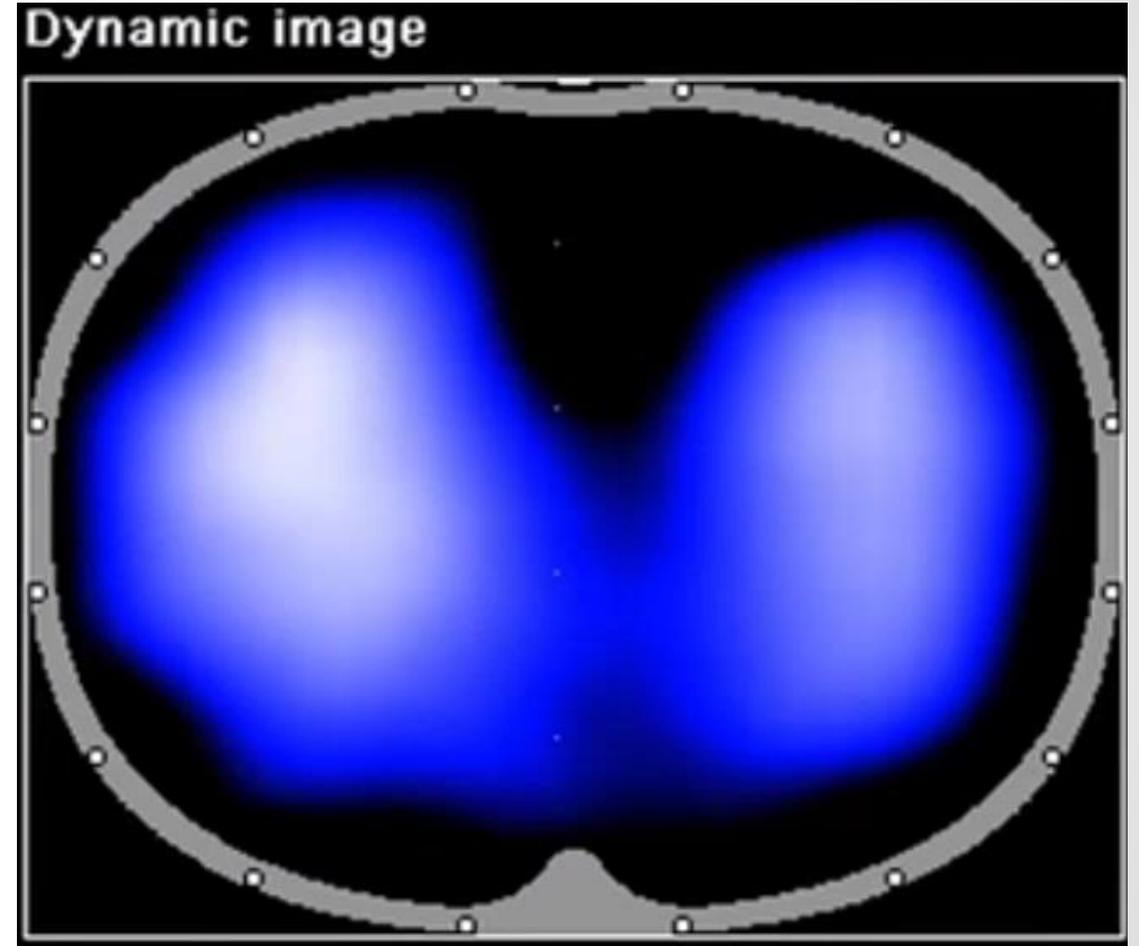
임피던스?

단층촬영

임피던스 (Impedance)

- 저항 (비슷한 것)
- 교류의 저항

Electrical Impedance Tomography



Electrical Impedance Tomography



Clin. Phys. Physiol. Meas., 1985, Vol. 6, No. 2, 109-121. Printed in Great Britain

Applied potential tomography: possible clinical applications

B H Brown, D C Barber and A D Seagar

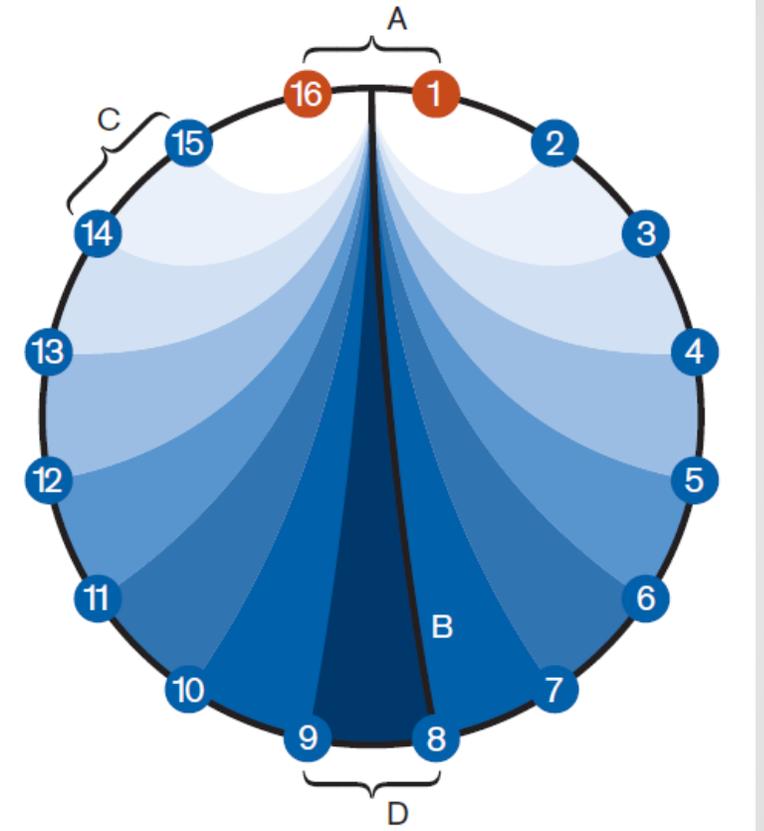
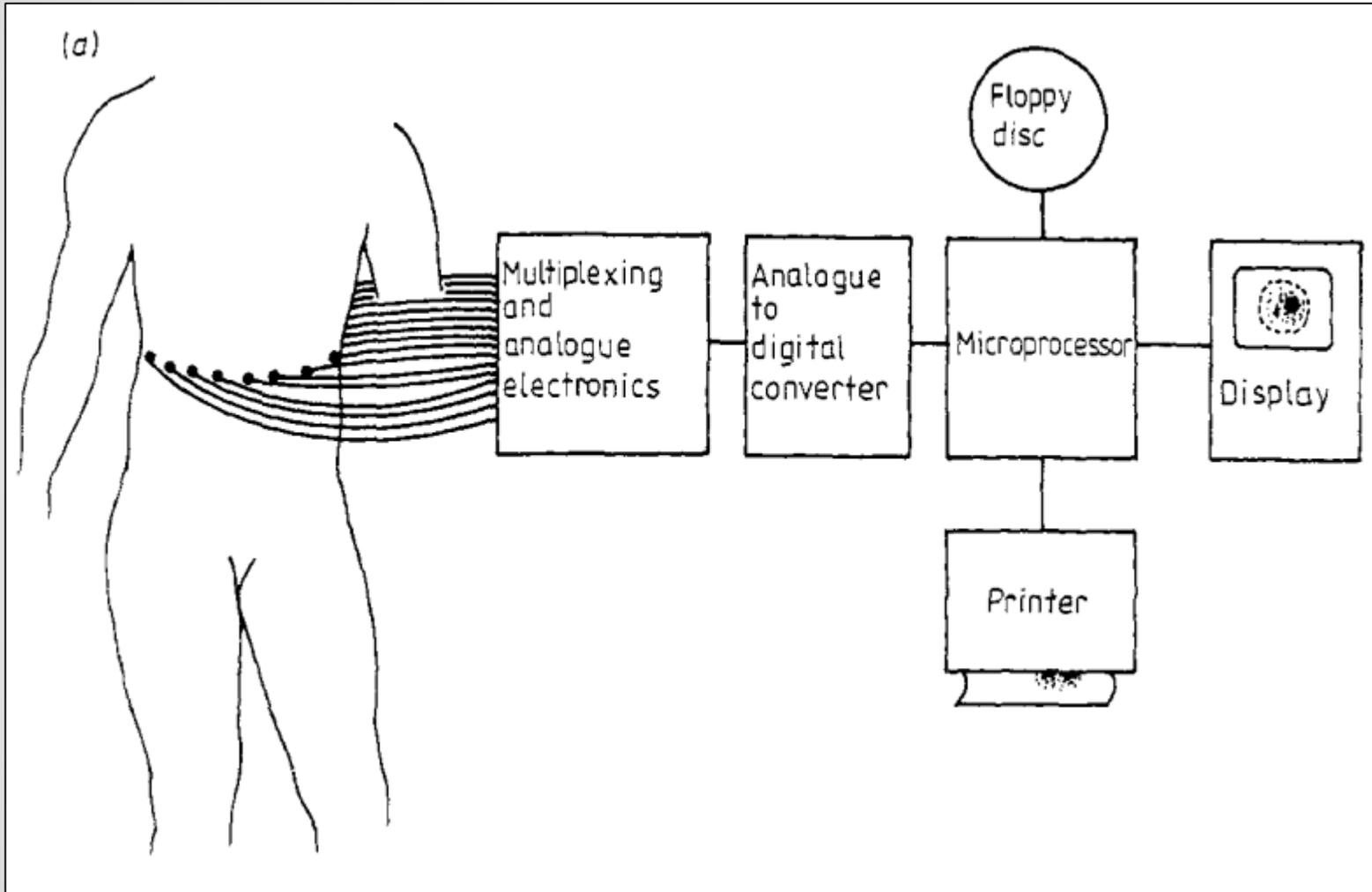
Sheffield University and Health Authority, Department of Medical Physics and Clinical Engineering, Royal Hallamshire Hospital, Glossop Road, Sheffield S10 2JF, England

Electrical Impedance Tomography

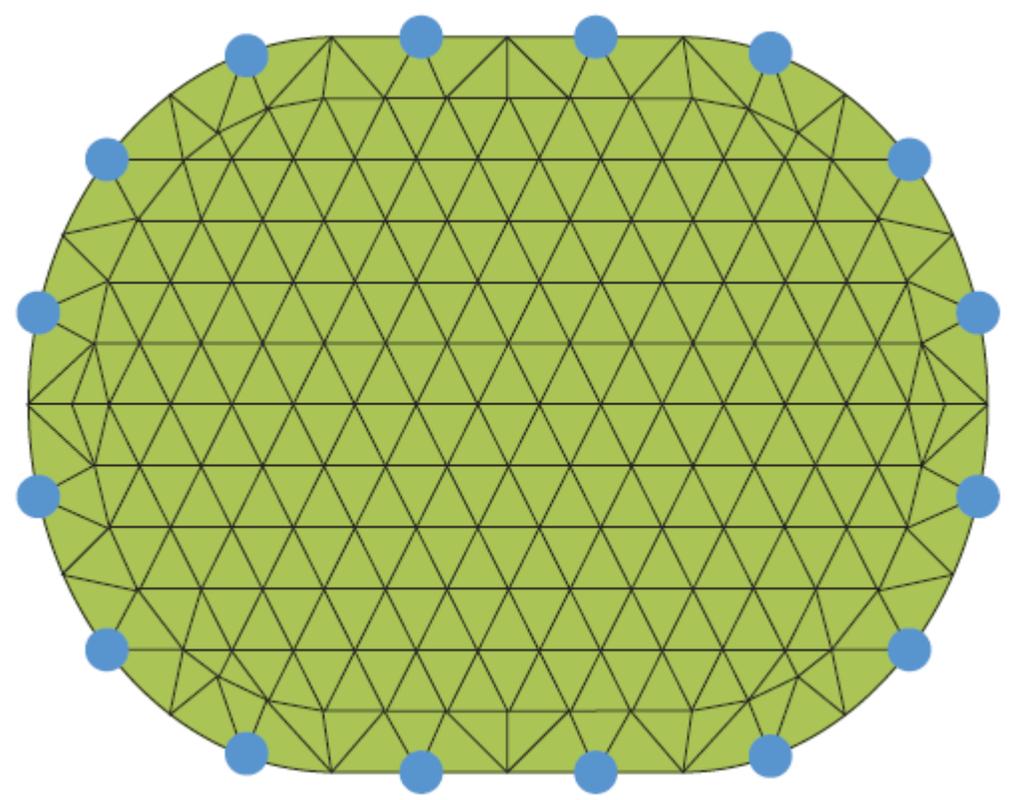
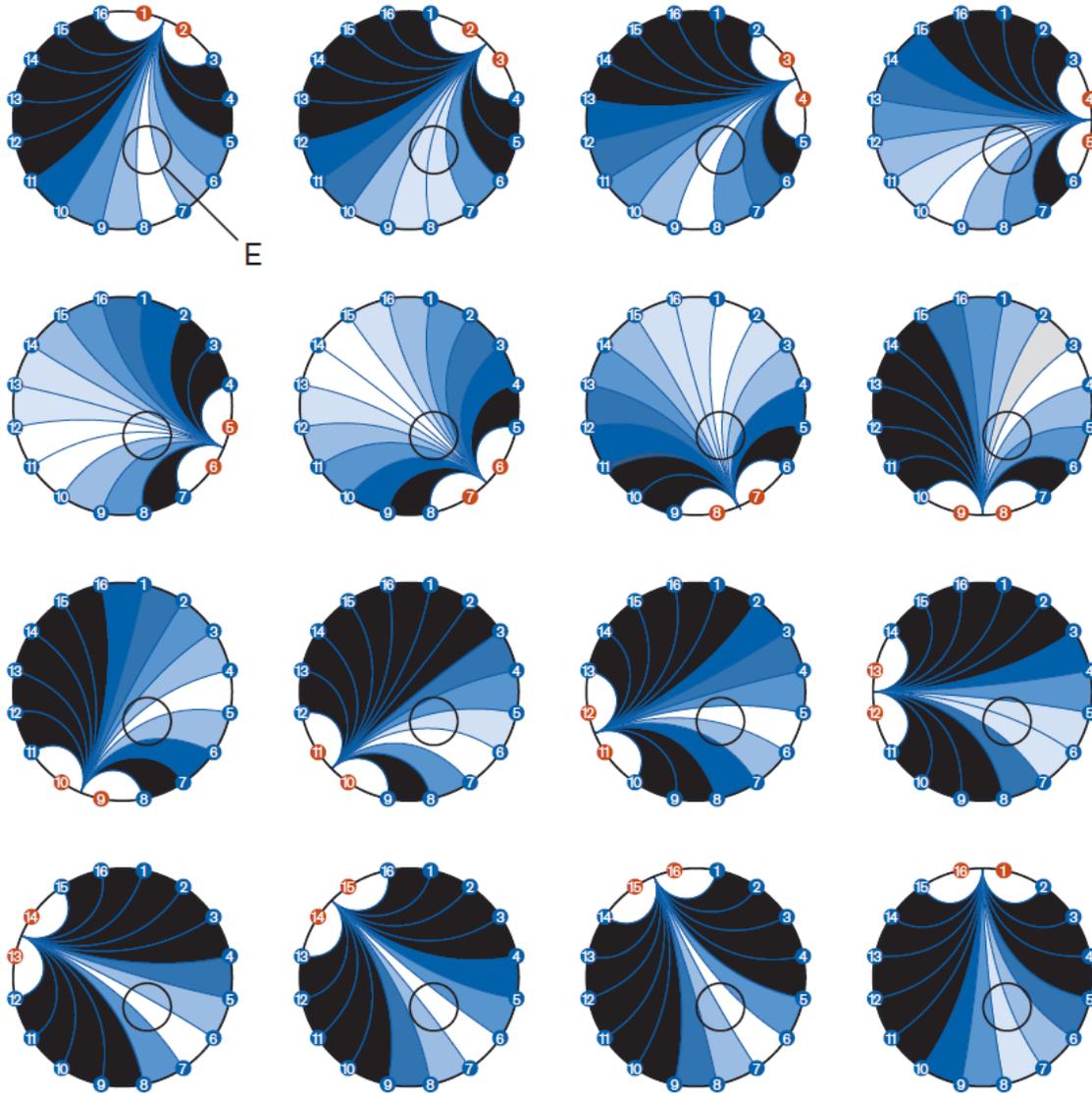


Tissue	Resistivity (Ωm)	Conditions
Cerebrospinal fluid	0.65	
Blood	1.5	50% haematocrit
Liver	3.5	<i>In vivo</i> perfused canine tissue
Human arm	2.4 (longitudinal)	
	6.75 (transverse)	
Skeletal muscle	1.25 (longitudinal)	
	18.00 (transverse)	
	5.3 (average of the above)	
Cardiac muscle	1.6 (longitudinal)	Calculated interstitial valve
	4.24 (transverse)	Calculated interstitial valve
	4.1-7.5 (average values)	
Neural tissue	5.8	Average results for rabbit, cow and pig
Grey matter	2.84	Rabbit tissue
White matter	6.82	Rabbit tissue
Lung	7.2-23.6	Range from expiration to inspiration
Fat	27.2	Average of many animal results
Bone	166	Wet bovine bone

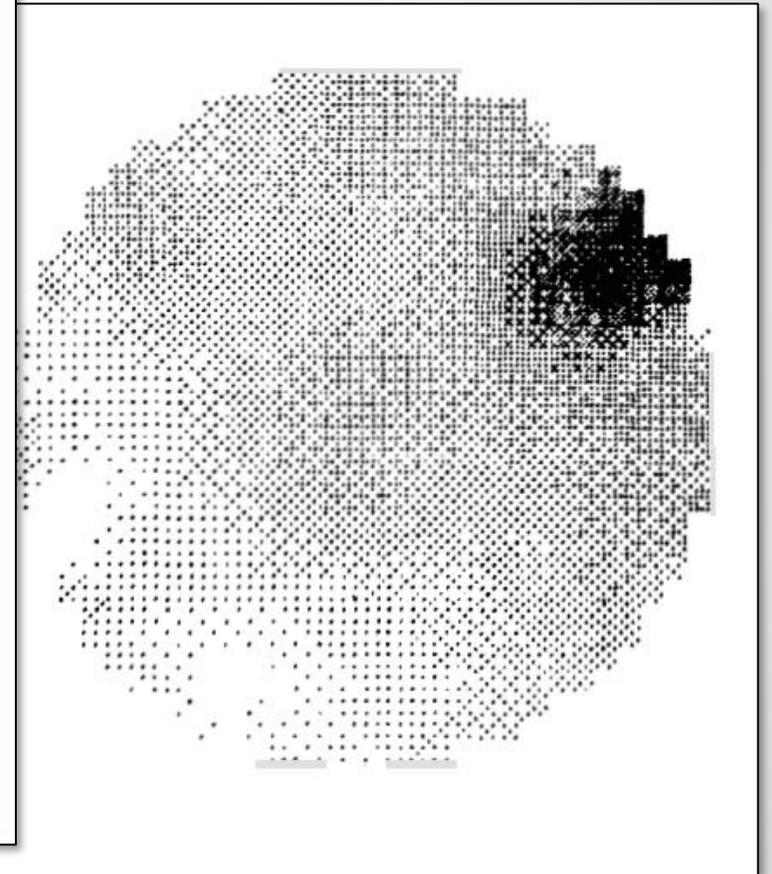
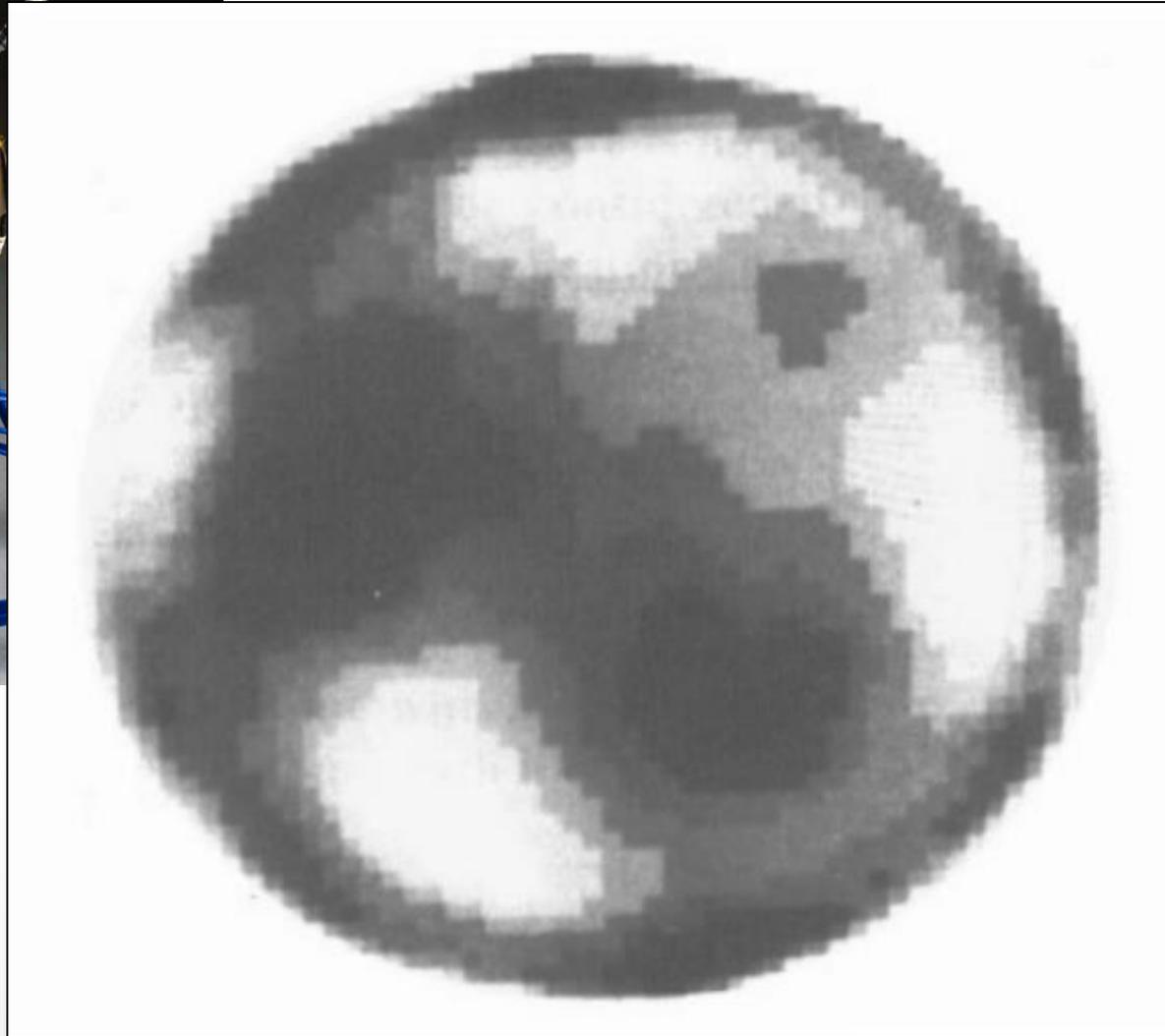
Electrical Impedance Tomography



Electrical Impedance Tomography



Electrical Impedance Tomography



EIT at Present



How to Measure EIT?



1 Mid position marker



2 Closure holes

Applying This EIT

Orientation of the patient cable and electrode belt



>wrong<



>correct<

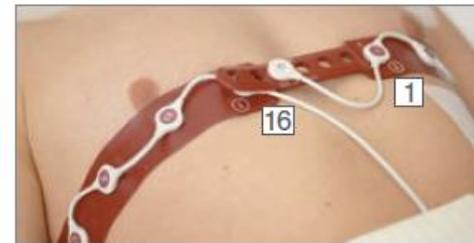
Patient cable

Electrode belt

Right port

6058-2014

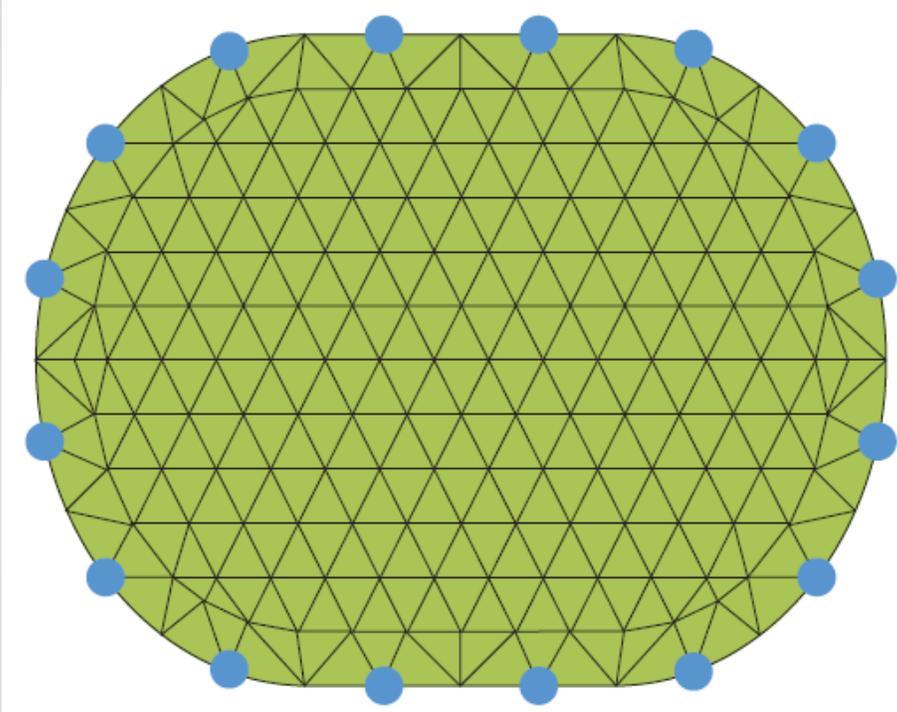
25-4-2010



Electrode orientation:

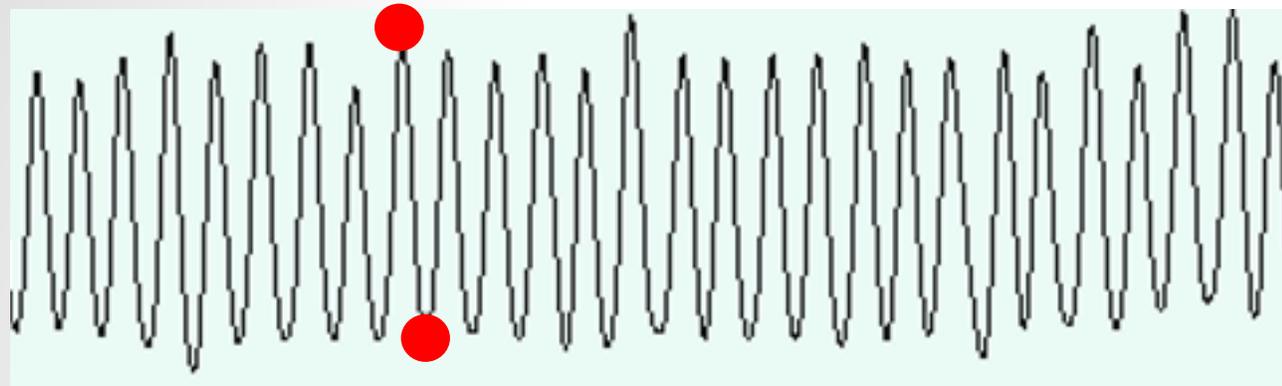
If possible, place the electrodes 1 and 16 symmetrically (equidistant) to the sternum (see picture). If possible, place the electrodes 8 and 9 symmetrically to the spine.

