Tracking lung recruitment and regional tidal volume at the bedside

Antonio Pesenti
Conflicts of Interest

• Maquet: Received research support and consultation fees
• Drager: Received research support and consultation fees
• GE: Received research support and consultation fees
• Patents on CO2 removal by acidification (University of Milan Bicocca)
ELECTRICAL IMPEDANCE TOMOGRAPHY (EIT): WHAT DOES IT MEASURE?
1. Low-amplitude alternate electric current applied to 2 electrodes, 14 electrodes monitor resulting current and calculate impedance.
2. Alternate current application rotates around patient’s chest and generates a map (tomography) of regional impedance.
WHAT IS EIT?

2. Alternate current application rotates around patient’s chest and generates a map (tomography) of regional impedance.
Alternating current rotation is very fast (up to 50 Hz) and enables continuous monitoring of regional lung impedance changes. Changes in regional lung impedance should reflect regional distribution of tidal ventilation.

Mauri, Pesenti et al. Unpublished data
Changes in end-expiratory regional lung impedance should mirror changes in end-exp Lung volume (EELV).

Mauri, Pesenti et al. Unpublished data
EIT

- Lung imaging technique, available at the bedside, non-invasive, no X-ray.

- EIT measures:
  1. Regional distribution of tidal ventilation
  2. Regional changes in end-expiratory lung volume

- Of one lung slice, 10-15 cm thick.
EIT ROLE AT THE BEDSIDE OF ICU PATIENTS

EIT limitations:
- Spatial resolution
- Single-slice imaging
- Measure air content, not F'tis%

EIT strenghts:
- Bedside
- No X-rays
- Continuous

EIT is no surrogate for CT scans.

Our hyp: EIT may help study lung mechanical properties and recruitinent when CT scan is not appropriate.
REGIONAL VENTILATION DURING SPONTANEOUS BREATHING

10 ALI/ARDS pts undergoing PSV
Semi-recumbent position
EIT monitoring.

20 min phases, randomized:

1. $\text{PEEP}_{\text{low}} (7\pm2 \text{ cmH}_2\text{O})$ vs. $\text{PEEP}_{\text{high}} (12\pm3 \text{ cmH}_2\text{O})$
2. $\text{PSV}_{\text{low}} (3\pm2 \text{ cmH}_2\text{O})$ vs. $\text{PSV}_{\text{high}} (12\pm2 \text{ cmH}_2\text{O})$

Mauri, Pesenti et al. Submitted
ARDS

ALVEOLI WITH ALTERED MECHANICAL PROPERTIES

TIDAL VENTILATION

HETEROGENEOUS DISTRIBUTION OF TIDAL VENTILATION

MECHANICAL INTERDEPENDENCE

HETEROGENEOUS DISTRIBUTION OF INSP PRESSURE AND VOLUME

INCREASED REGIONAL STRESS AND STRAIN

VILI

Mead et al. JAP 1970
DIAPHRAGM USE AND REGIONAL VENTILATION

Mauri, Pesenti et al. Submitted
Higher PEEP was associated with increased ventilation of dependent regions.

Mauri, Pesenti et al. Submitted
Lower PSV was associated with increased ventilation of dependent regions.

Mauri, Pesenti et al. Submitted
During all study phases, the % of tidal ventilation reaching dependent lung regions was correlated with oxygenation (improved Va/Q matching?).
REGIONAL VENTILATION DURING SPONTANEOUS BREATHING

1. Higher PEEP and lower PSV levels are associated with increased ventilation of dependent lung regions.

2. Underlying mechanisms may differ (alveolar recruitment vs. increased diaphragm activity) and this may, in part, explain differences in regional heterogeneity changes.

3. More homogenous distribution of tidal ventilation in ARDS may reduce risk of VILI.

Mauri, Pesenti et al. Submitted
WHY DID WE STUDY SIGH?

Sigh, alternative to PEEP: improves oxygenation with limited hemodynamic effect.

- Patroniti et al. Anesthesiology 2002 1 sigh/min, PSV
- Foti et al. Intensive Care Med 2000 2 sigh/min, CMV
- Pelosi et al. AJRCCM 1999 3 sigh/min, CMV
One medical student during 30 min of quiet (?!??) breathing (i.e., studying to pass our residency program test). Approx 1 Sigh/3 min. Sigh is a normal way to prevent lung collapse in nature.

Mauri, Pesenti et al. Unpublished data
ALTERNATIVES TO PEEP FOR RECRUITMENT

11 acute respiratory failure pts (p/f ≤ 300 mmHg, PEEP ≥ 5 cmH₂O) undergoing PSV, semi-recumbent position, EIT monitoring

20 min phases, randomized (PEEP, PSV and FiO₂ unchanged):

1. PSV
2. PSV + 0.5 SIGH (35 cmH₂O x 3-4 sec)/min
3. PSV + 1 SIGH/min
4. PSV + 2 SIGH/min

Mauri, Pesenti et al. Unpublished data
SIGH EFFECTS

No effects on MVe, RR, mean Paw, p0.1 and hemodynamics

Mauri, Pesenti et al. Unpublished data
Oxygenation increased with application of Sigh.

Mauri, Pesenti et al. Unpublished data
EIT: SIGH MECHANISMS UNVEILED

Sigh promoted iso-PEEP increase in EELV (recruitment?)

Mauri, Pesenti et al. Unpublished data
At variance from PEEP: no effects on ventilation distribution and heterogeneity.

Mauri, Pesenti et al. Unpublished data
SIGH

- Sigh improves oxygenation with minimal