Electric Impedance Tomography



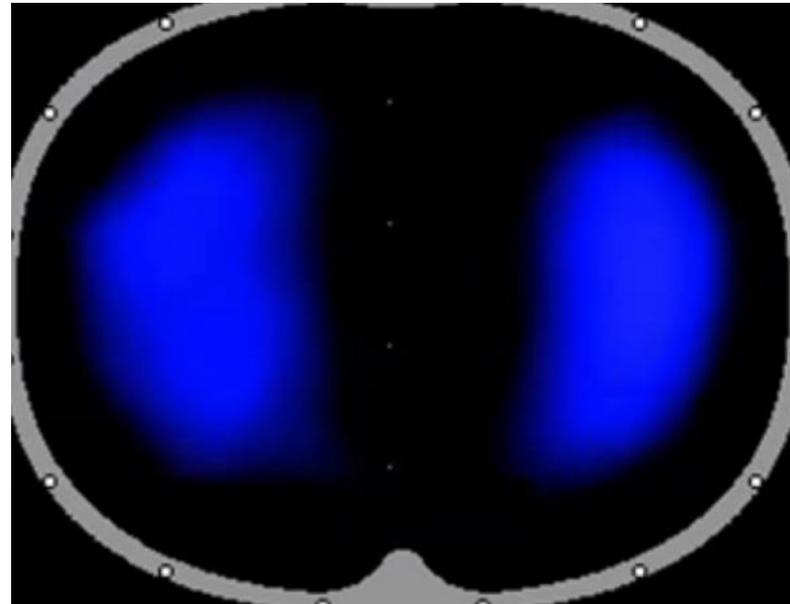
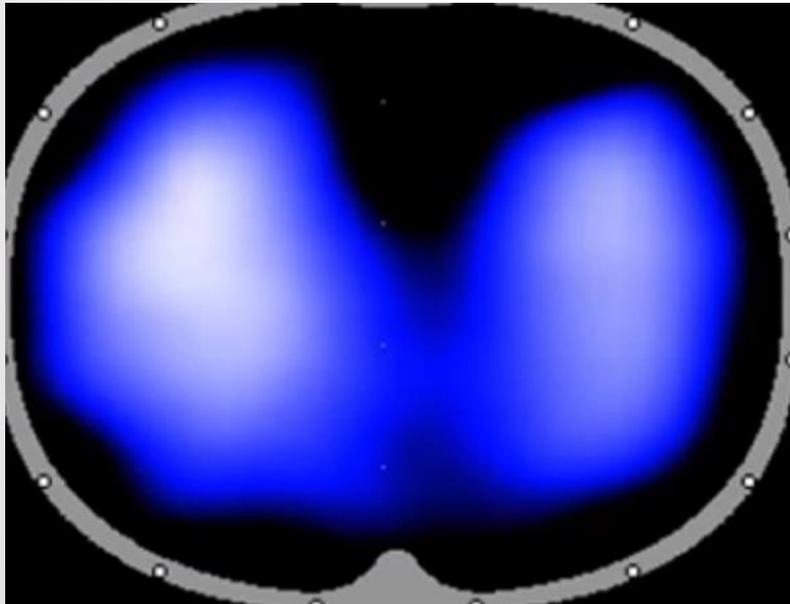
Visualize!!

Electric Impedance Tomography



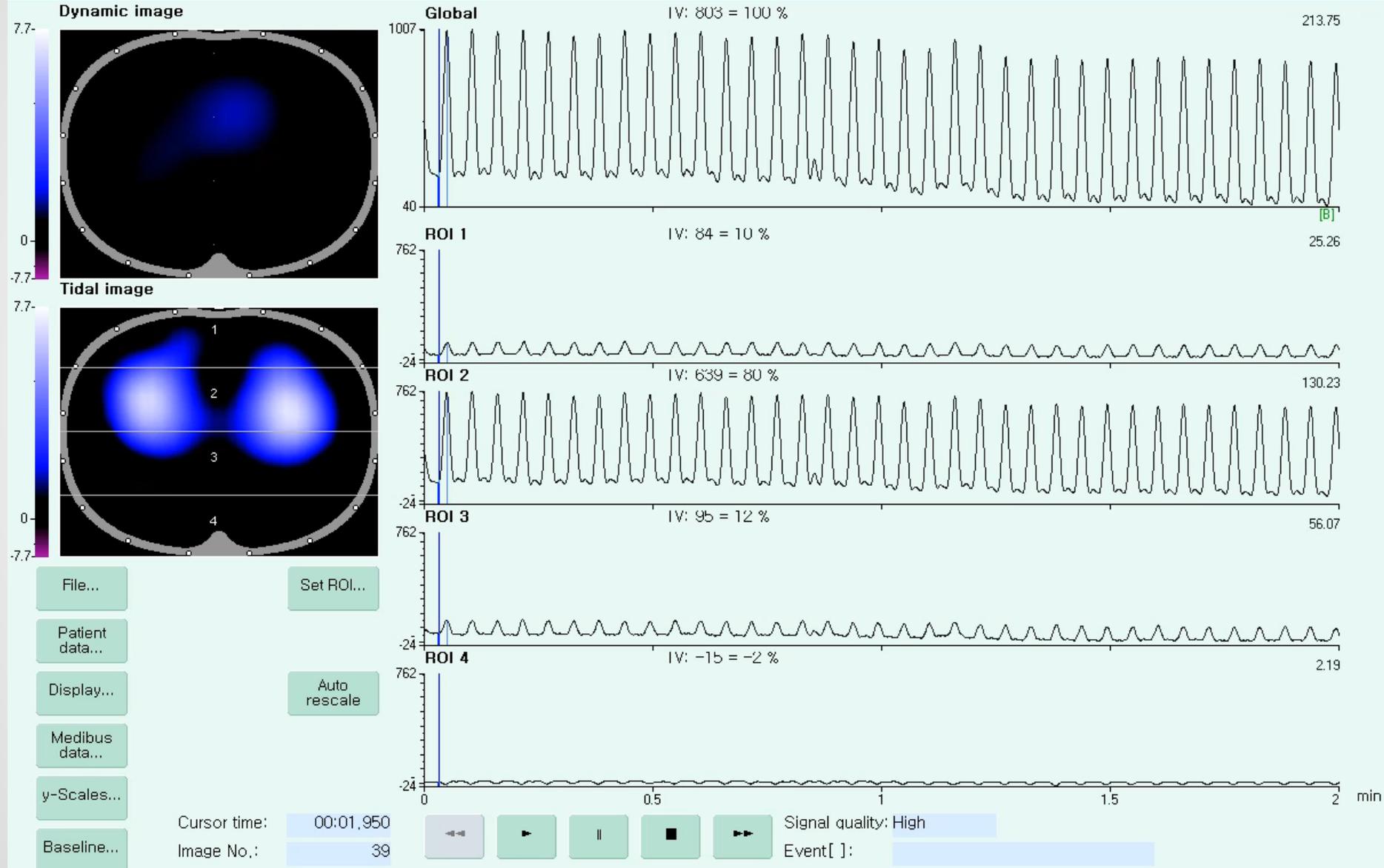
Tidal Variation

Impedance의 차이 (변화)를
수치로 제공할 수 있다.

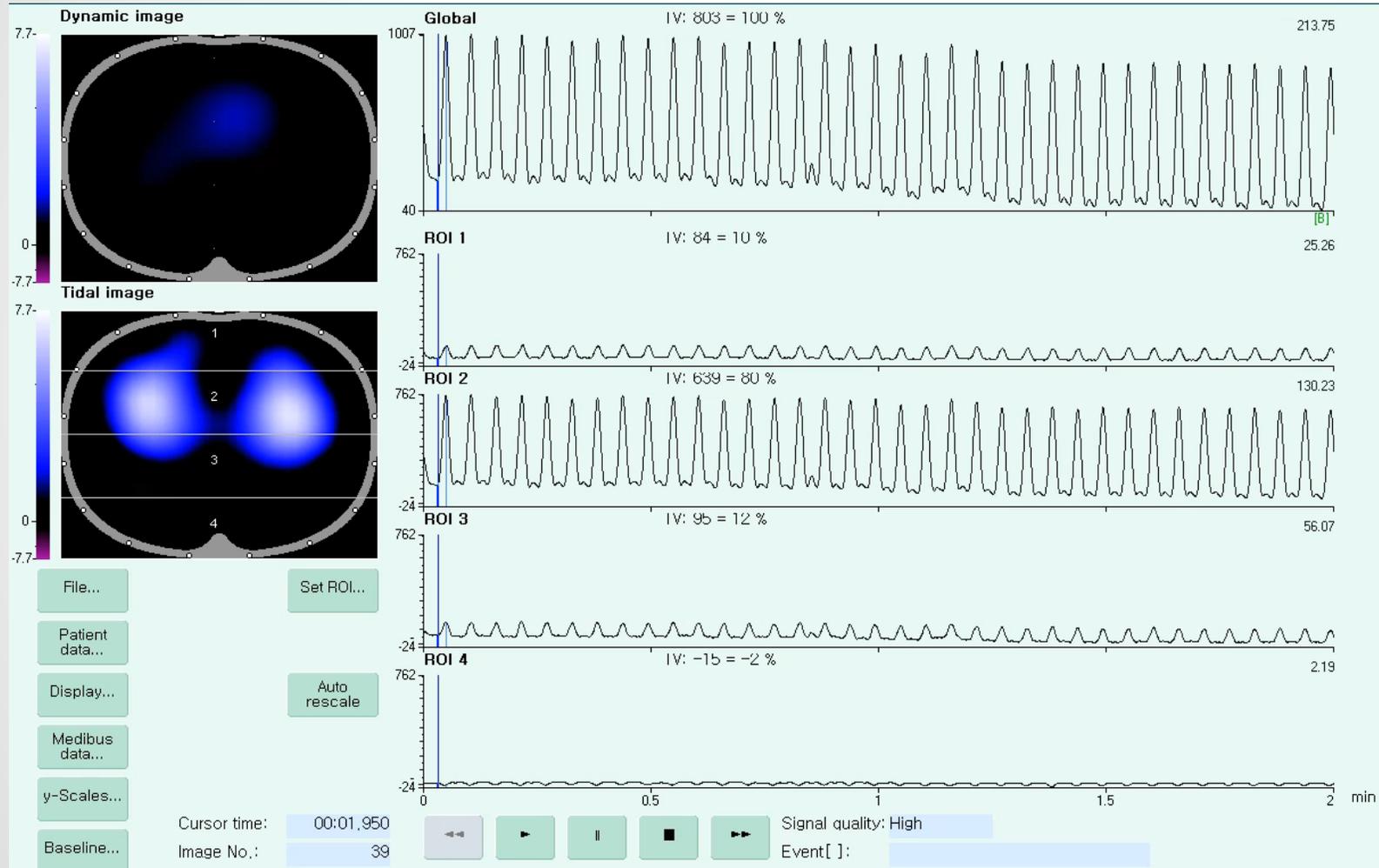


Tidal Variation
of
Impedance

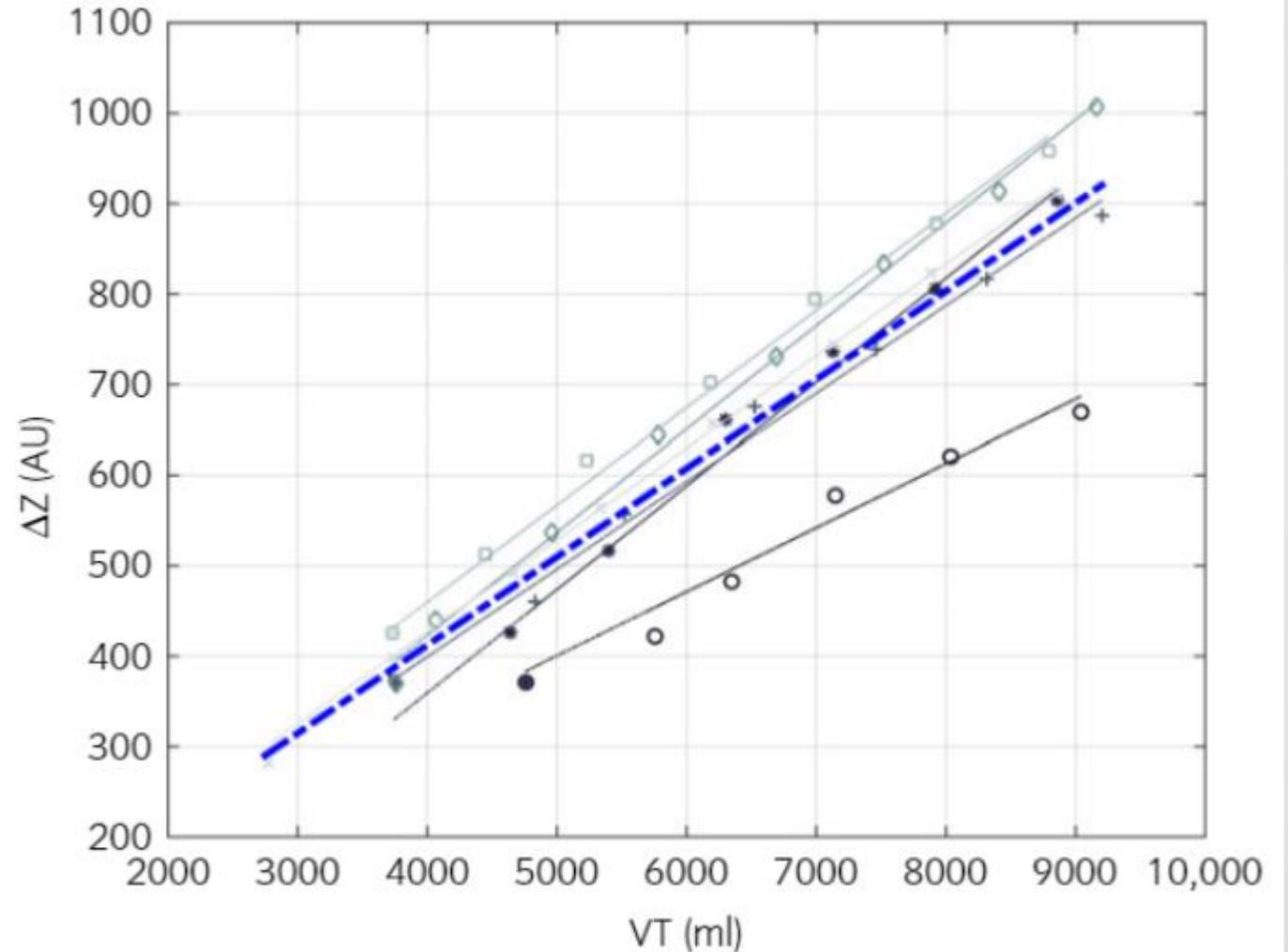
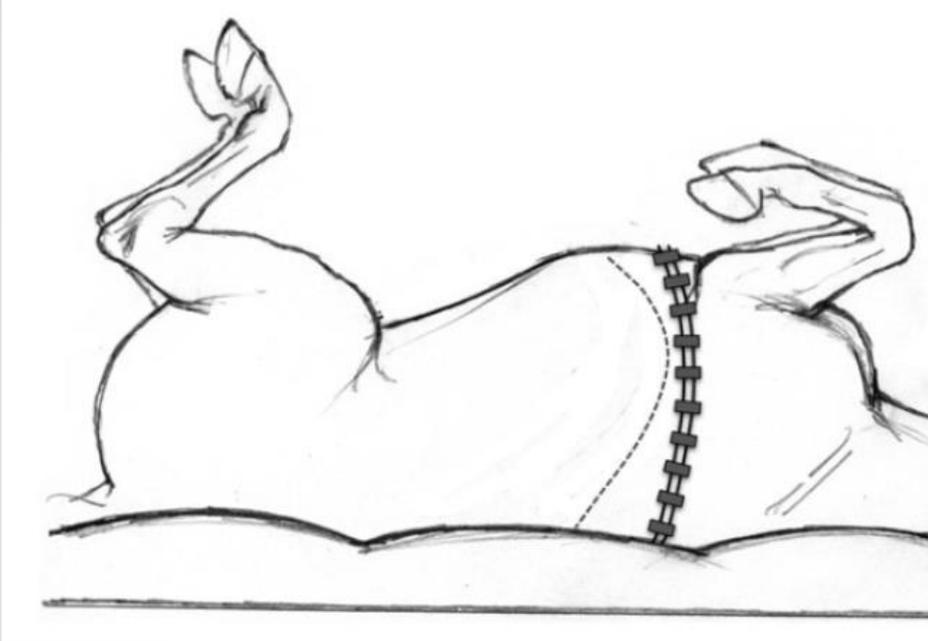
Tidal Variation



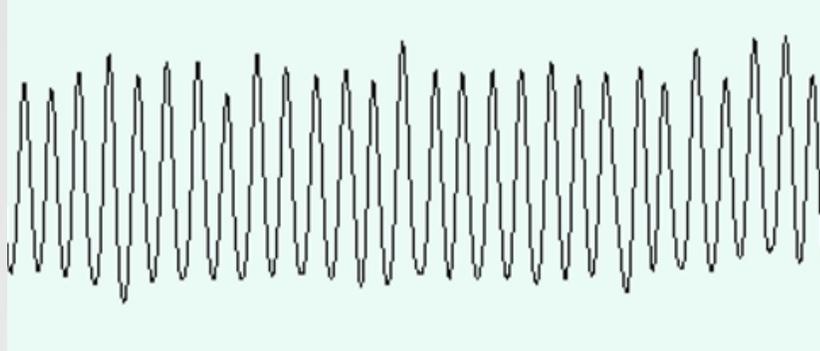
Tidal Variation



Tidal Variation & Tidal Volume

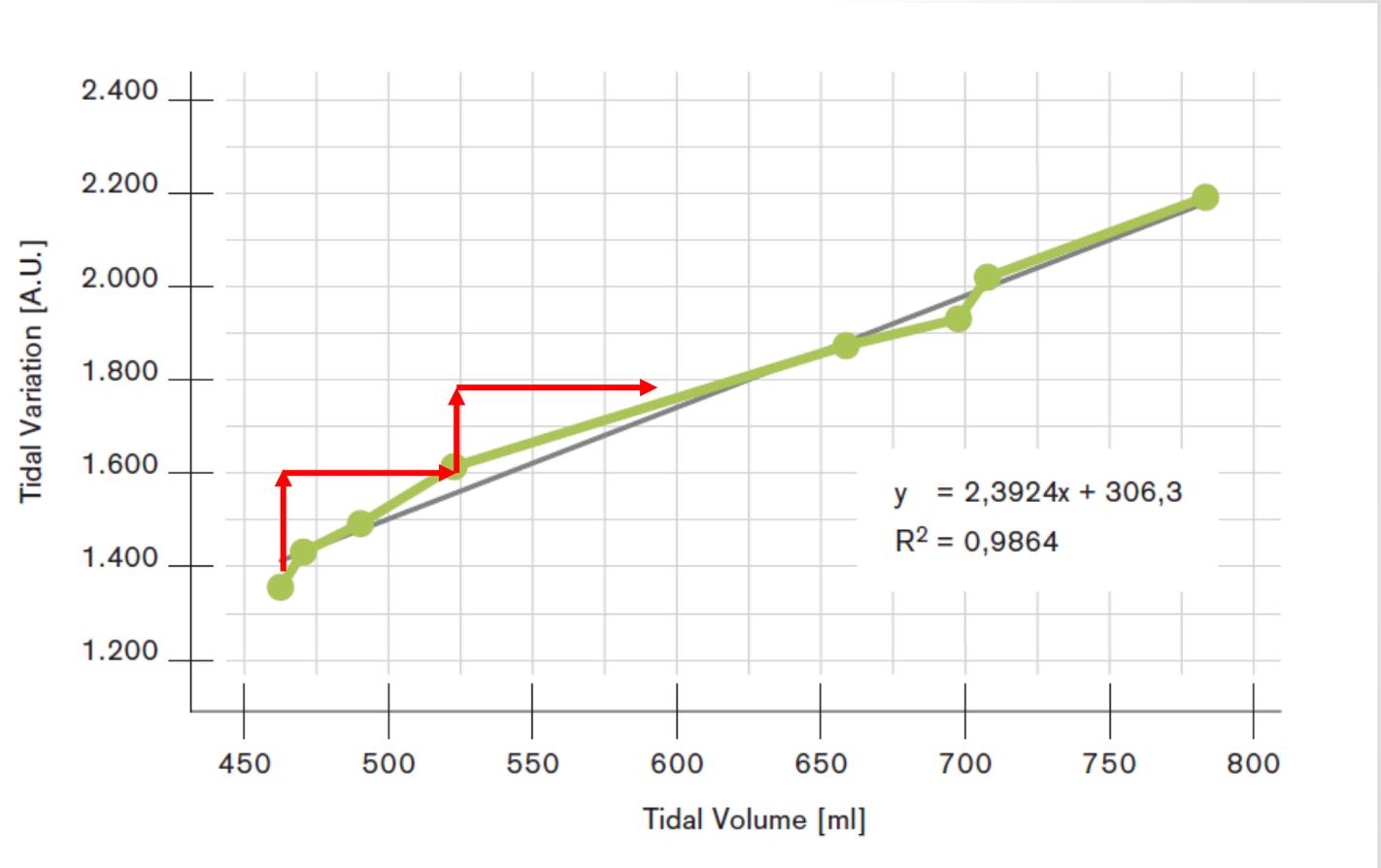


Tidal Variation & Tidal Volume



TV

- ① Tidal Volume
- ② Tidal Variation



EIT for Pulmonary Monitoring

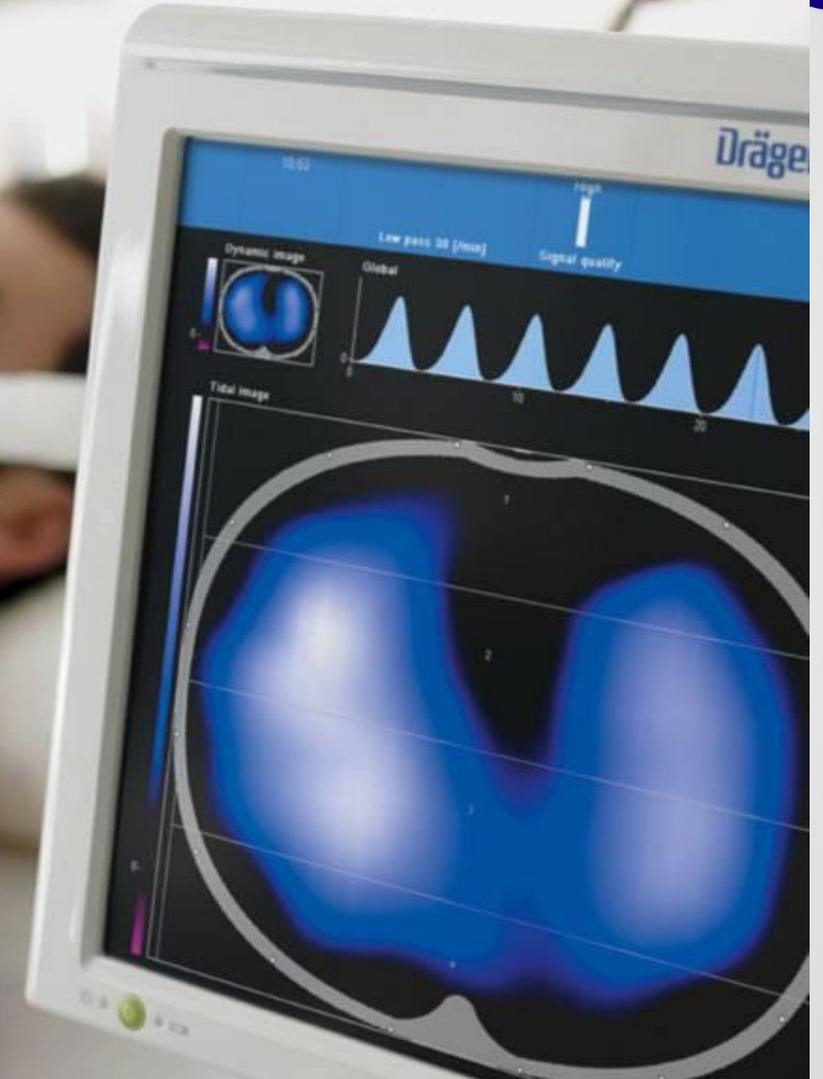


Non-Invasive & Radiation Free

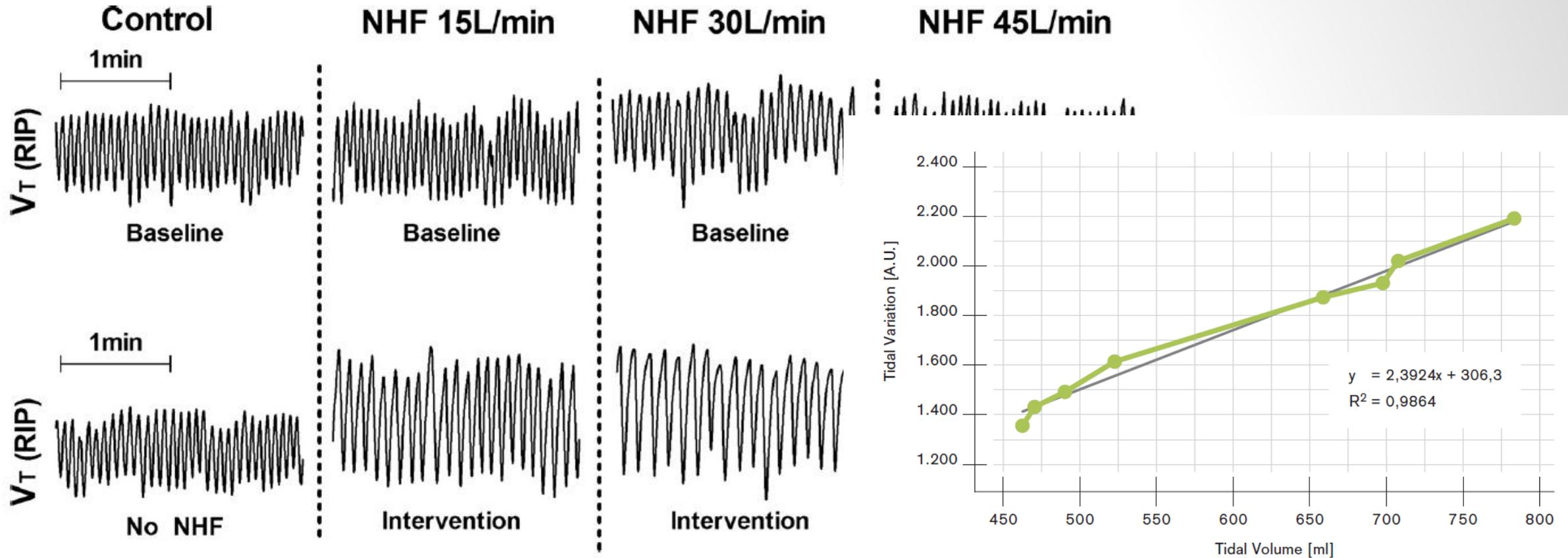
TV (Tidal Variation) (of Impedance)

Global & Regional TV (360 segments)

Real Time (50 /sec)



Tidal Volume during HFNC



HFNC만 달아도 폐 환기가 좋아진다!!
폐의 모든 부위에서 일관되게 증가할까?

Global and Regional Ventilation during High Flow Nasal Cannula in Patients with Hypoxia

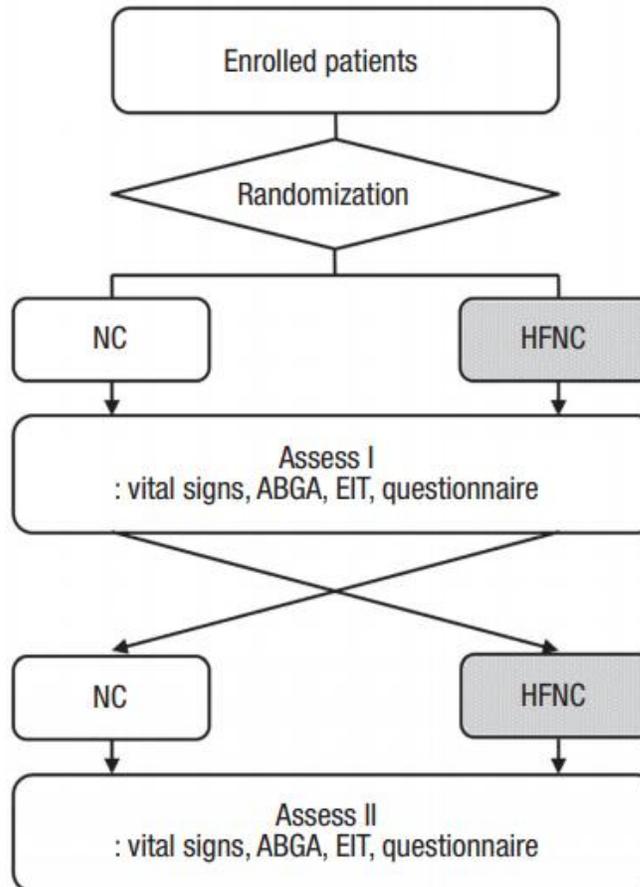


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¹Department of Pulmonology and Intensive Care Medicine, Dong-A University Hospital, Dong-A University College of Medicine, Busan;

²Department of Pulmonary and Critical Care Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

- > 20 years
- Subjective dyspnea
- SaO₂ < 90% in room air

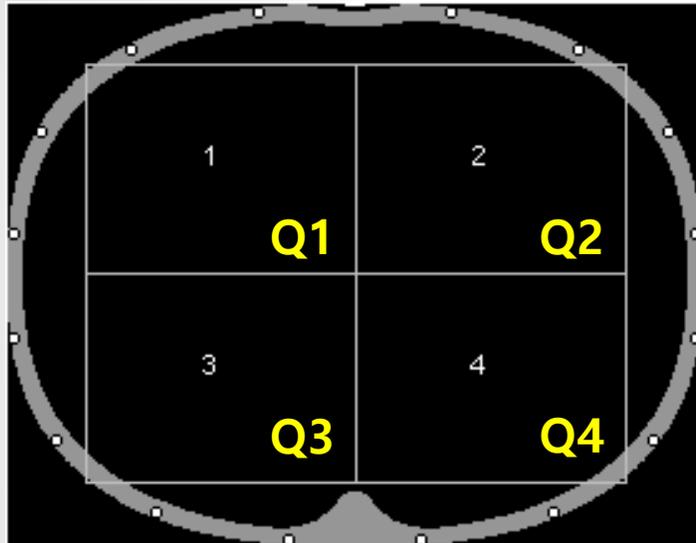


- Unstable vital sign
 - SBP < 90 mmHg
 - DBP < 60 mmHg
 - HR > 120 bpm
 - RR > 30 bpm
 - Persistent dyspnea with NP
- PaO₂/FiO₂ < 200 mmHg
- Unable to cooperate
- Symptomatic IHD
- Labored breathing
- Impossibility of HFNC or NP application (facial deformity)

Regional Ventilation Assessment with EIT

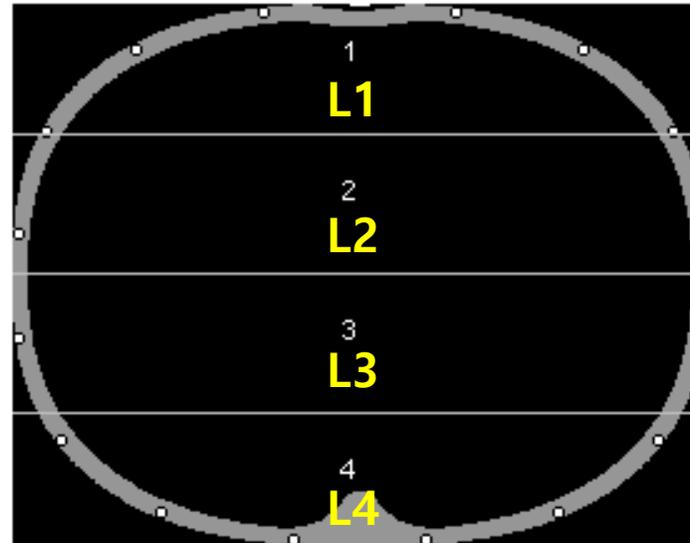


Quadrants



Quadrangular Plane

Layers



Dorso-ventral Plane

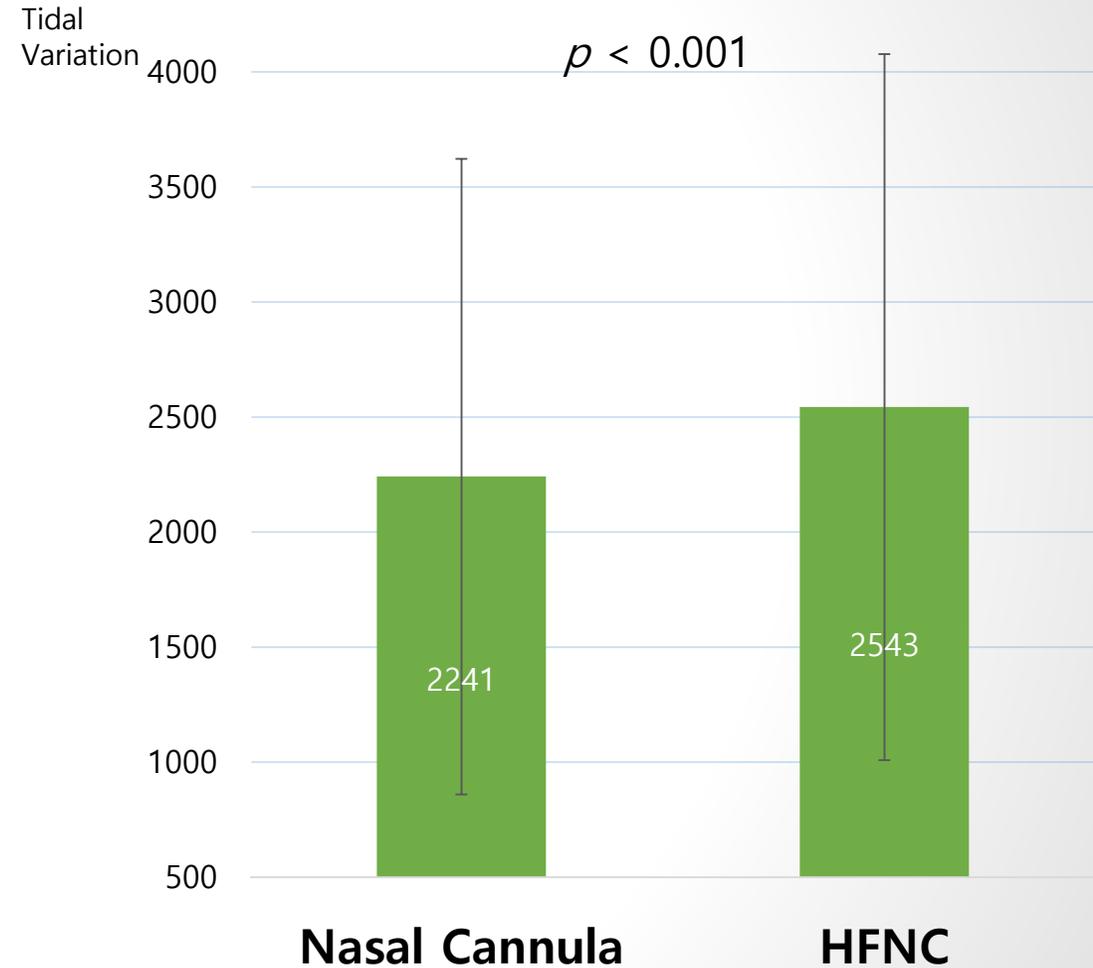
Global Ventilation with EIT



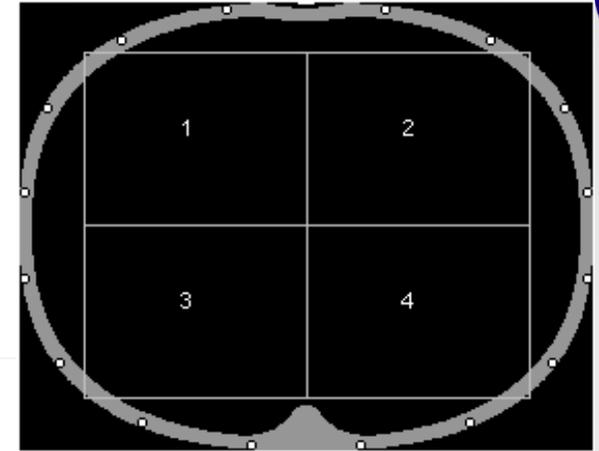
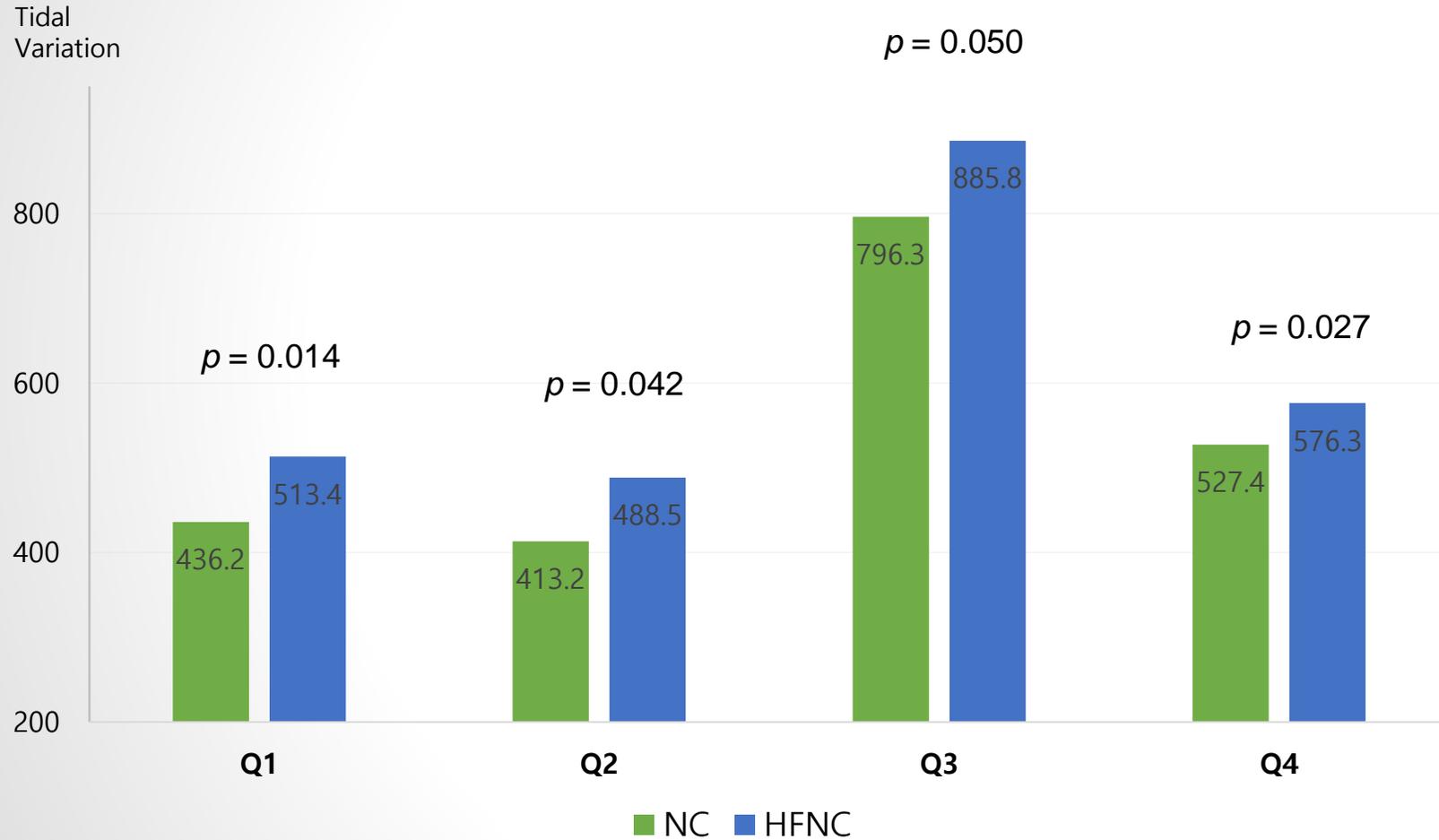
Higher tidal variation
with HFNC



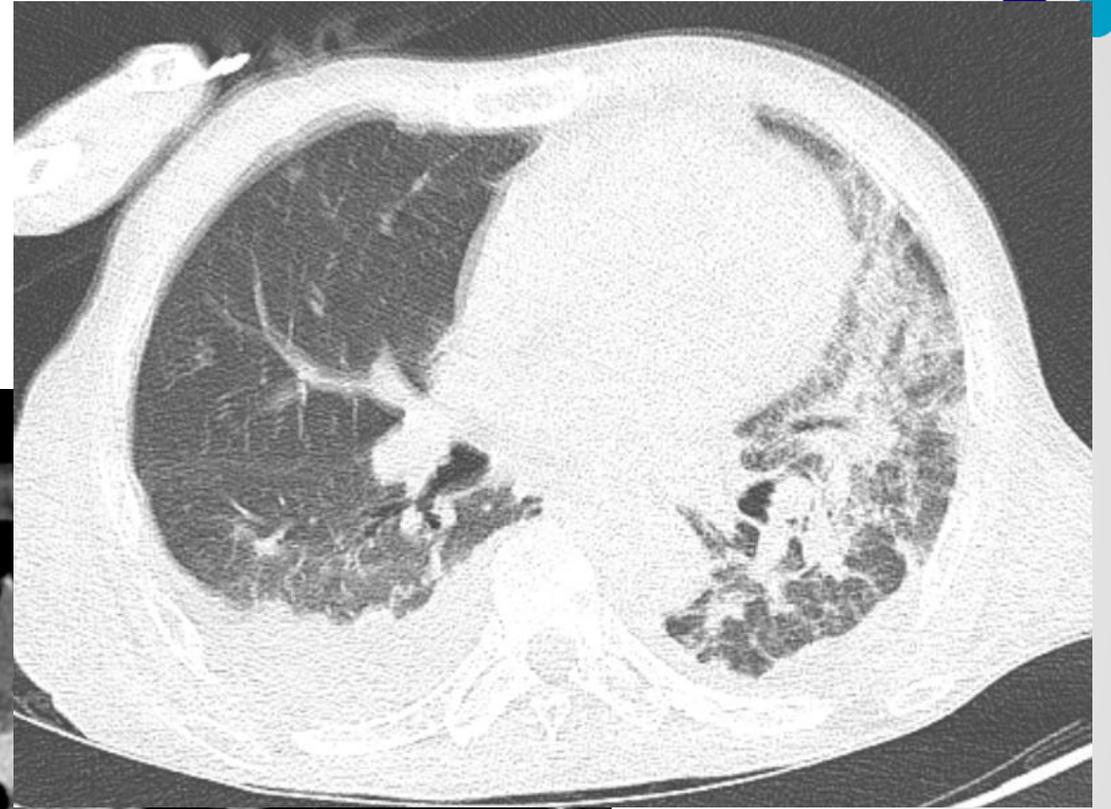
Higher tidal volume
with HFNC



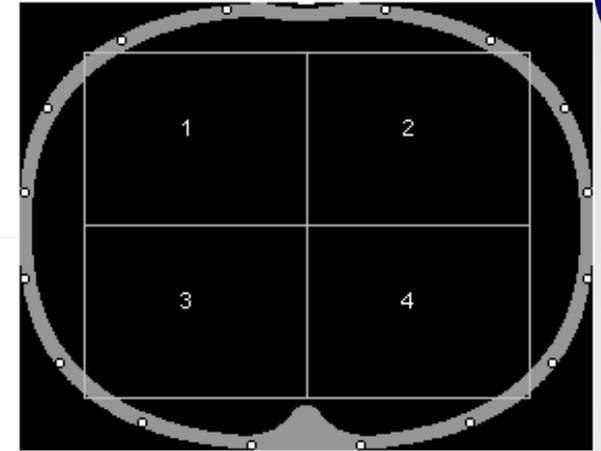
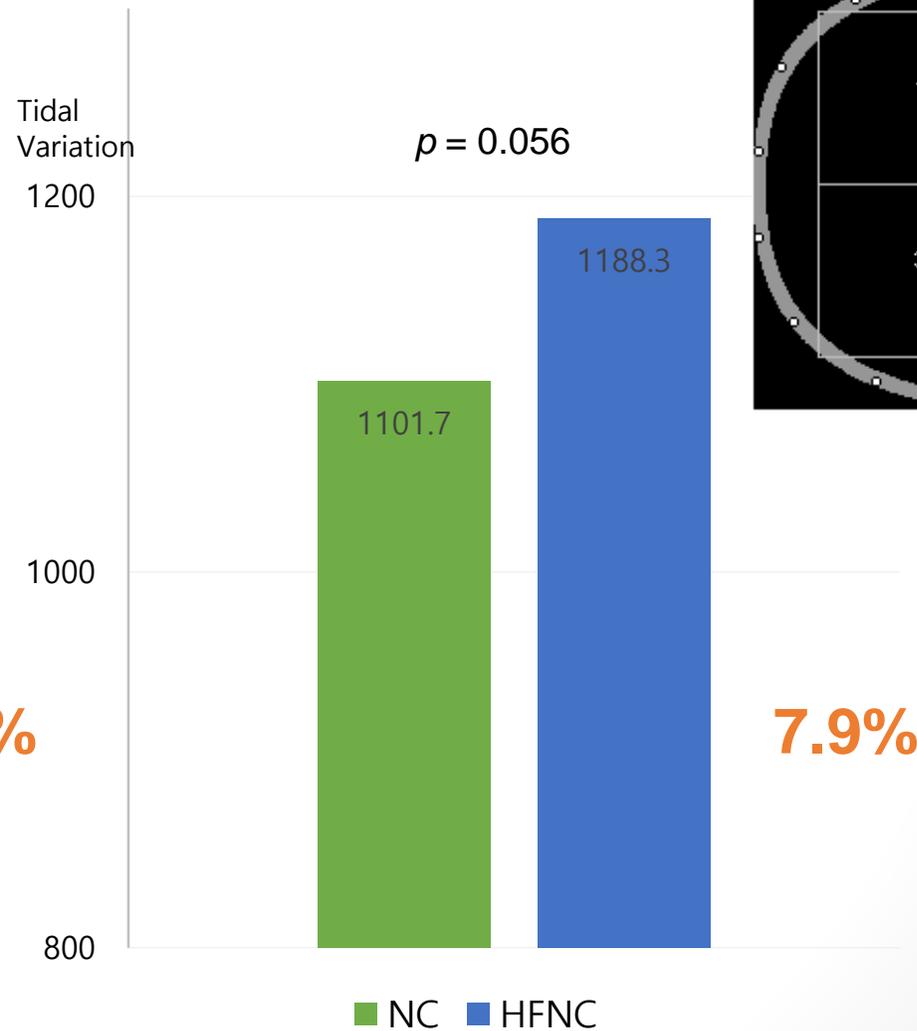
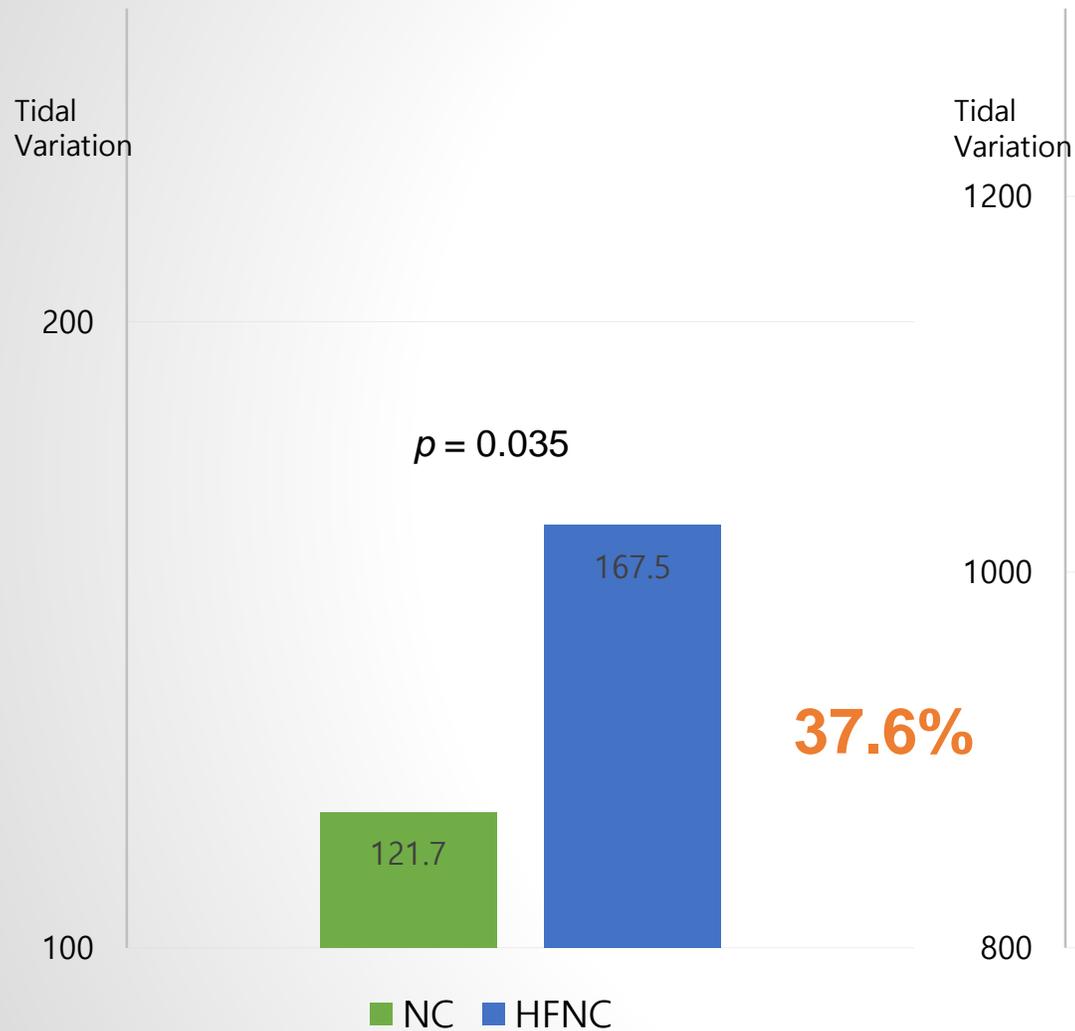
Quadrangular Distribution of Ventilation



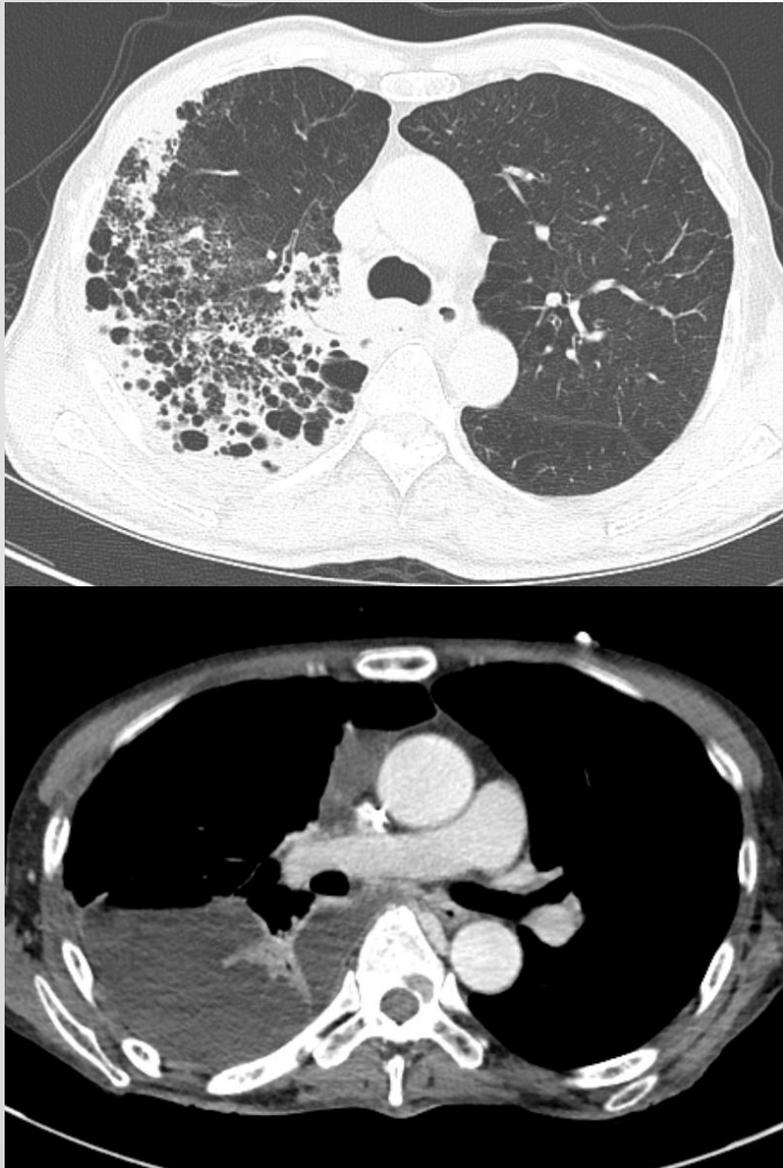
Regional Ventilation Distribution of Lung



Minimal & Maximum Ventilated Quadrant



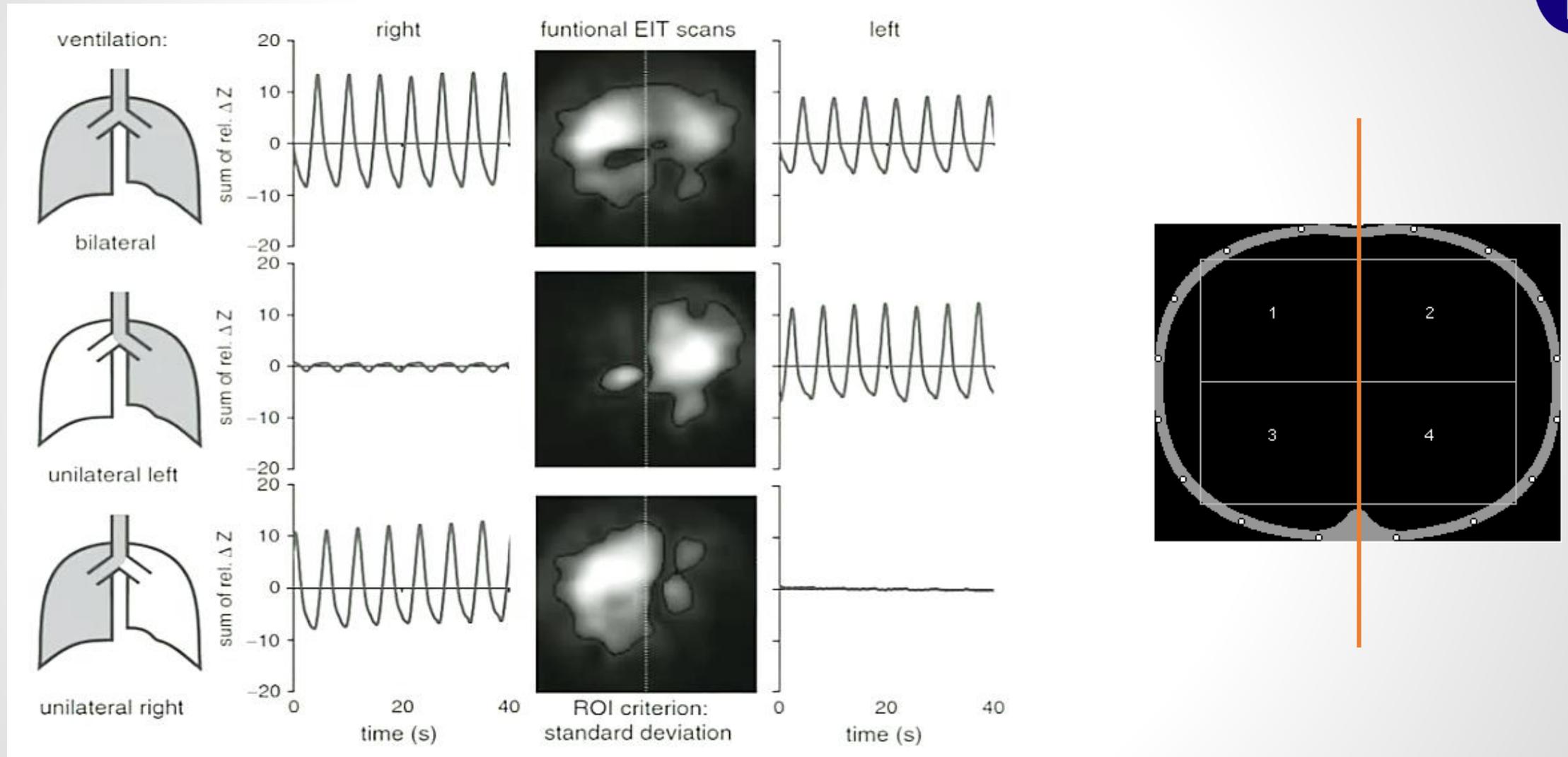
HFNC Favors Hypo-Ventilated Lung



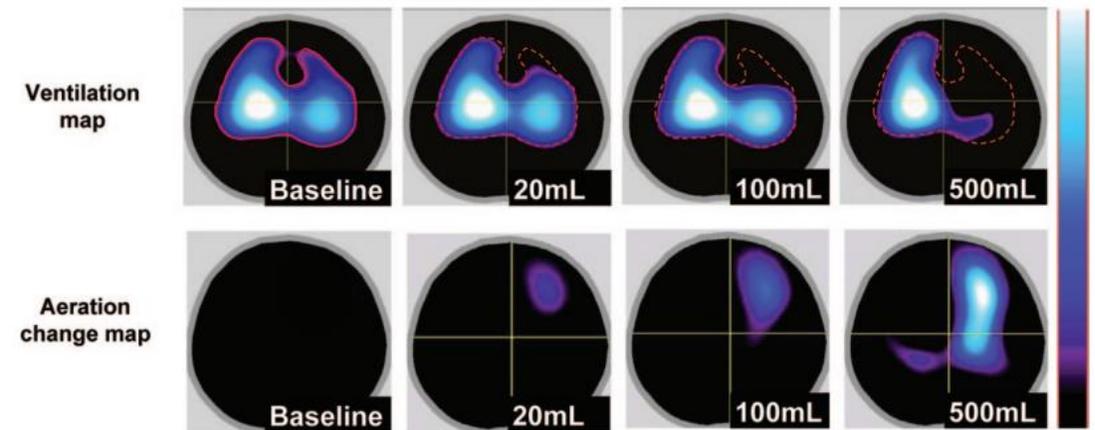
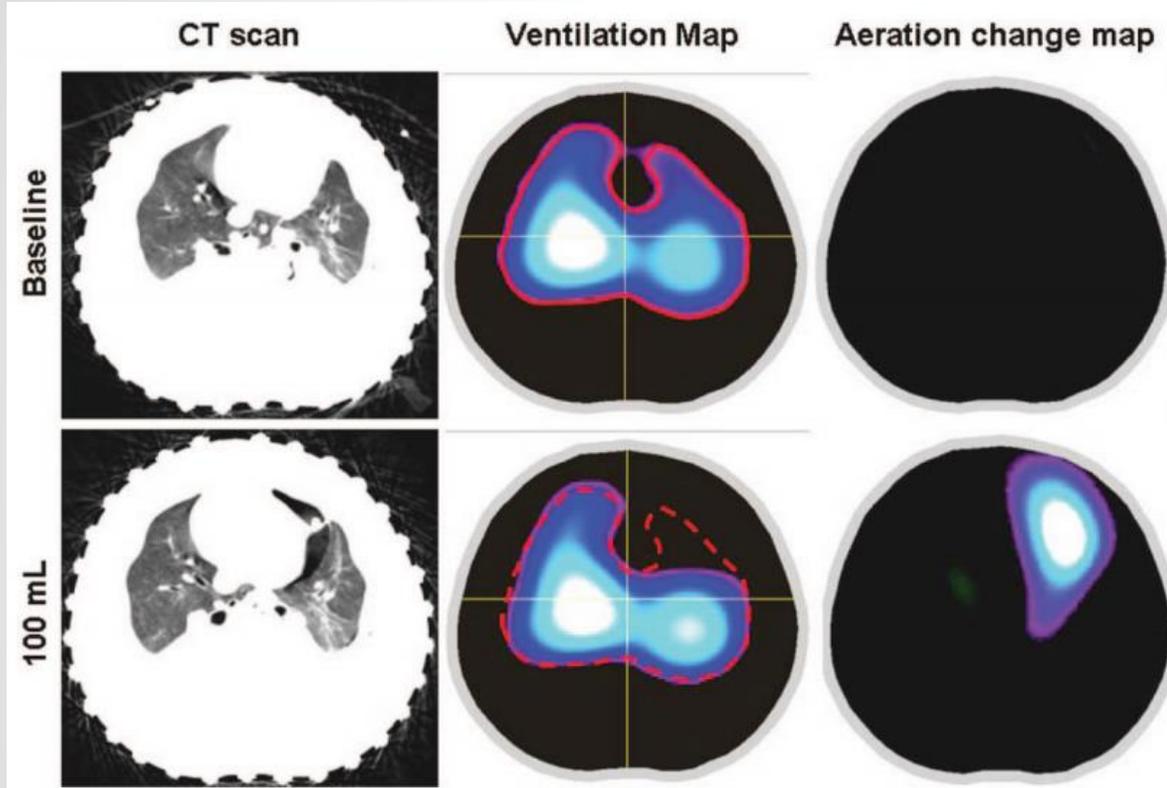
does not become less meaningful.

In conclusion, during HFNC oxygen therapy, in addition to increased global ventilation, regional ventilation and its distribution was improved compared with conventional NC.

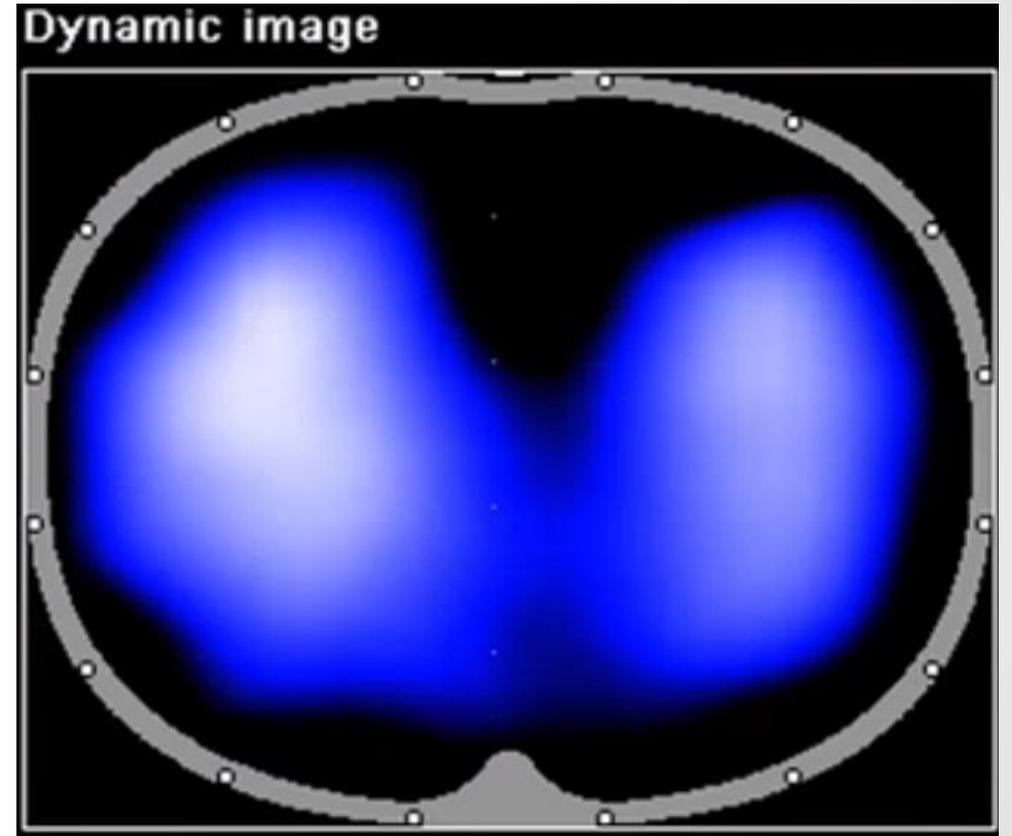
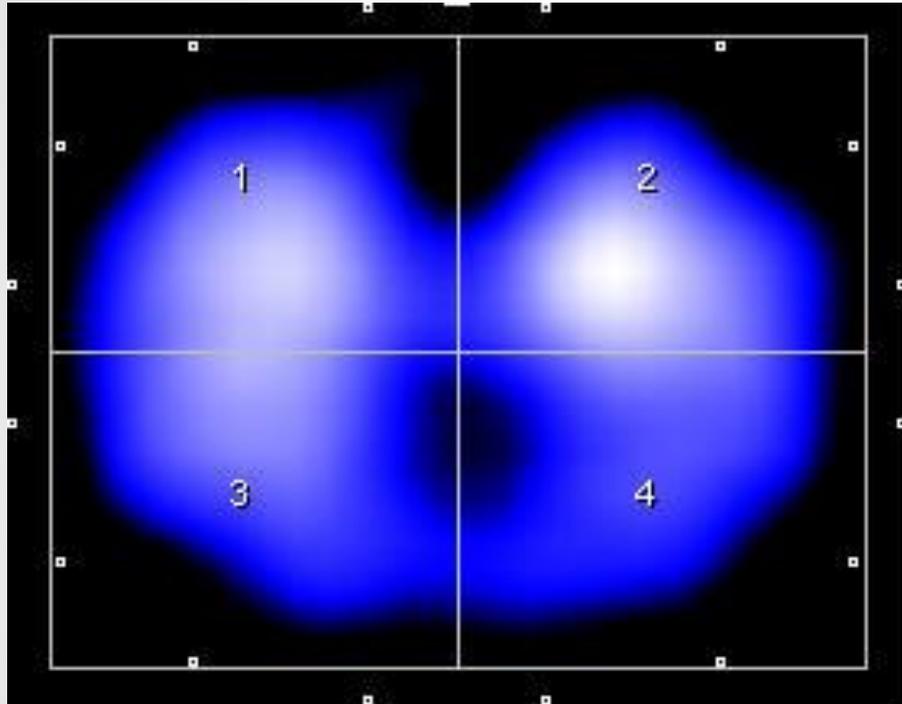
EIT during Endotracheal Intubation



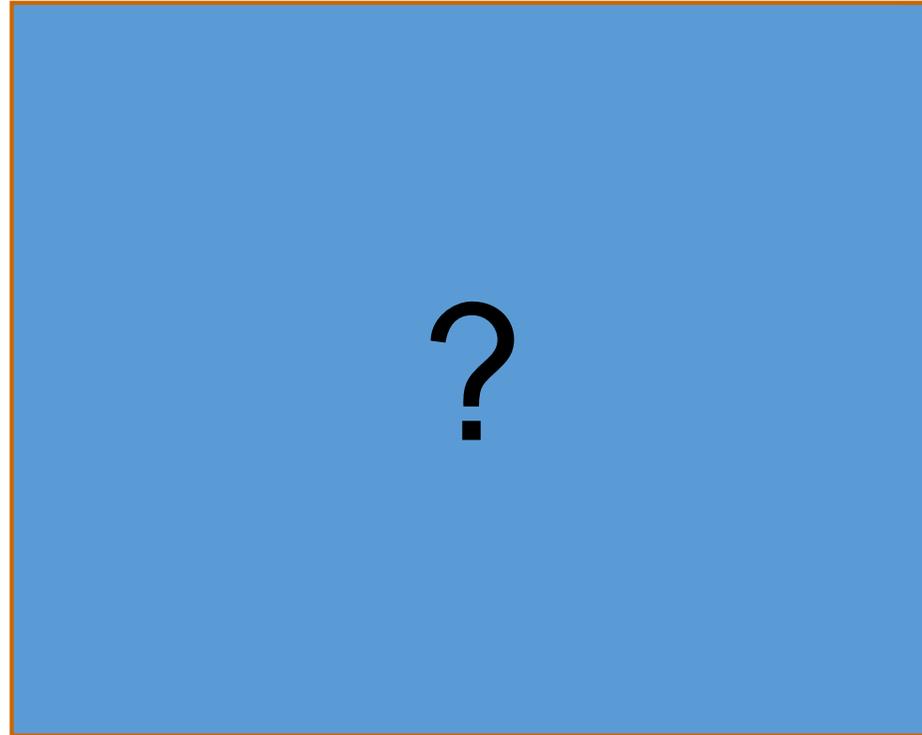
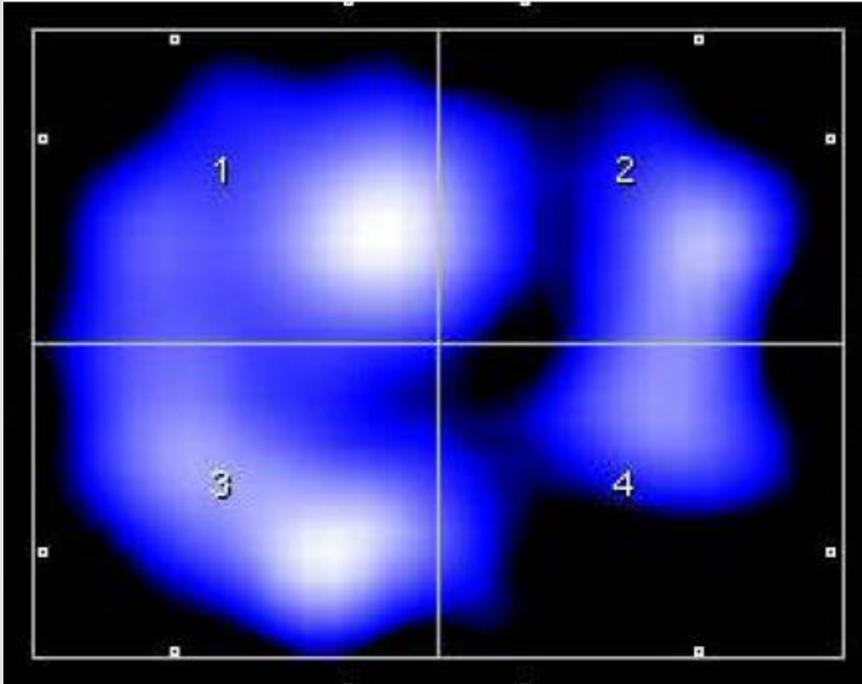
EIT for Pneumothorax Detection



EIT of Healthy Lung

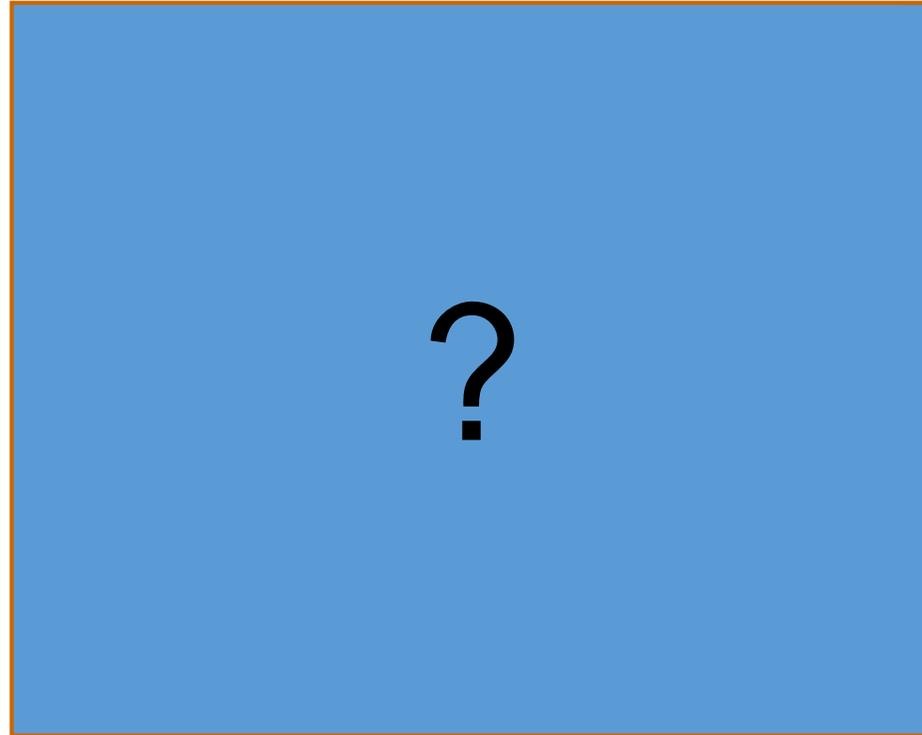
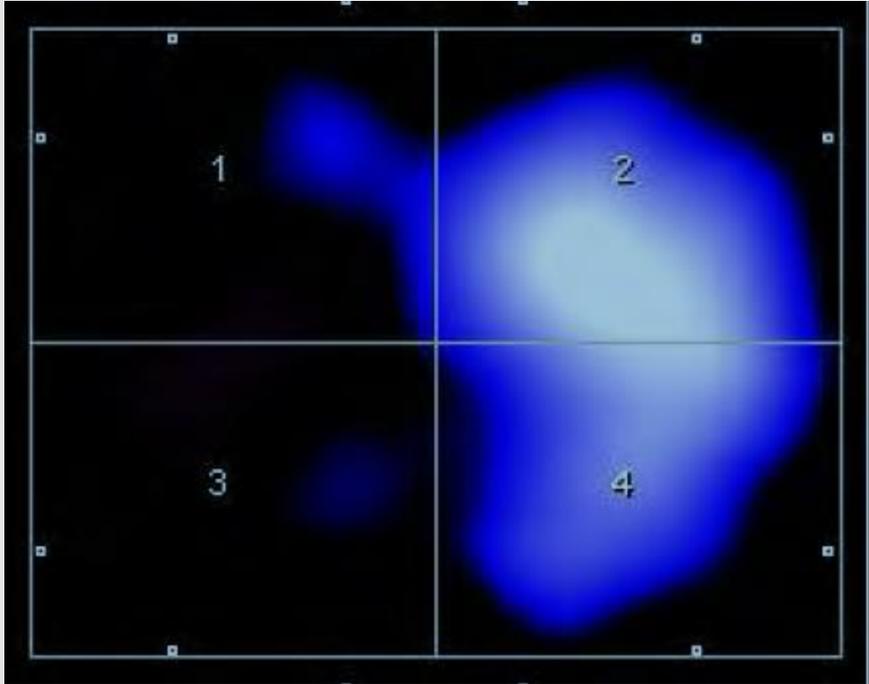


EIT of OOOOOOOO???



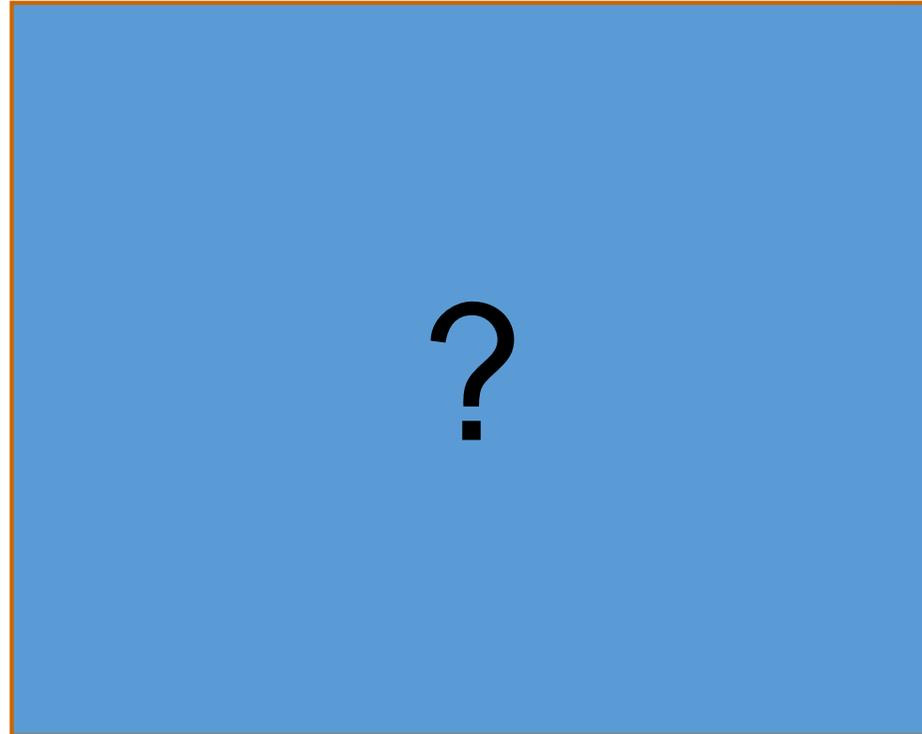
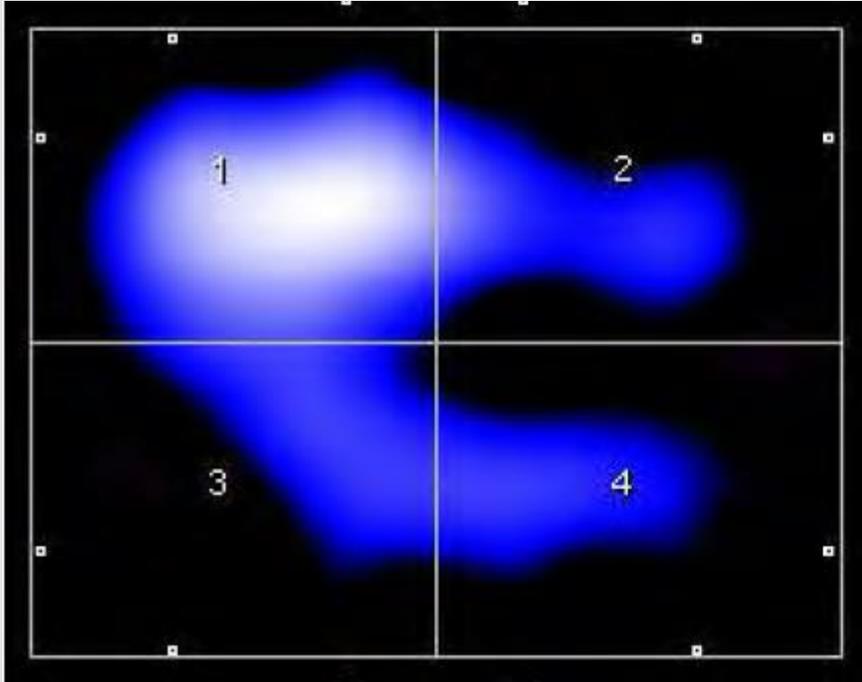
- Unilateral left dorsal pleural effusion

EIT of OOOOOOOO???

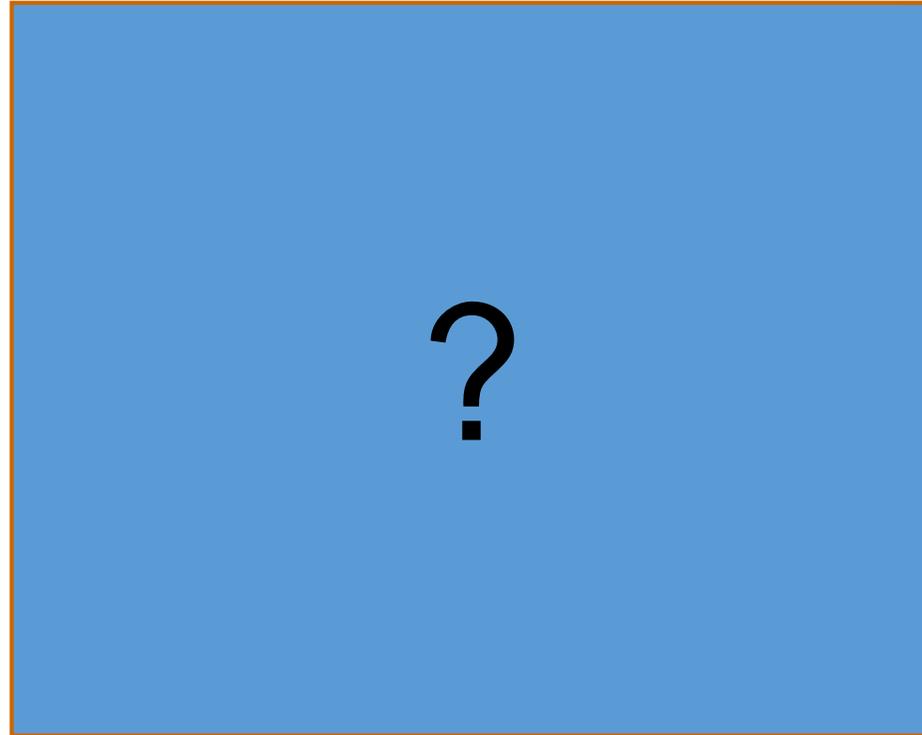
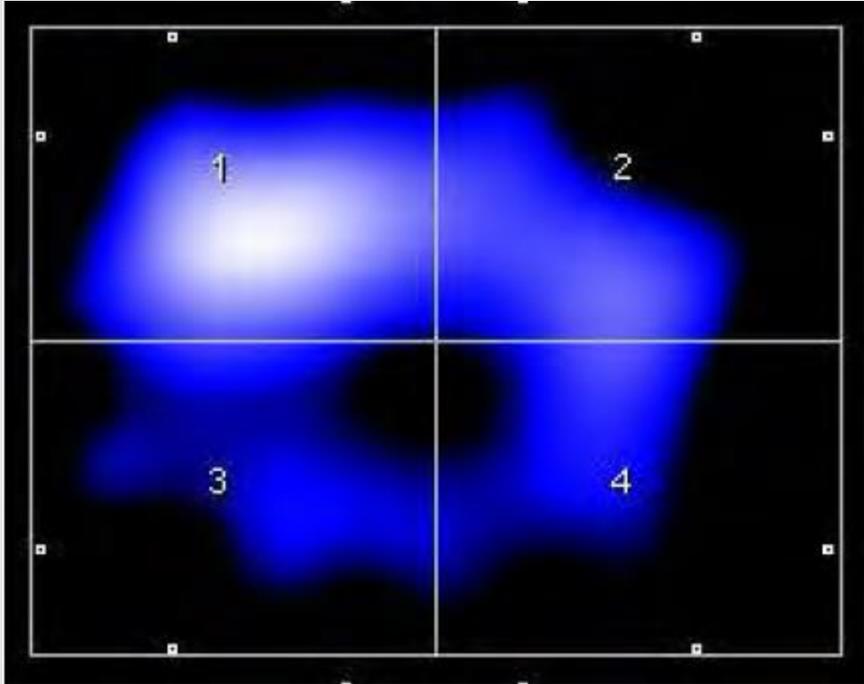


- Patient after right pneumectomy

EIT of 00000000???

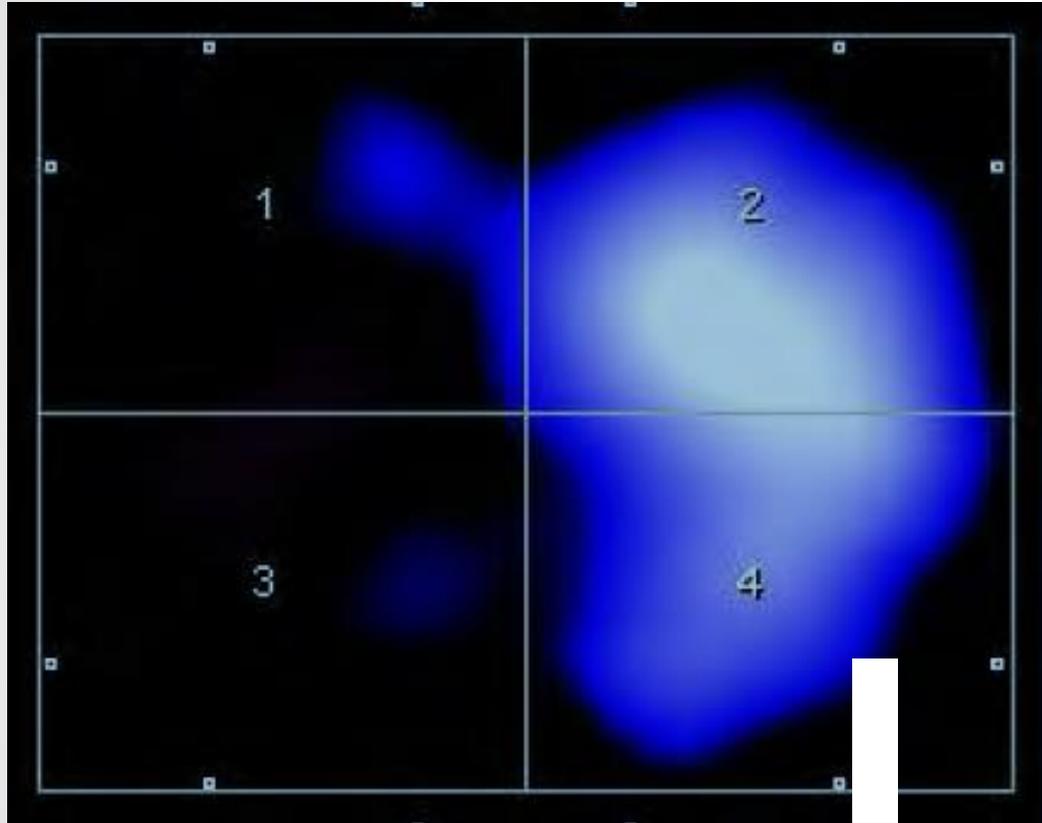


EIT of 00000000???



- ARDS patient

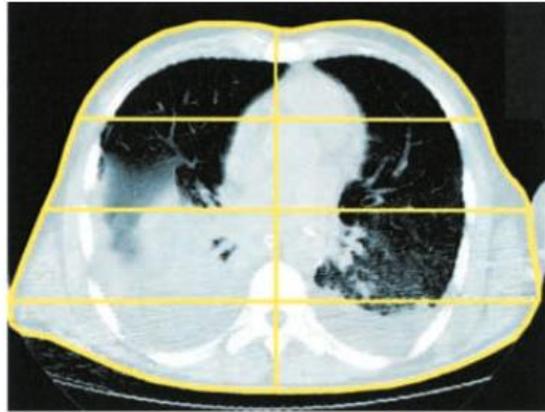
EIT는 Regional Ventilation Defect를 잘 찾아낼까?



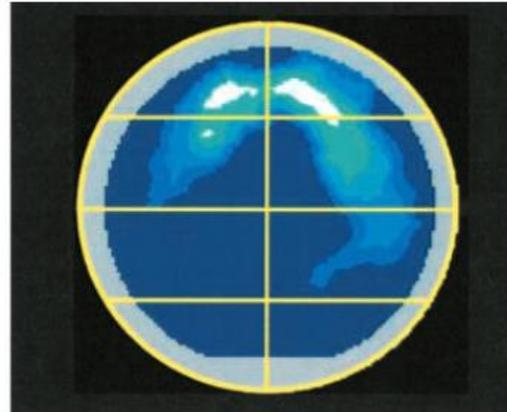
Bildnummer



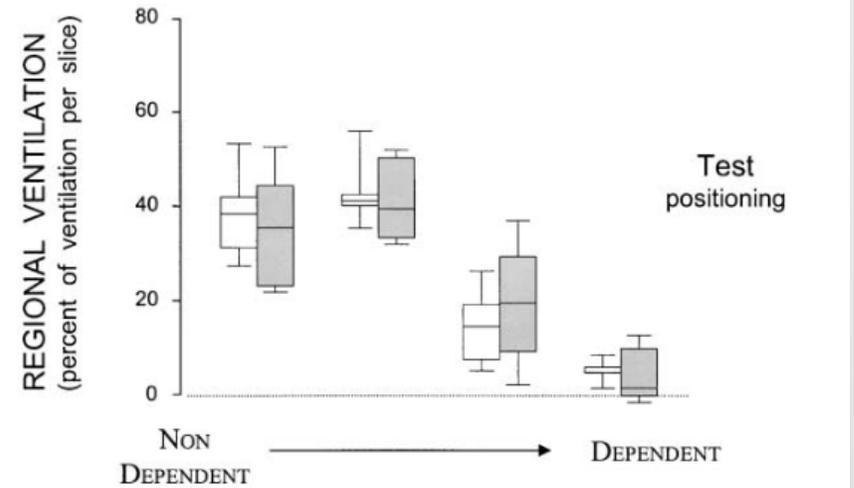
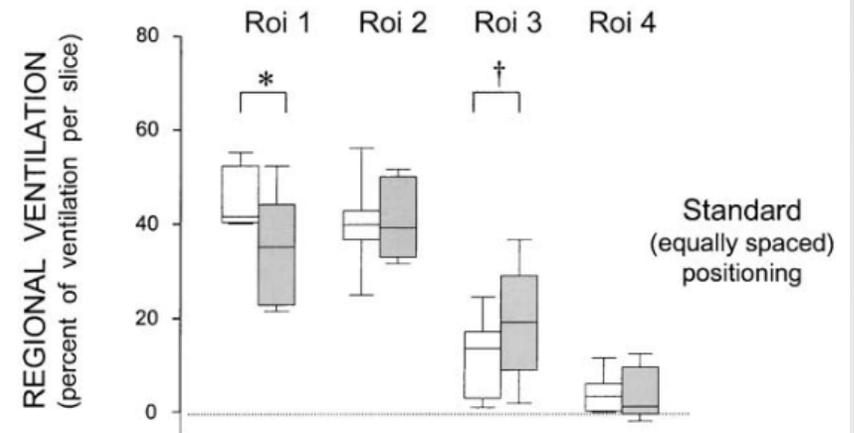
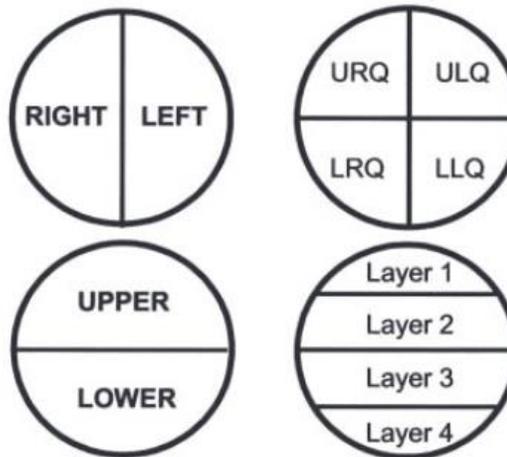
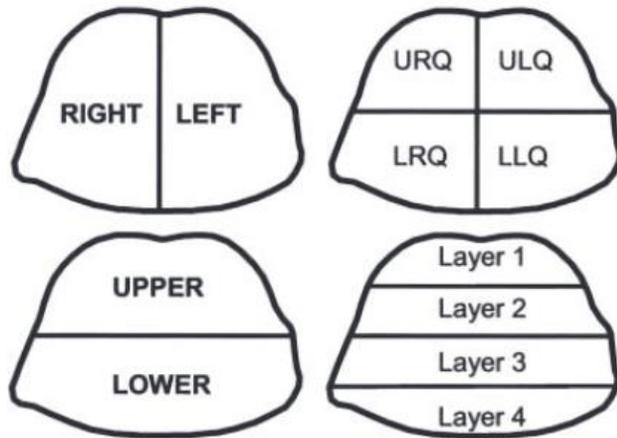
Regional Ventilation; EIT vs CT



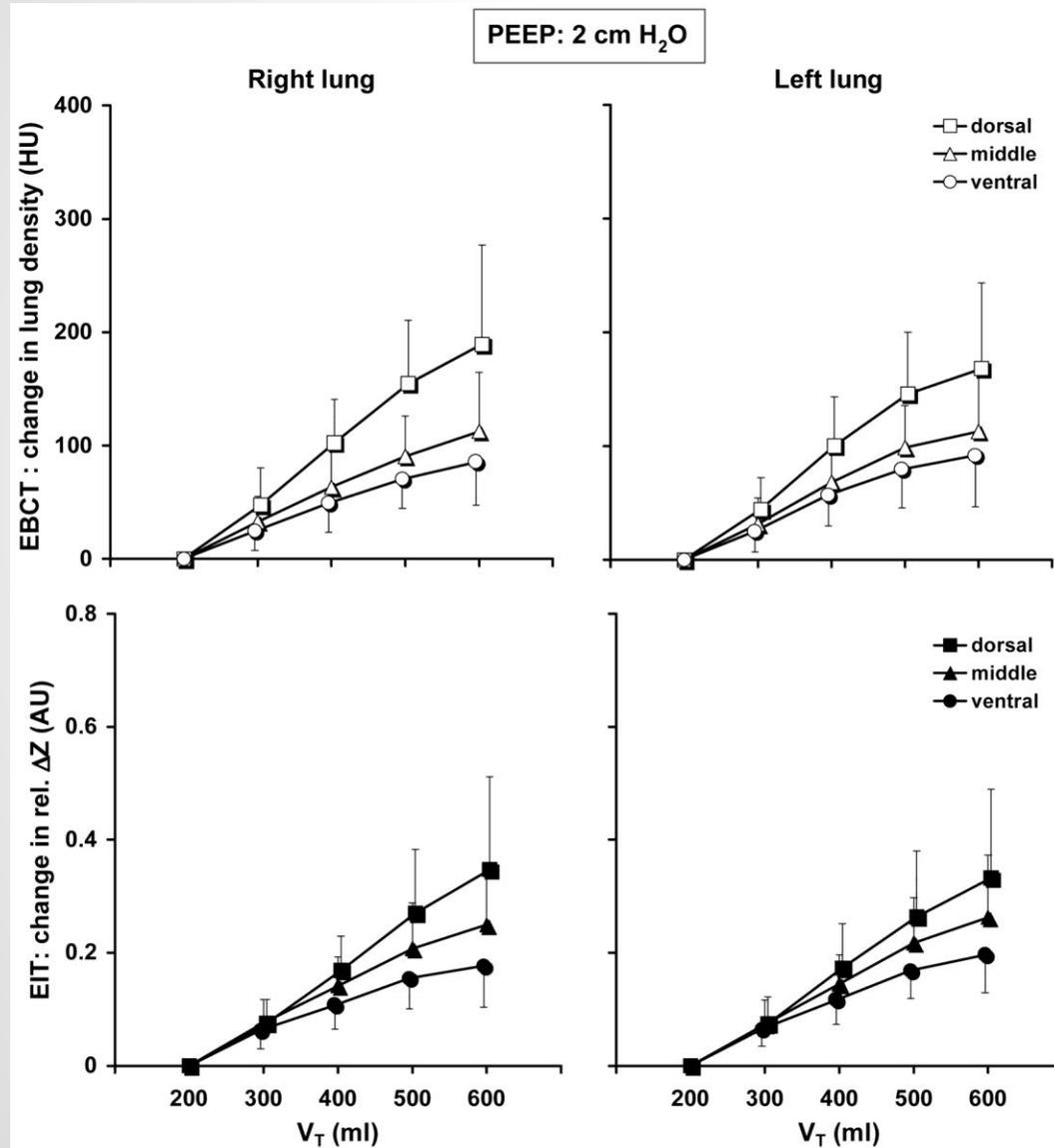
CT



EIT



Regional Ventilation; EIT vs Electron beam CT



급성호흡곤란증후군(ARDS)

임상진료지침

Clinical Practice Guideline of

**Acute
Respiratory
Distress
Syndrome**

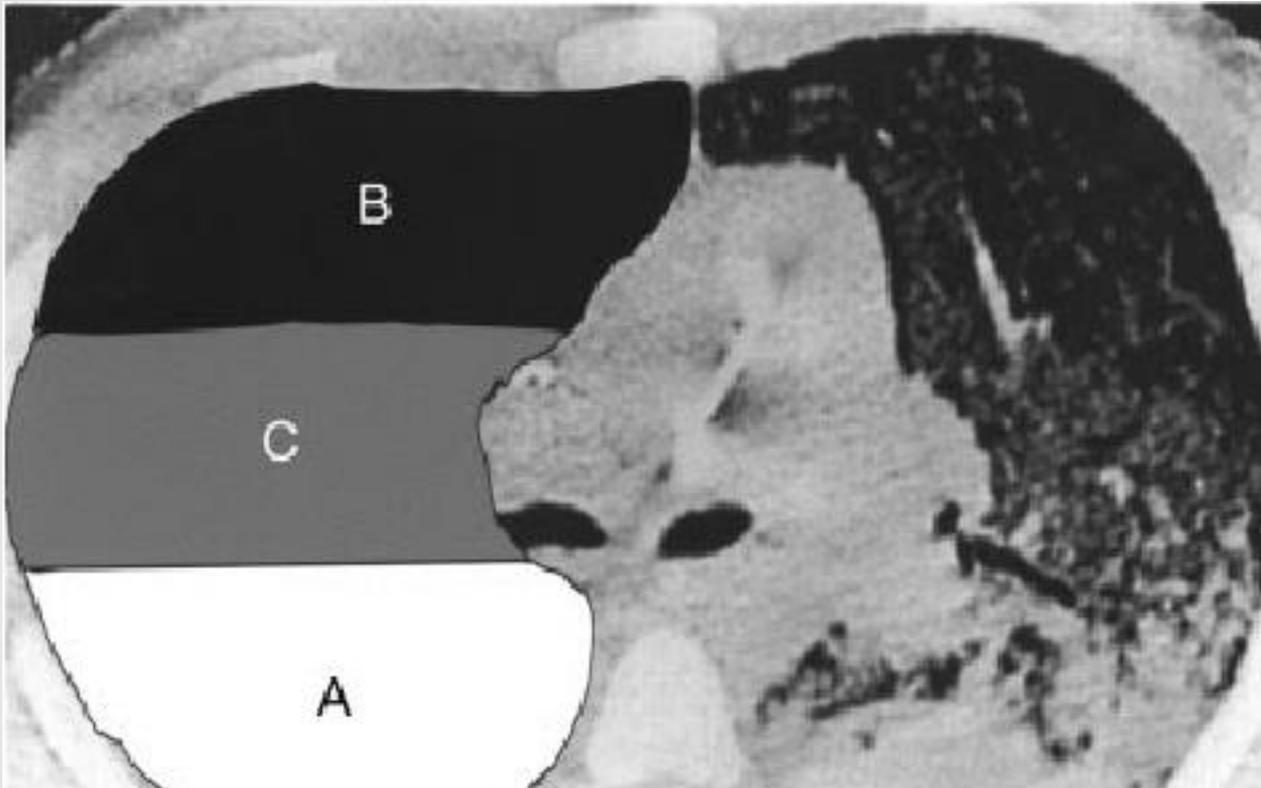


대한결핵 및 호흡기학회



대한중환자의학회

Lung with ARDS



급성호흡곤란증후군 환자의 폐는 기저부(dependent)는 심한 염증반응으로 인한 울혈 및 무기폐, 반대편(non-dependent)은 상대적으로 정상인, 비균질적인(heterogeneous) 염증반응을 특징으로 한다^[1]. 이
런 상태에서 고산전 환기(conventional ventilation) 시에 괴자되는 10-12 ml/kg의 이환호흡량 (tidal

Ventilator Induced Lung Injury, VILI



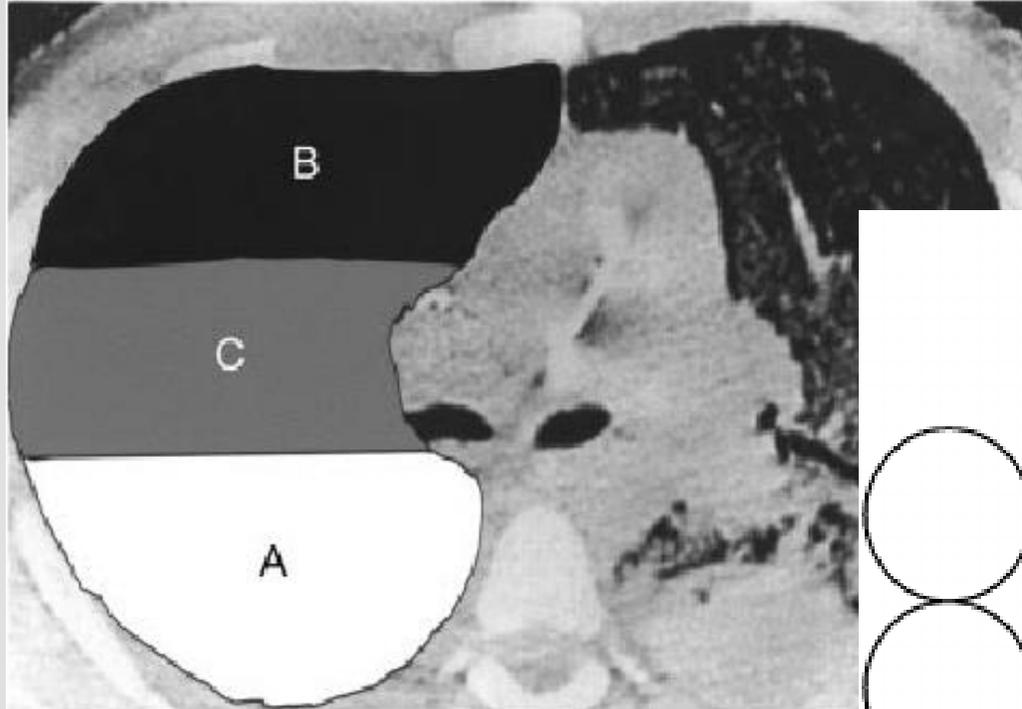
1. 환기기 유발 폐손상 (ventilator-induced lung injury, VILI)

급성호흡곤란증후군 (acute respiratory distress syndrome, ARDS)은 다양한 직·간접적 원인으로 폐포-모세혈관 막 (alveolar-capillary membrane)의 투과성이 증가해 폐포공간 내 부종액이 차고, 활성화된 호중구 및 사이토카인으로 인한 손상, 계면활성제와 응고체계의 이상으로 인해, 산소치료에 반응하지 않는 저산소증 및 비균질적인 염증성 급성폐손상이 발생하는 것이다^[1]. 지난 수십 년 간 급성호흡곤란증후군에 대한 치료적 접근과 중환자 관리에 있어서 괄목할 만한 발전에도, 급성호흡곤란증후군의 사망률은 약 40% 정도로 매우 높다^[2]. 국내에서는 최근 시행된 전국적인 조사가 없지만, 2009년 7월 한 달 동안 전국 28개 대학병원 중환자실에 79명의 급성호흡곤란증후군 환자들이 입원을 하고, 이중 45명이 사망을 해서 57%의 높은 사망률이 보고된 바 있다^[3].

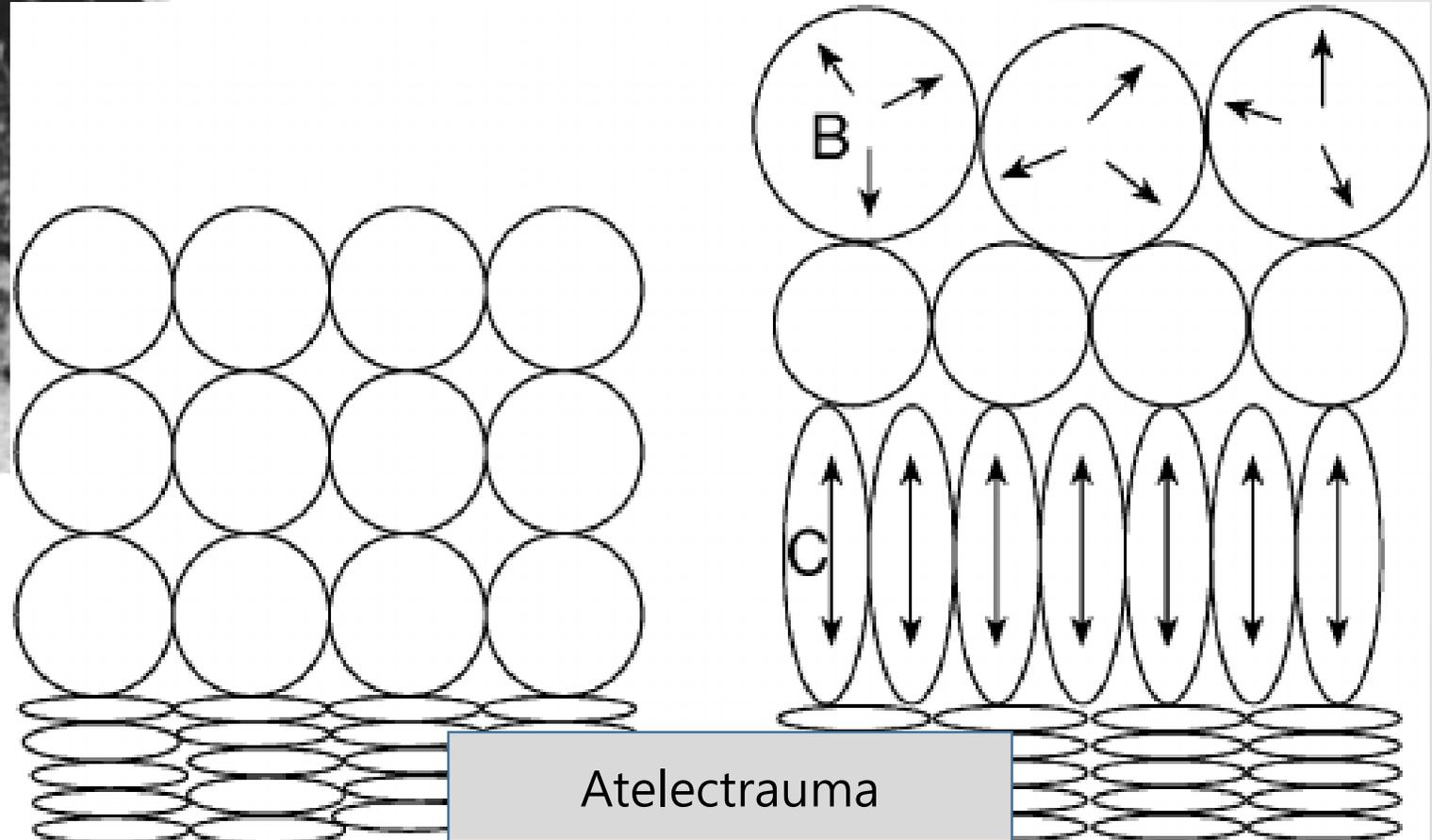
VILI in ARDS



Barotrauma
Volutrauma



Stretch Injury
(Overdistension)



Atelectrauma



2. 폐 보호 환기

폐 보호 환기는 환기기 유발 폐손상의 기전들을 근거로, 고식적으로 적용하는 일회호흡량보다 적은 일회호흡량을 적용하여, 폐포에 직접 영향을 미치는 고원부 기도내압 (plateau airway pressure)을 제한하고, 적절한 날숨끝양압을 적용하여 허탈손상을 감소시켜 환기기 유발 폐손상을 최소화하는 기계 환기 전략이다^[11]. 넓은 의미로는 비균질성을 감소시켜 환기기 유발 폐손상을 예방하고자 하는 복와위 환기 (prone position ventilation) 및 폐포동원술 (alveolar recruitment maneuver), 그리고 기계 환기 및 고농도의 산소로 인한 폐손상의 위험을 감소시키고자 하는 체외막산소공급 (extracorporeal membrane oxygenation, ECMO) 등도 폐 보호 환기라고 할 수 있다.

Lung Protective Ventilation



Low Tidal Volume Ventilation

Overdistension

Limit Plateau Airway Pressure

Overdistension

Proper PEEP Titration

Atelectrauma

Prone Positioning

Atelectrauma

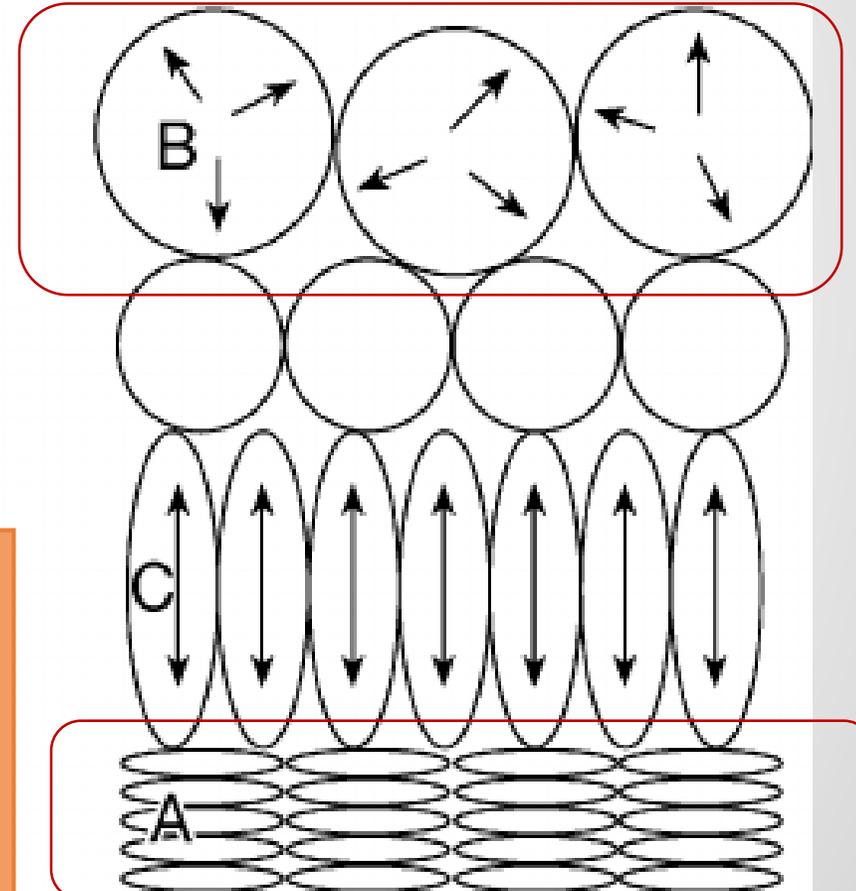
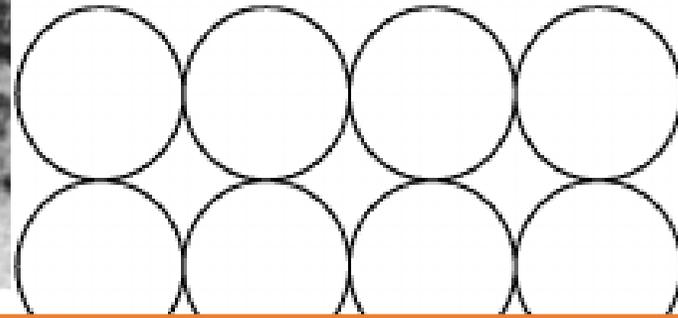
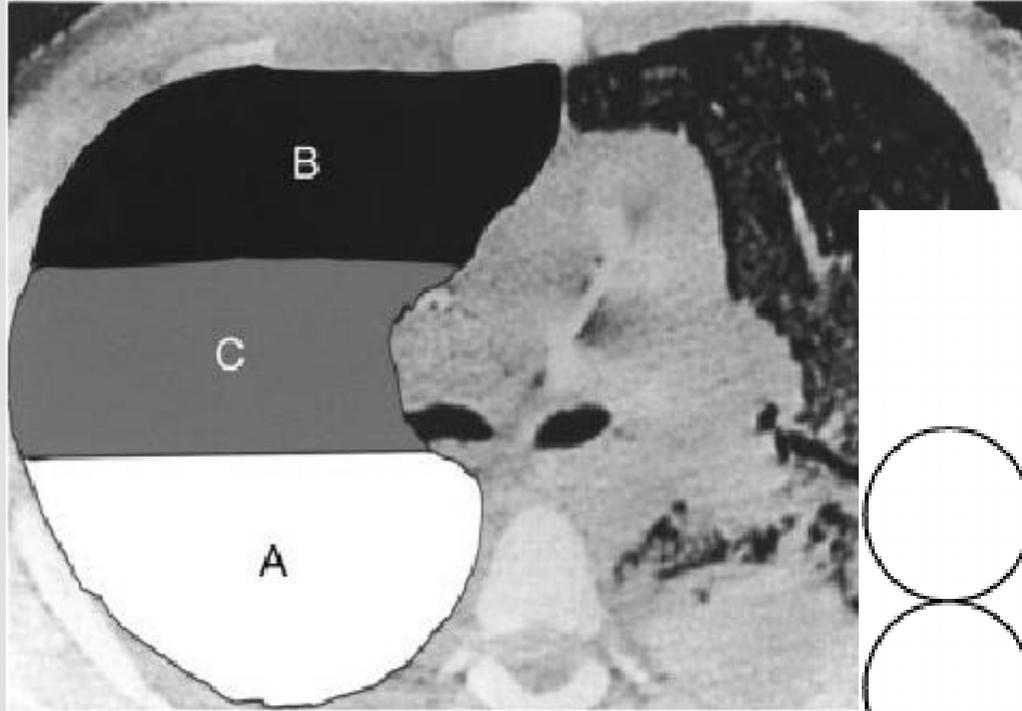
Recruit Maneuver

Atelectrauma

ECMO

Overdistension

VILI in ARDS



**EIT를 이용하면
Overdistension 되었거나,
collapse 된 alveoli를 확인할 수 있다?**

EIT for Overdistended Alveoli Detection

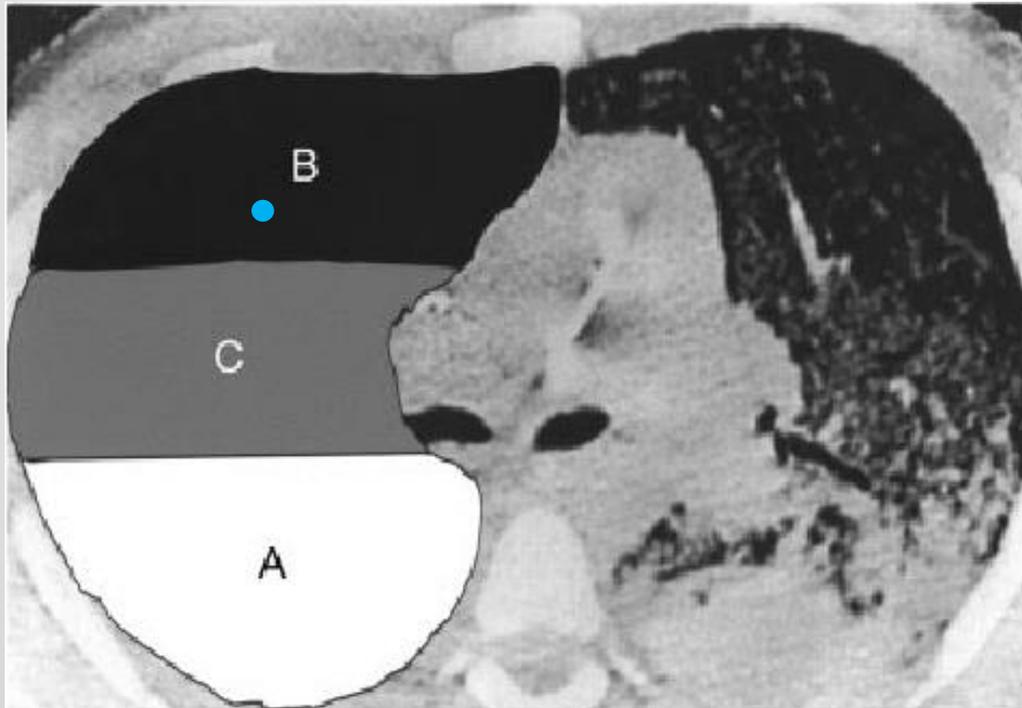


Eduardo L. V. Costa
João Batista Borges
Alexandre Melo
Fernando Suarez-Sipmann
Carlos Toufen Jr
Stephan H. Bohm
Marcelo B. P. Amato

Bedside estimation of recruitable alveolar collapse and hyperdistension by electrical impedance tomography

$$\text{Compliance}_{\text{pixel}} = \frac{\Delta Z}{P_{\text{plateau}} - \text{PEEP}}$$

Finding Overdistended Alveolous



PEEP: 20 / TV: 50

PEEP: 14 / TV: 100

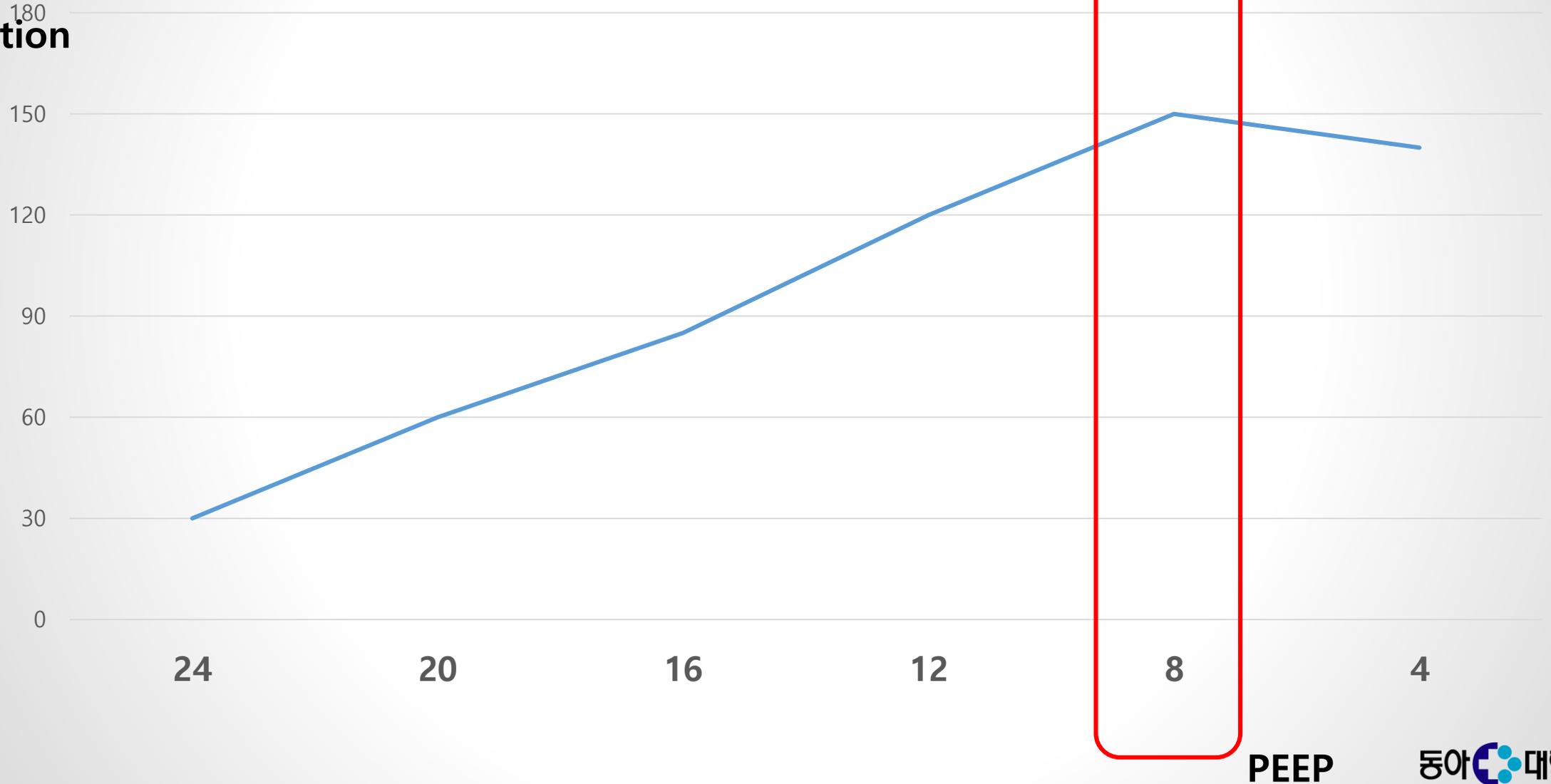
PEEP: 8 / TV: 150

PEEP: 2 / TV: 100

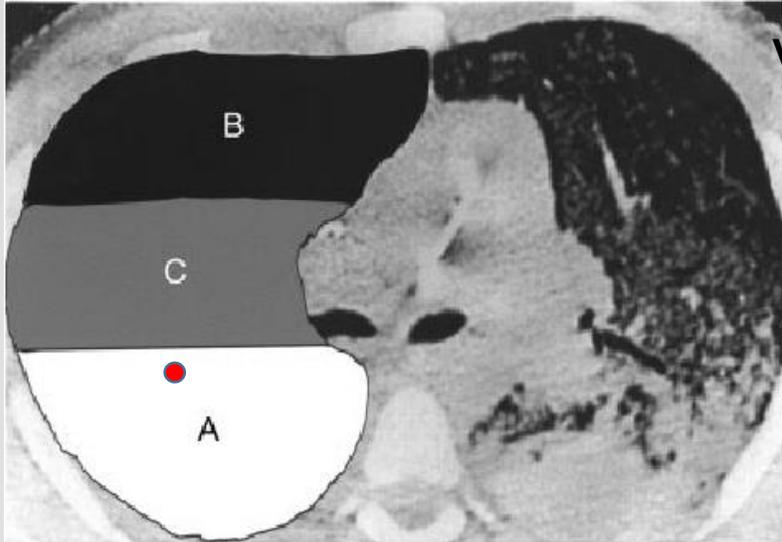
PEEP & Tidal Variation in a Single Alveolous



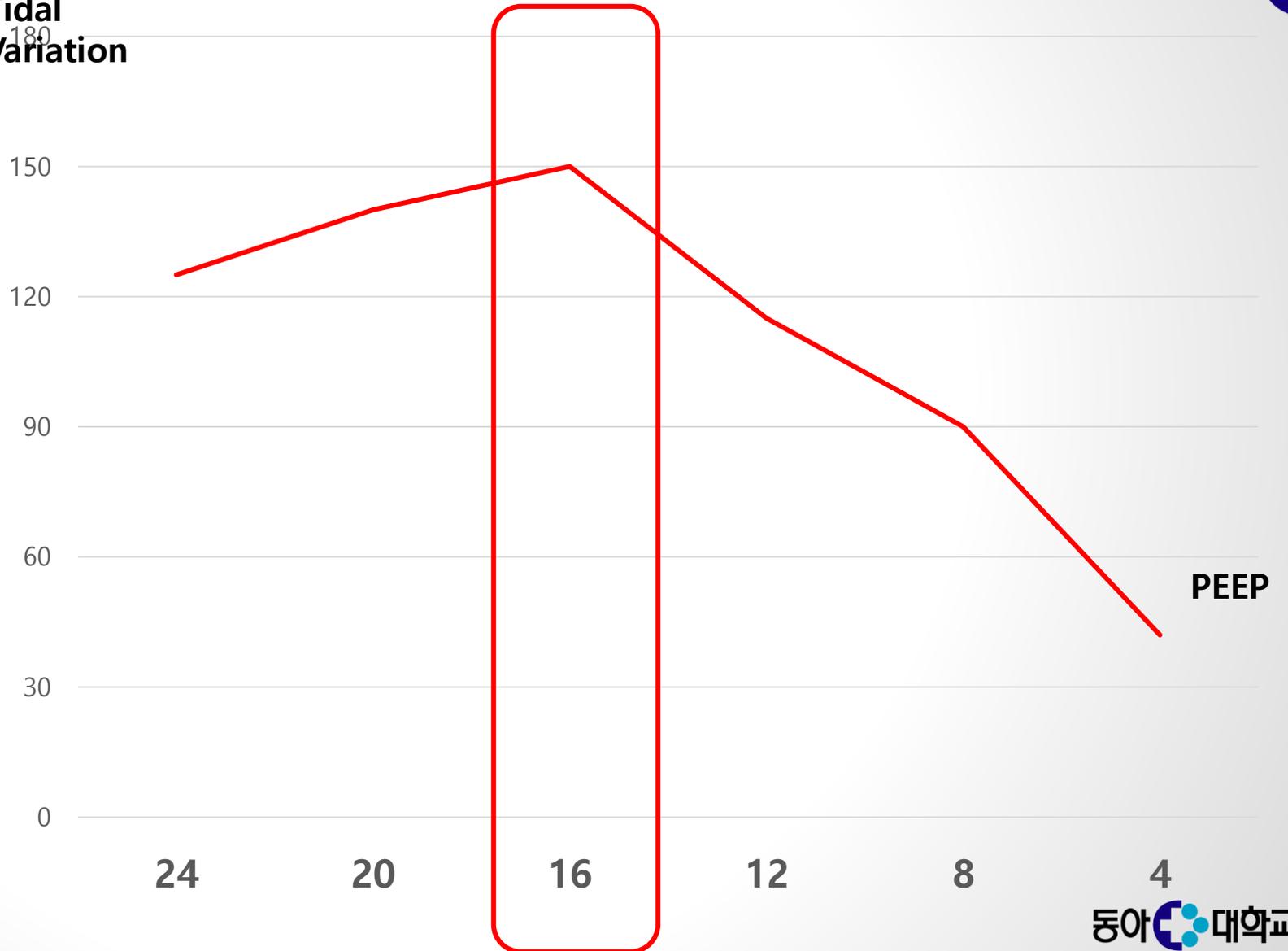
Tidal
Variation



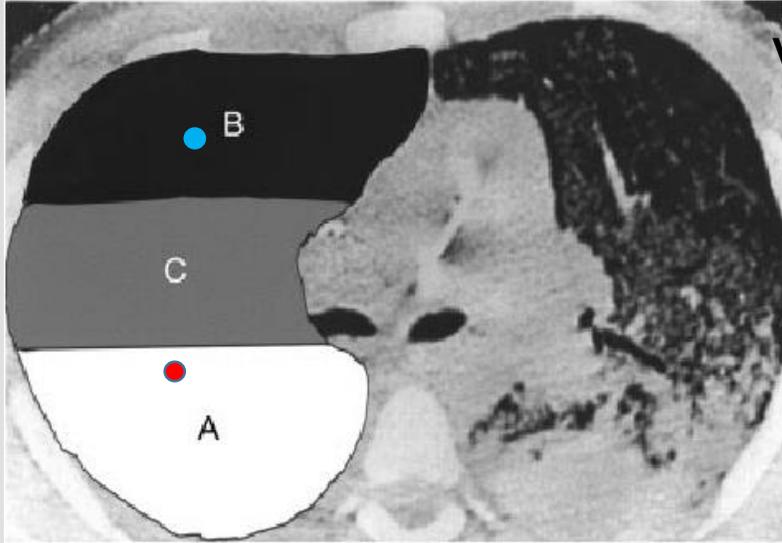
PEEP & Tidal Variation in a Single Alveolous



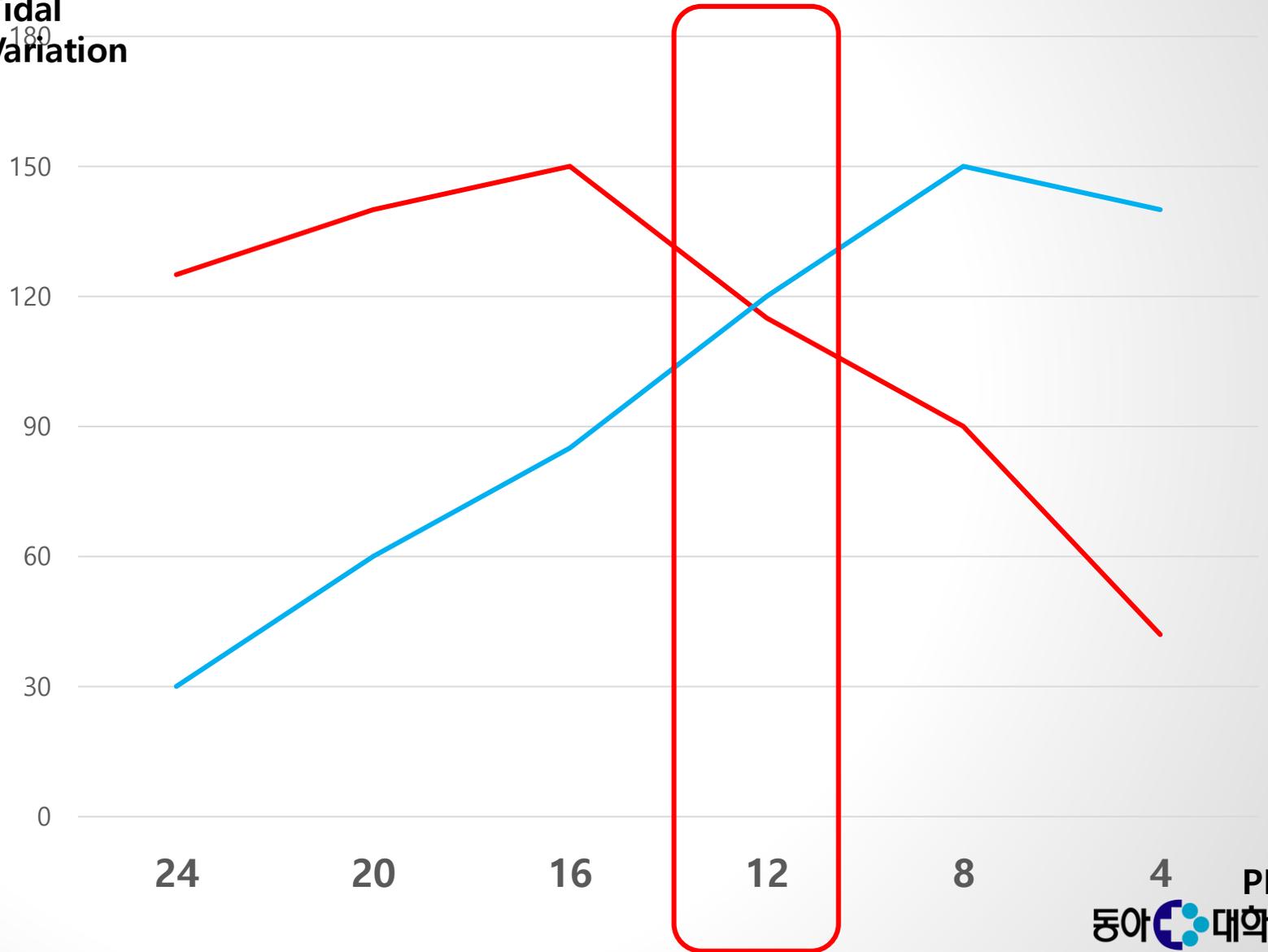
Tidal
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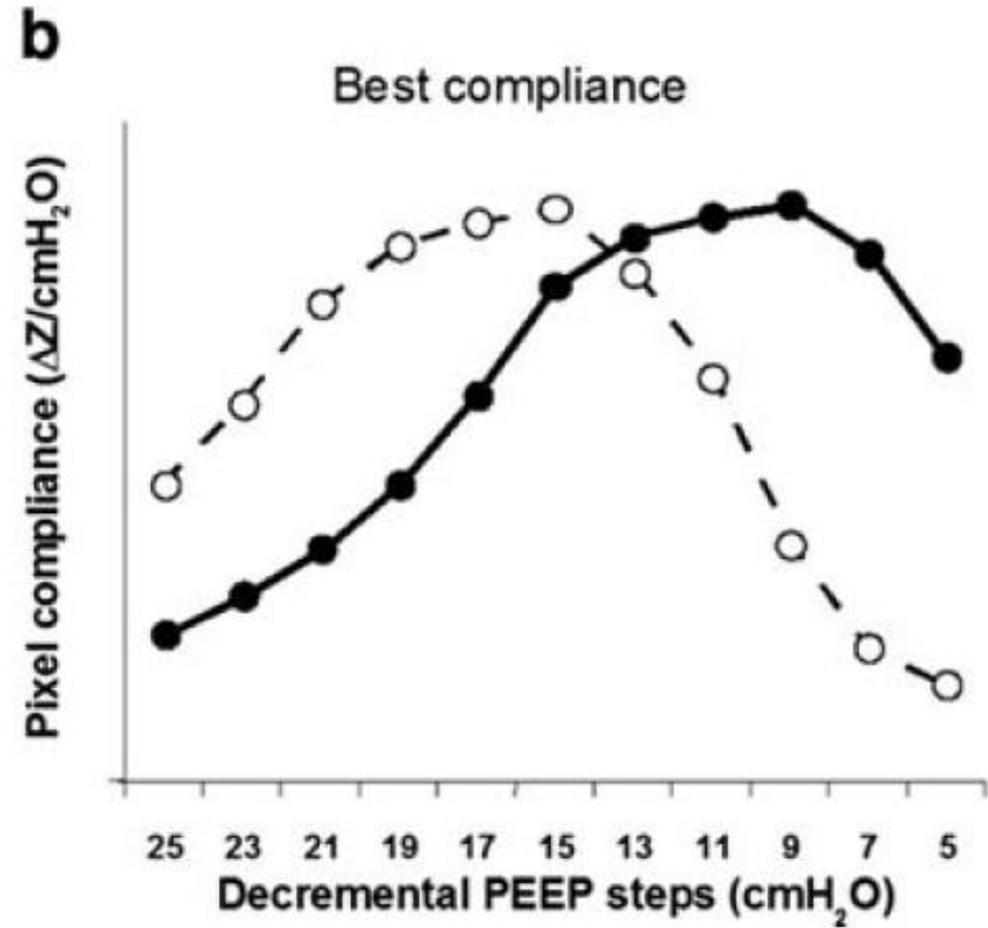
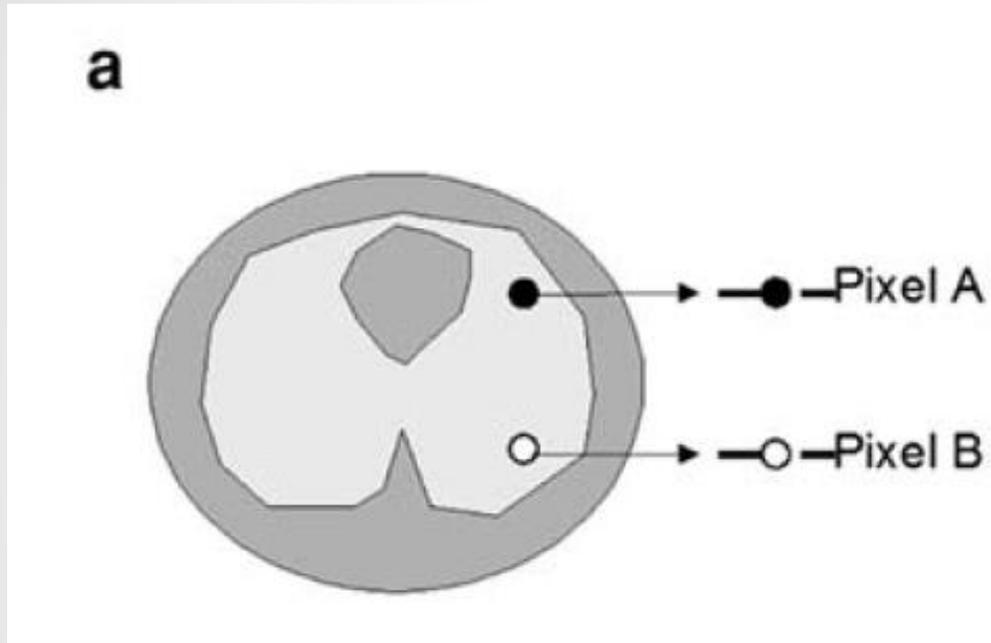


PEEP & Tidal Variation in a Single Alveolous

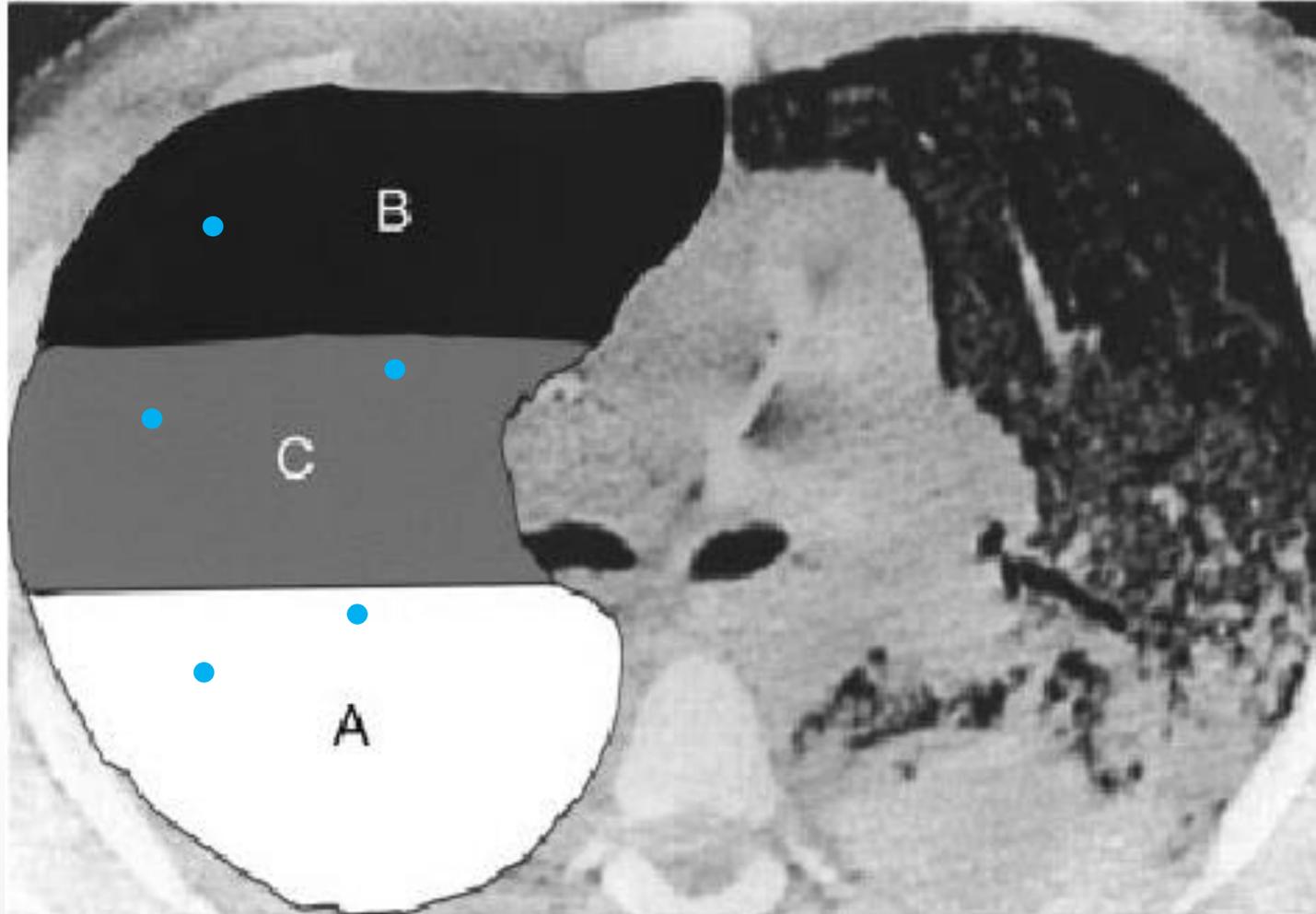


Tidal
Variation

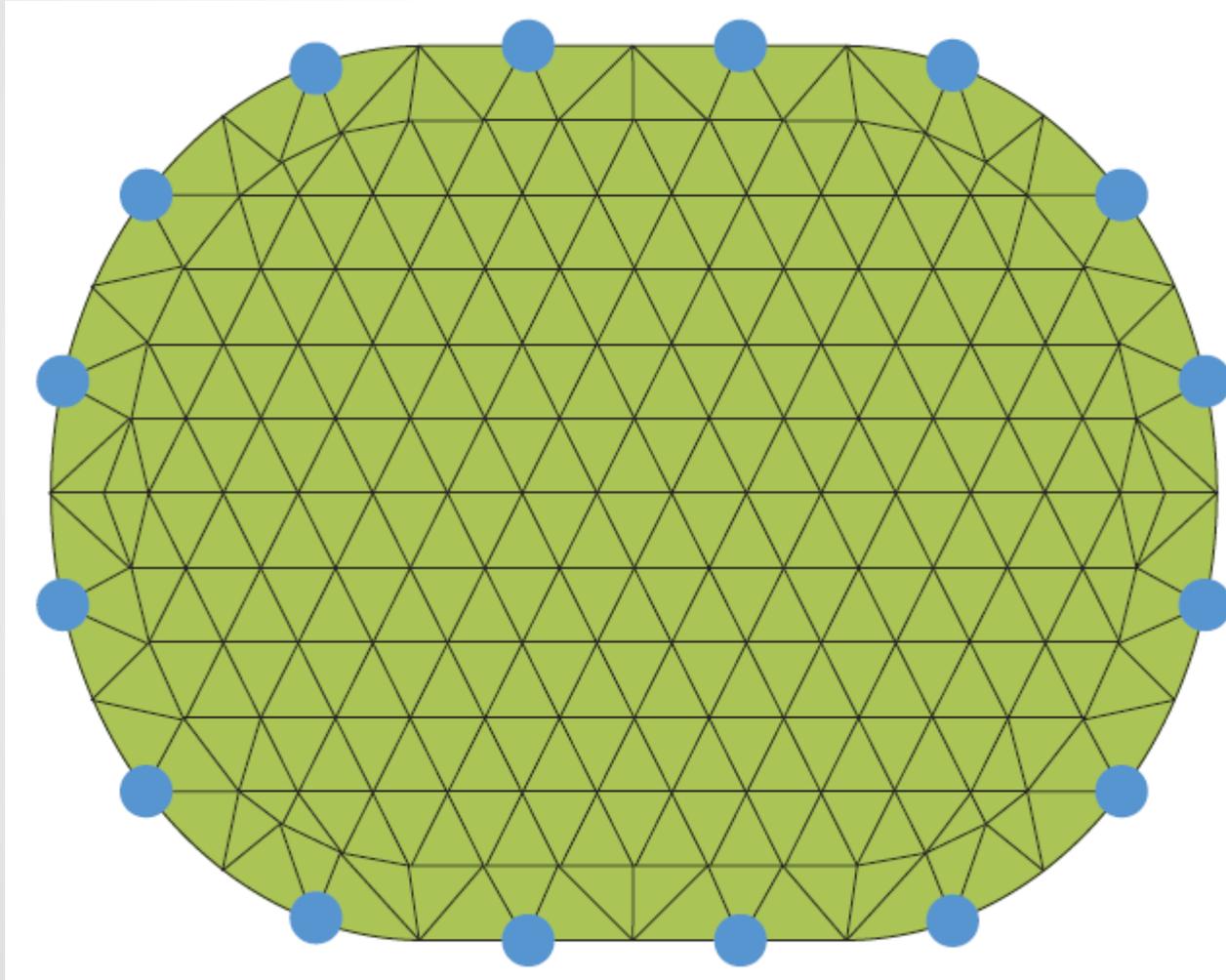




Finding Best PEEP Level!!



Segments of EIT

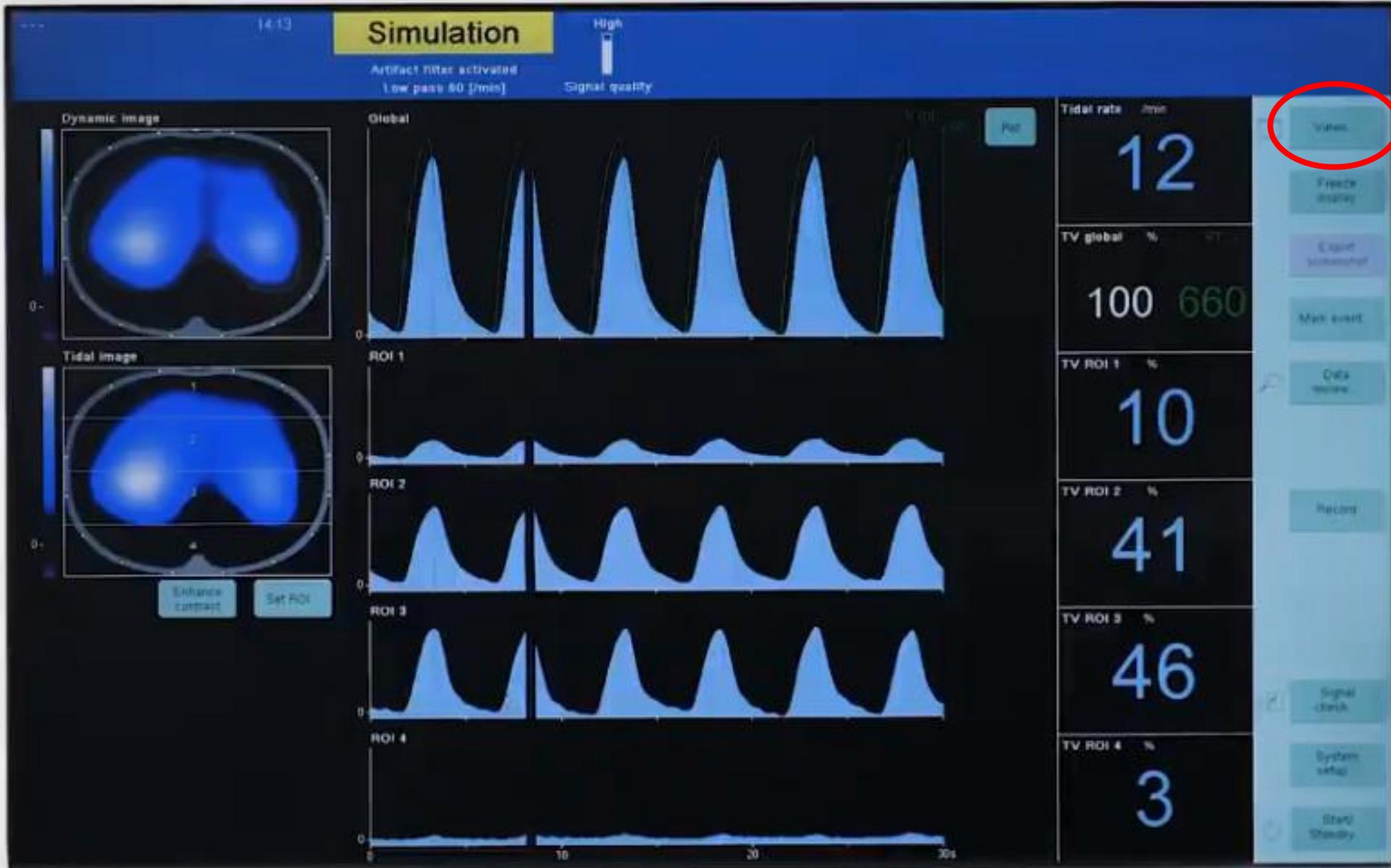


- 340 element
- 50 EITs / sec

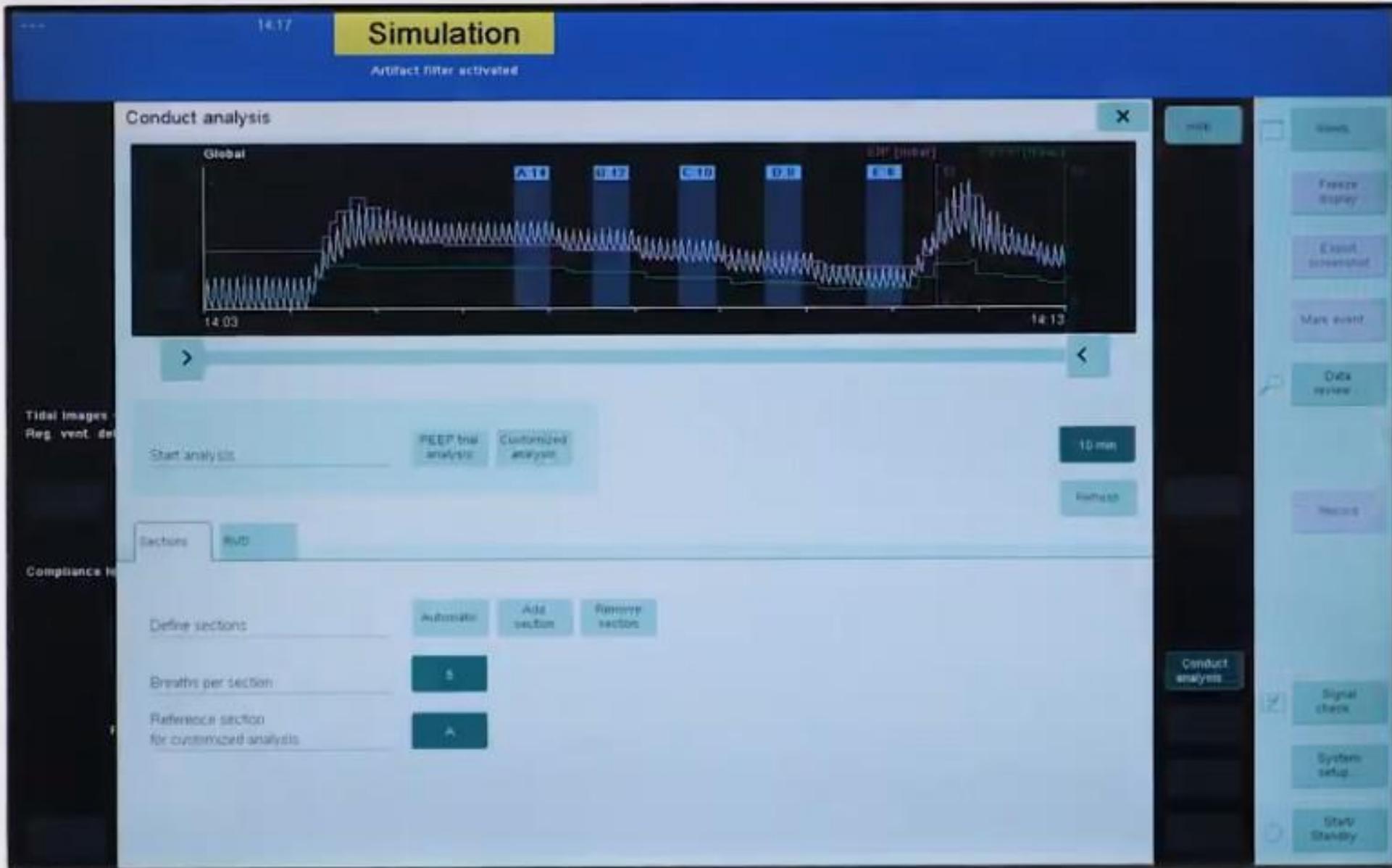
Decremental PEEP Trial



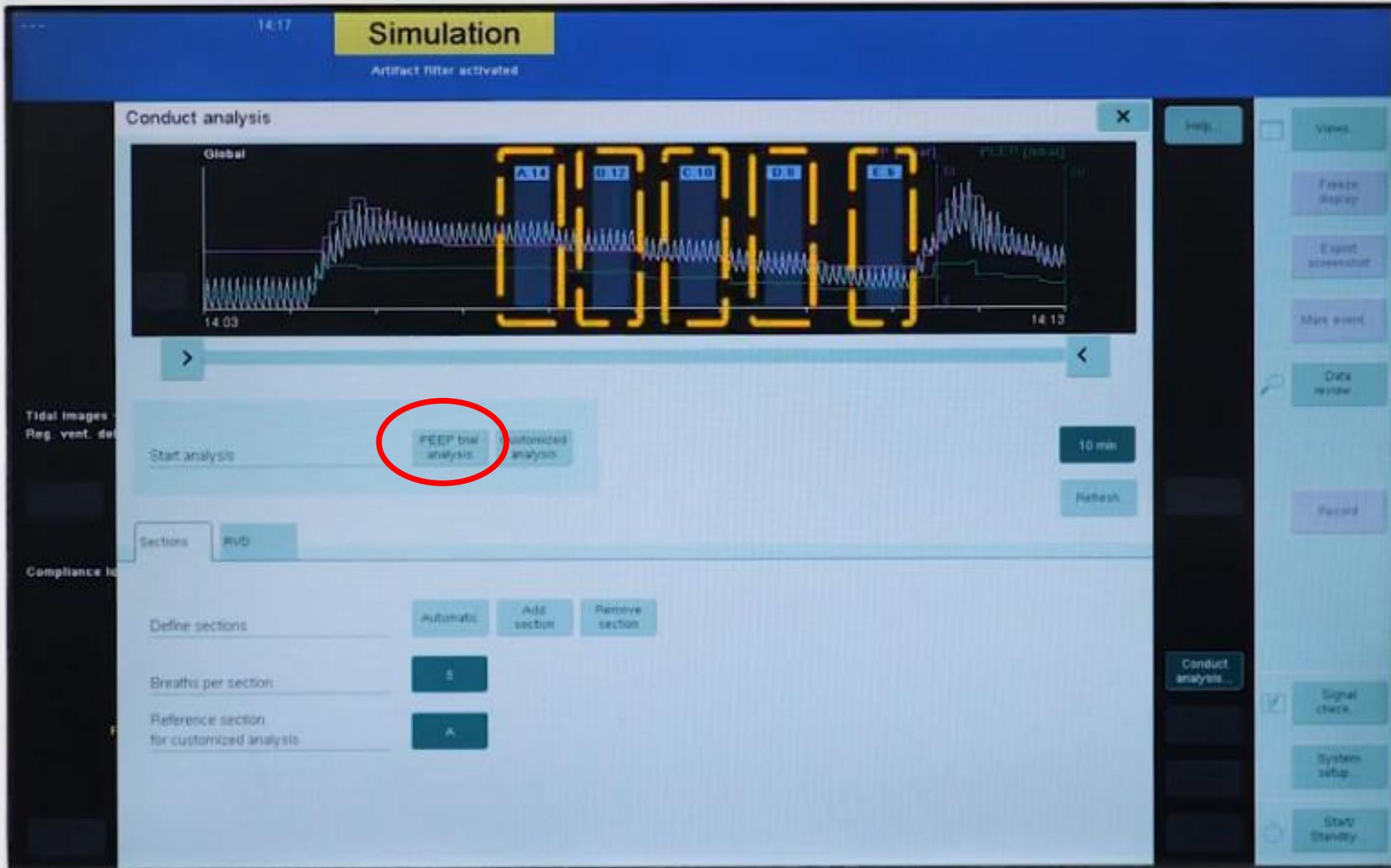
PEEP Trial Analysis



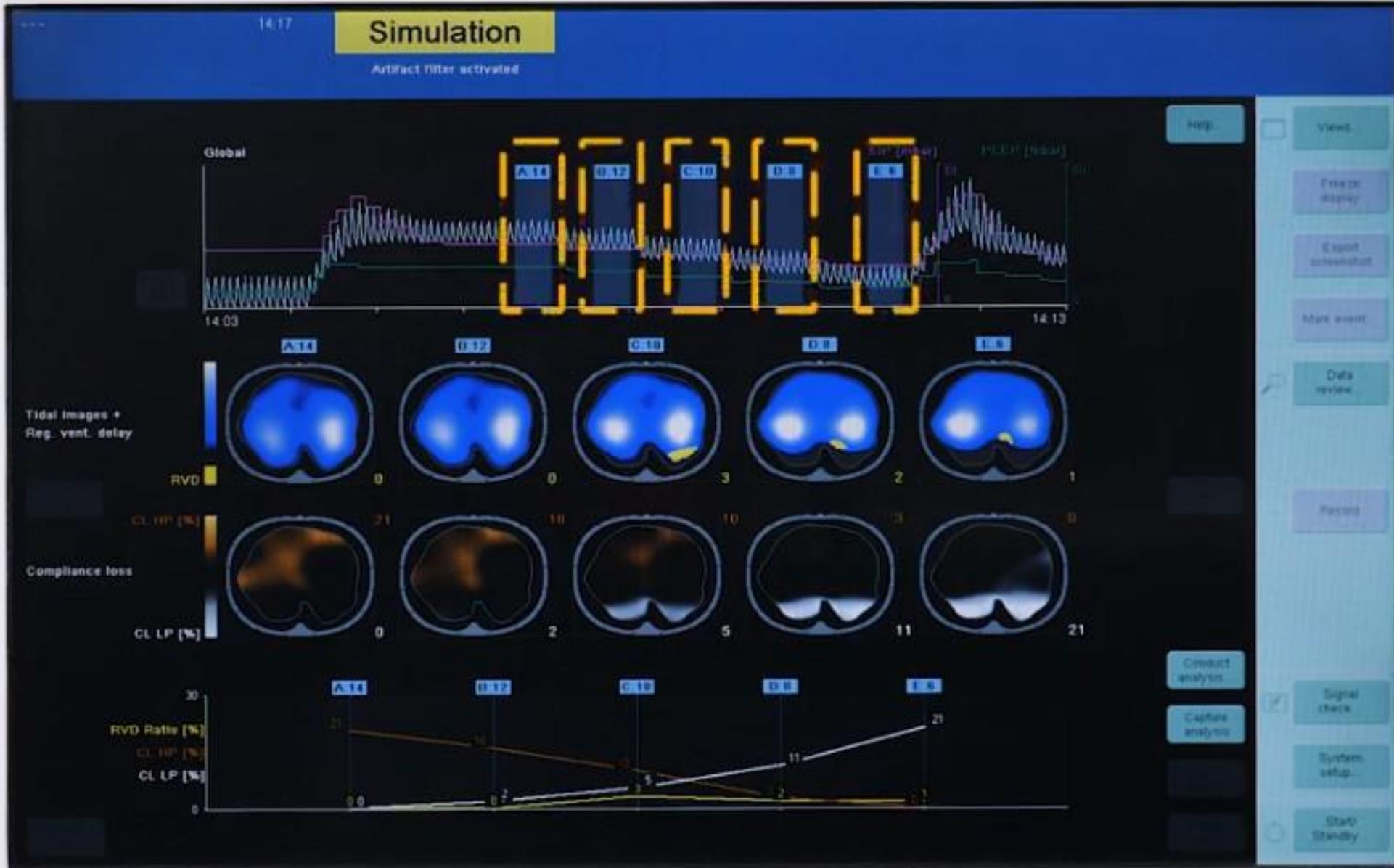
PEEP Trial Analysis



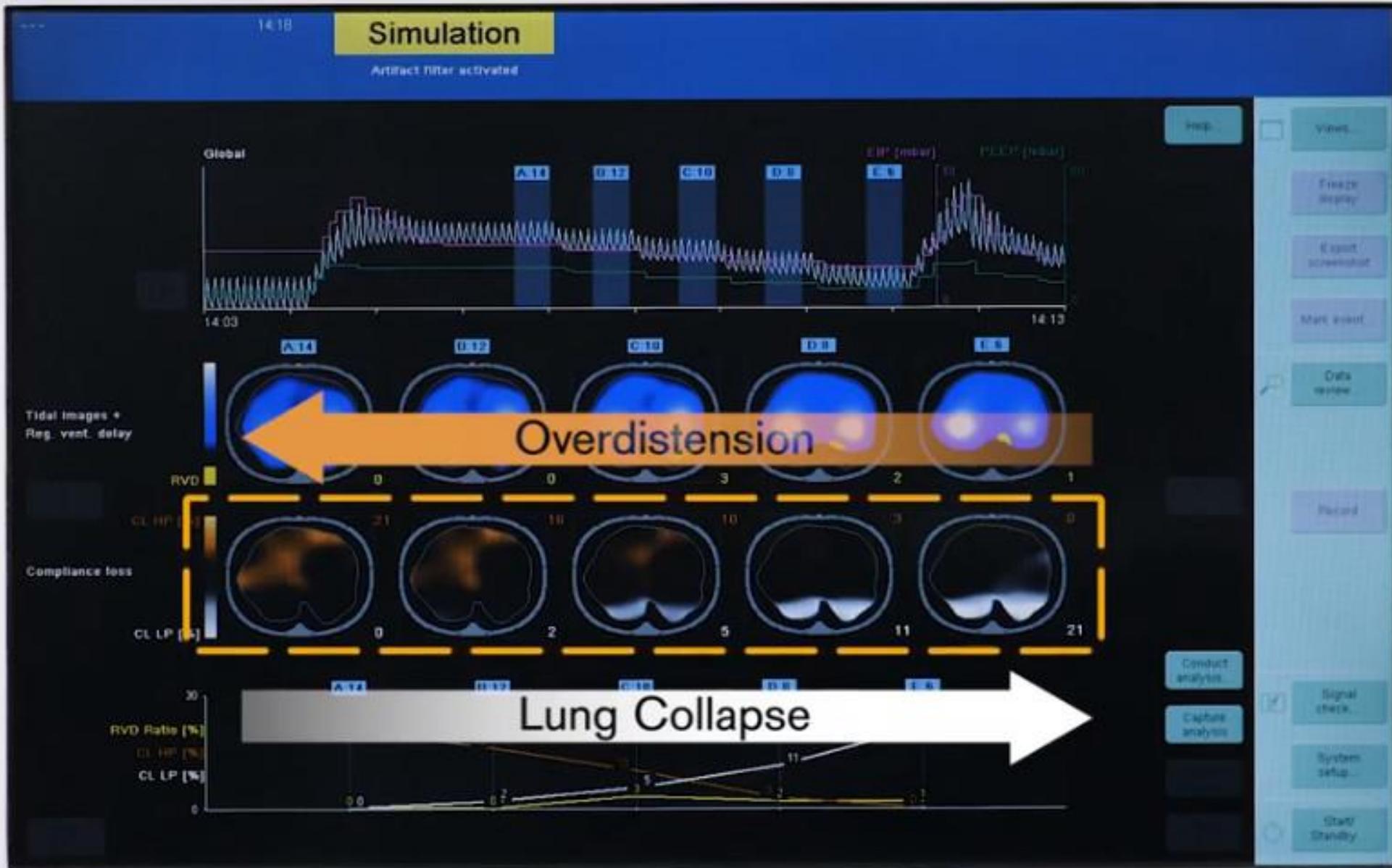
PEEP Trial Analysis



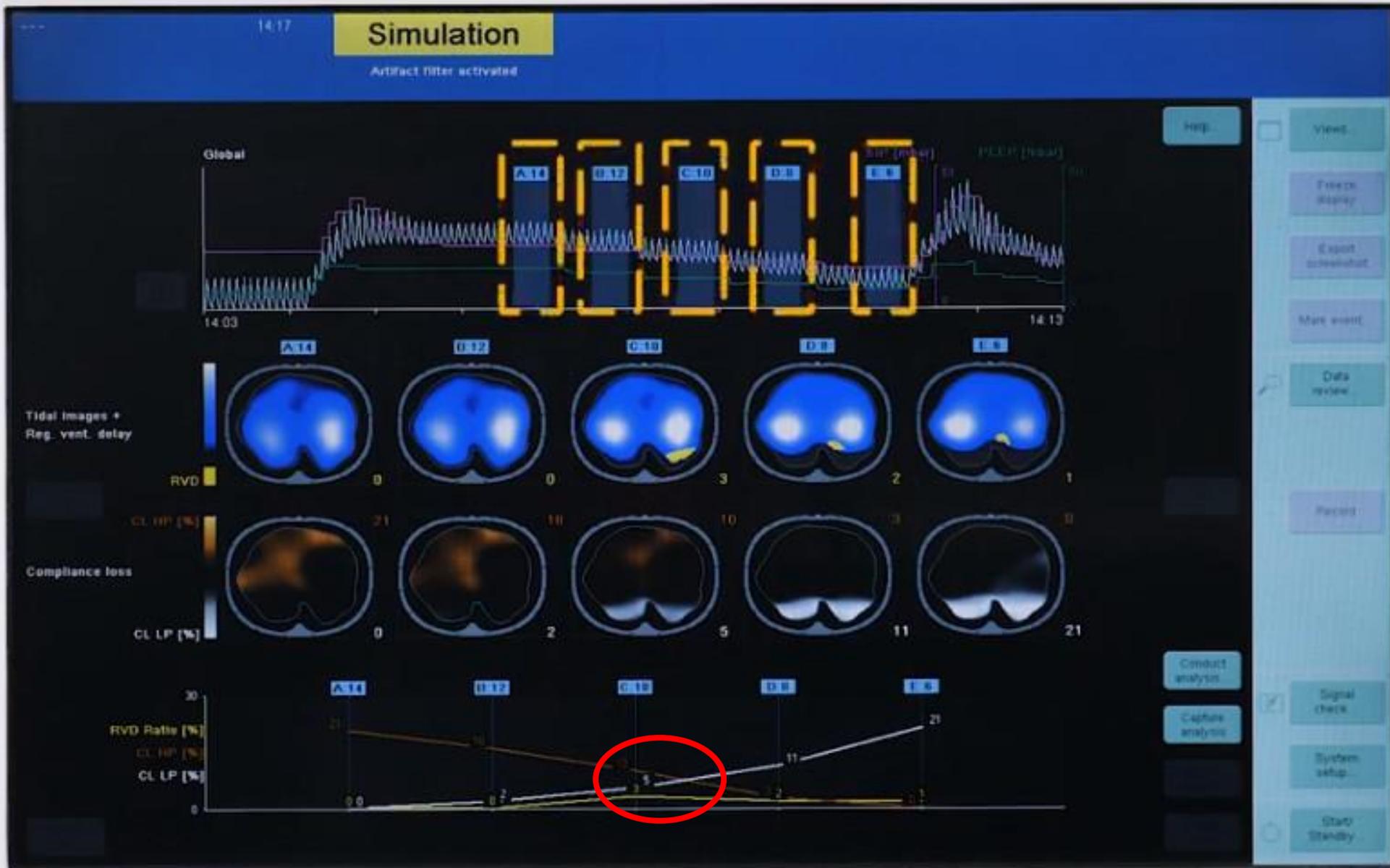
PEEP Trial Analysis

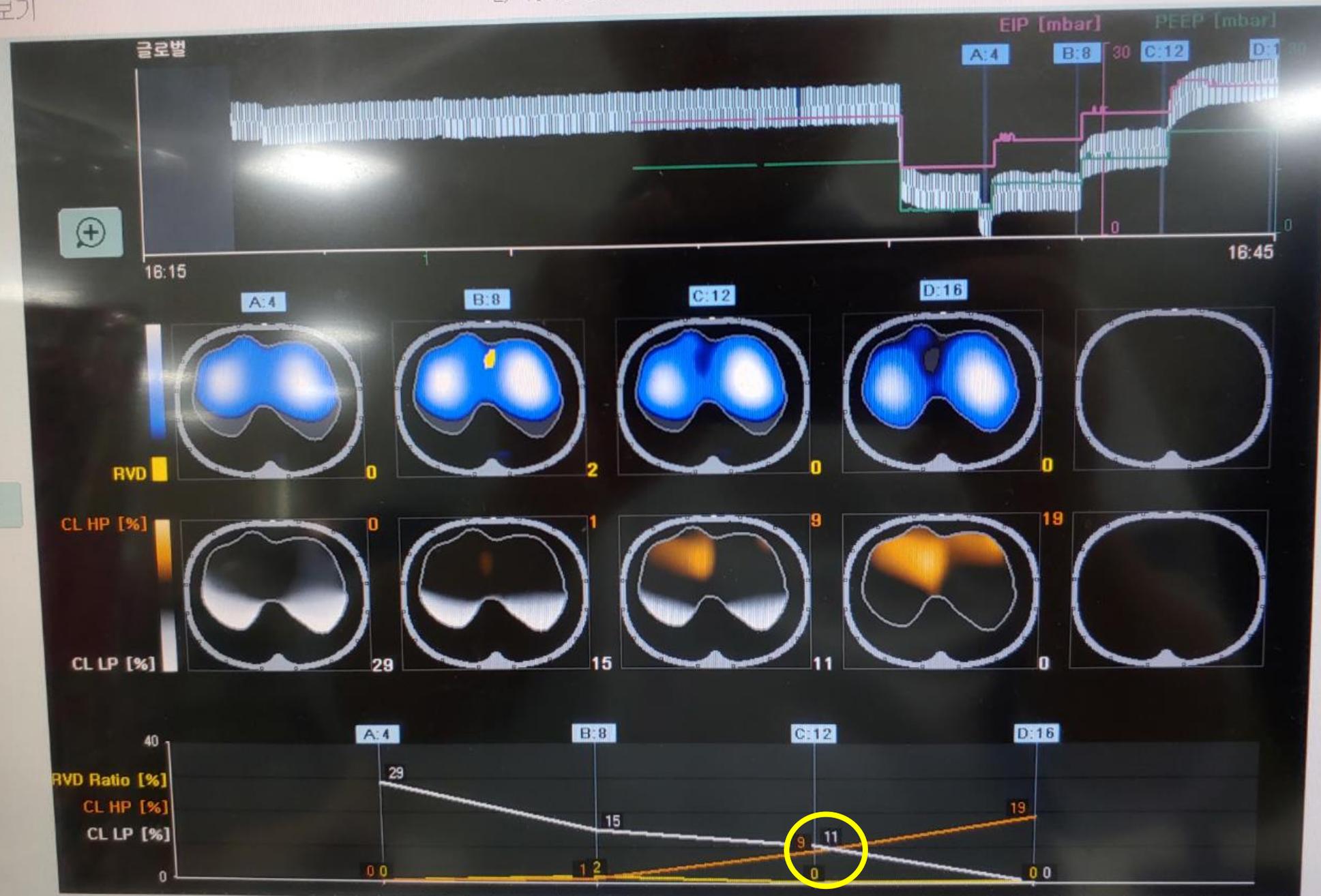


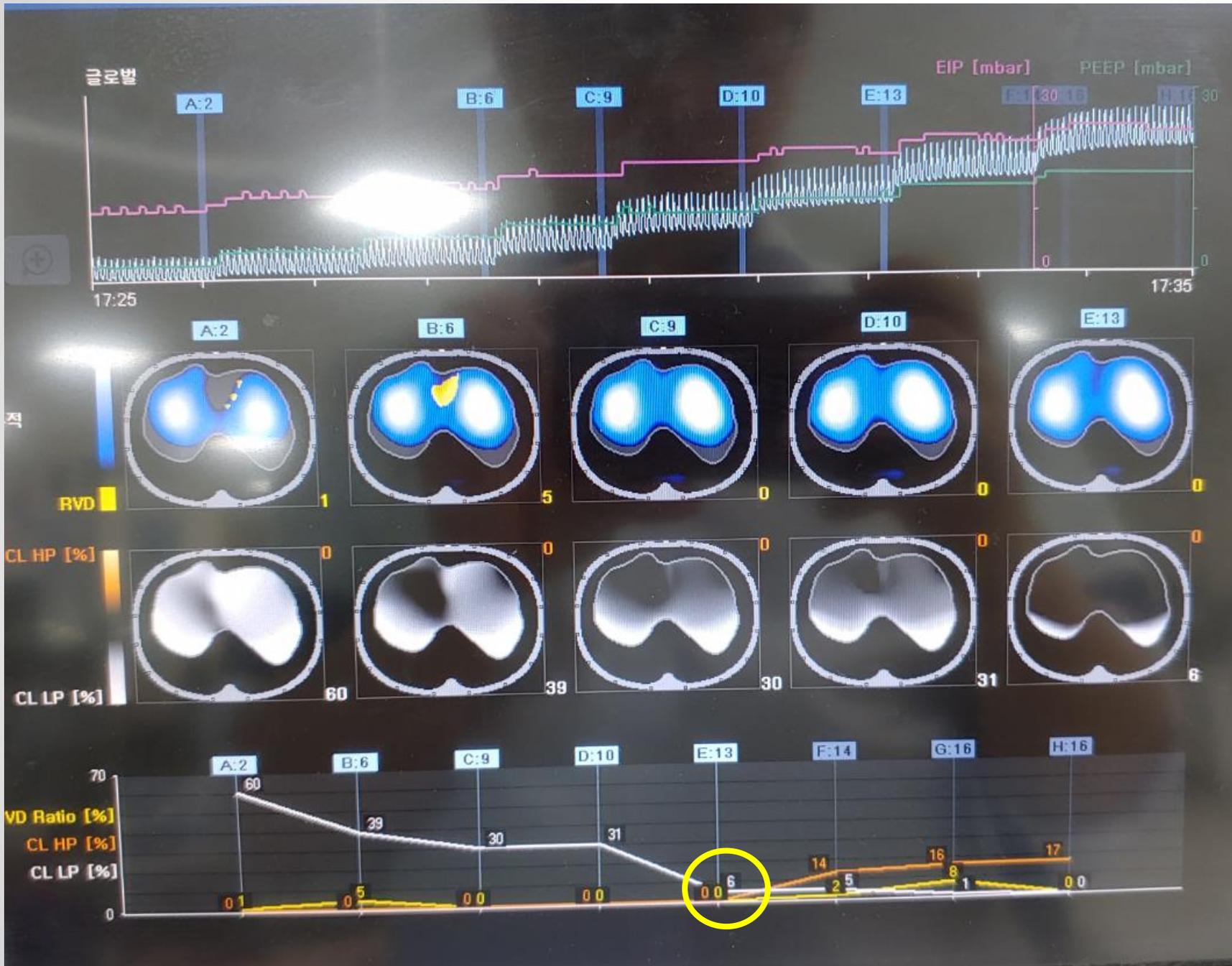
PEEP Trial Analysis



PEEP Trial Analysis





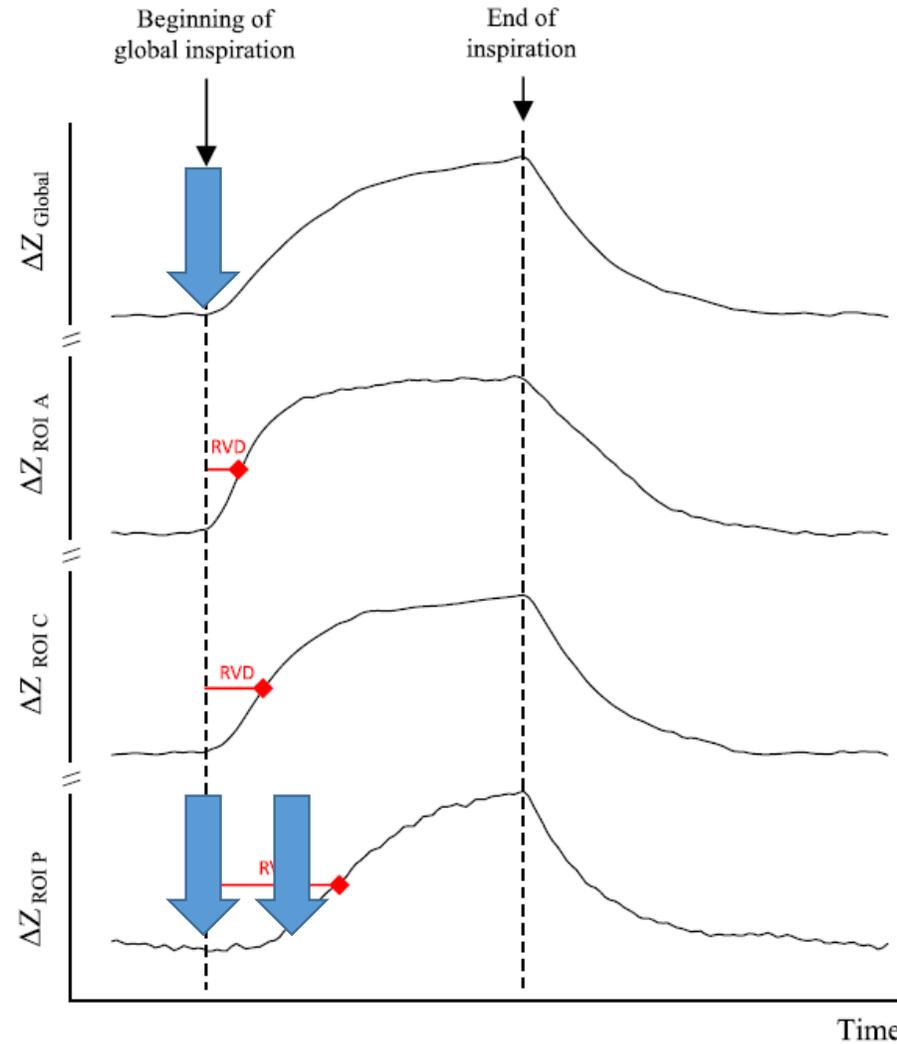
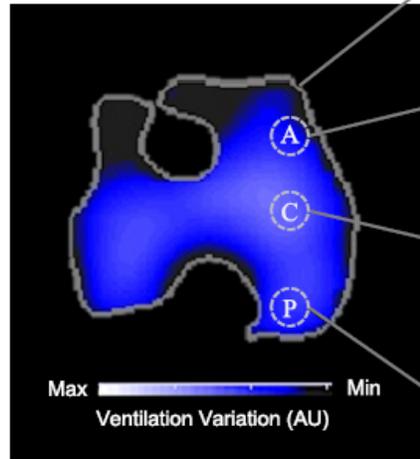


Clinical Application of EIT for ARDS

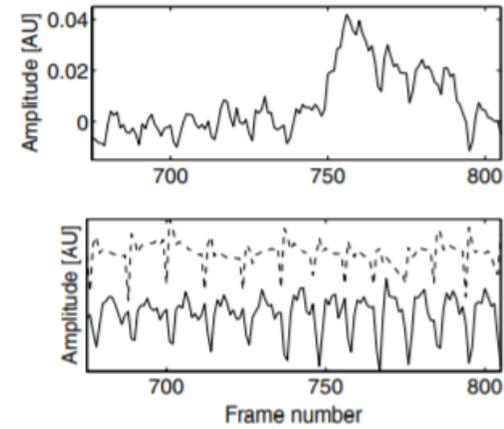
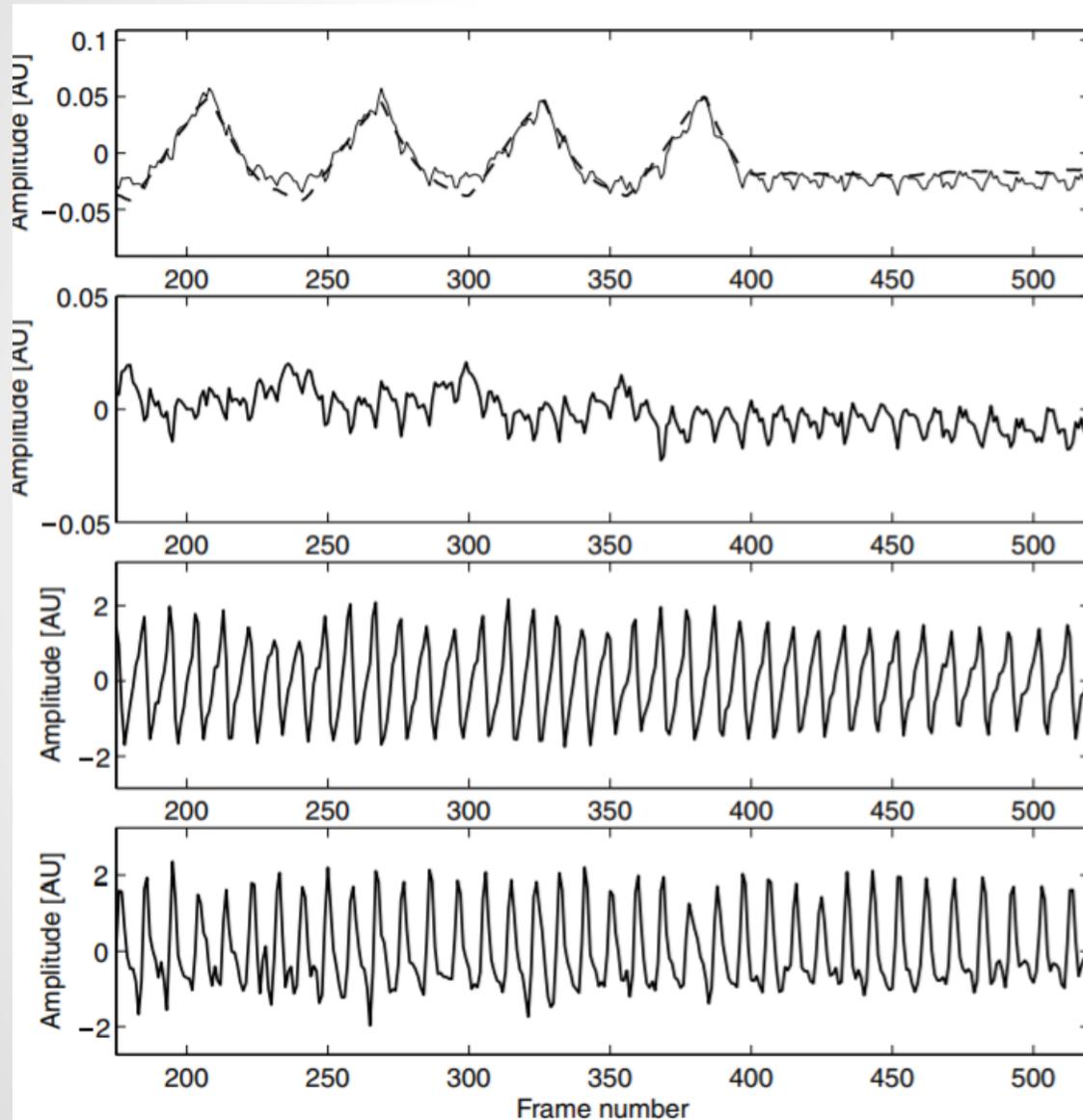


- Lung collapse & overdistension
- Recrutable alveoli prediction
- Detecting airway closure
- Pneumothorax detection
- Ventilator dyssynchrony
- Regional ventilation delay

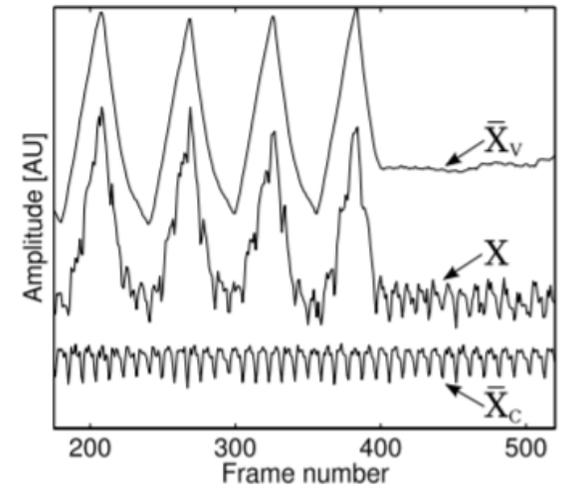
Regional Ventilation Delay



Filtering Raw EIT Data



(a)

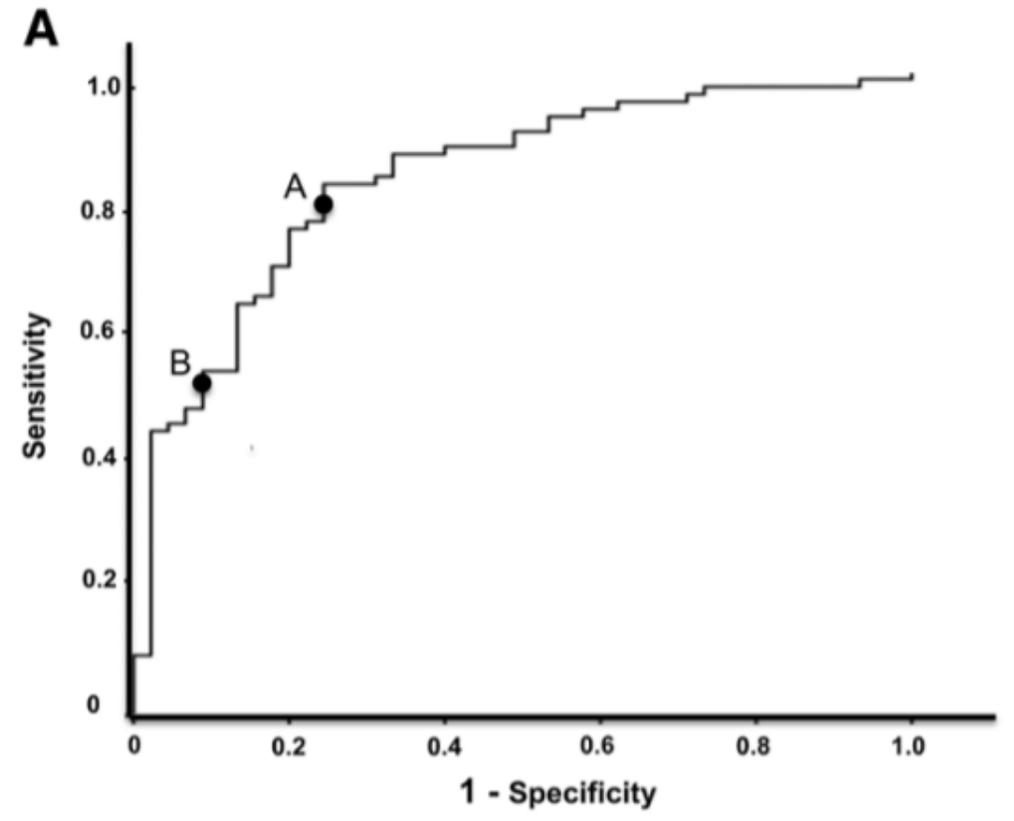
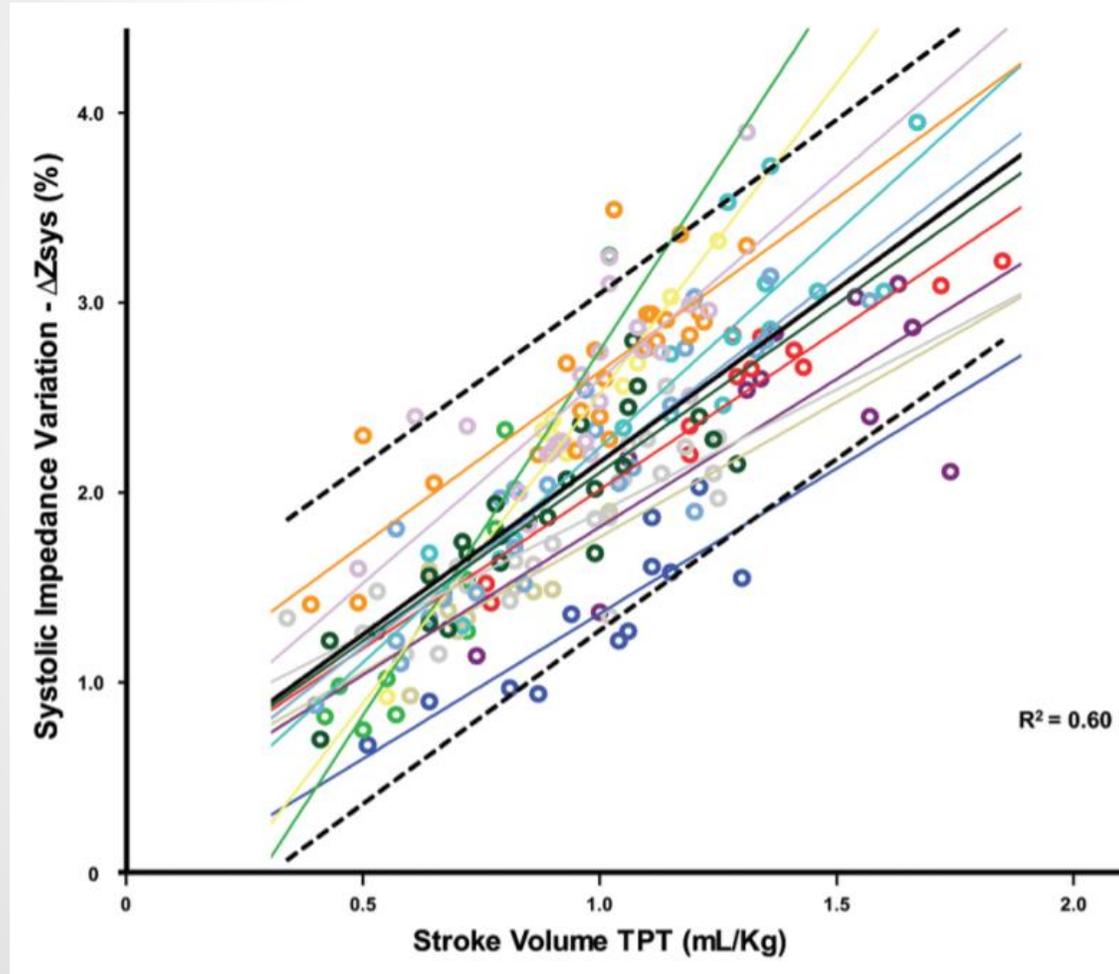


(b)

Estimation of Stroke Volume and Stroke Volume Changes by Electrical Impedance Tomography



Fernando José da Silva Ramos, MD,* André Hovnanian, MD, PhD,*† Rogério Souza, MD, PhD,†
Luciano C. P. Azevedo, MD, PhD,* Marcelo B. P. Amato, MD, PhD,† and Eduardo L. V. Costa, MD, PhD*†





How To

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Electrical Impedance Tomography



- Non-Invasive
- Radiation free
- Real time
- Promising (development → clinical application)

Electrical Impedance Tomography in ARDS



- Brand new Information
- Efficacy in MV / ARDS / ...
- Further studies...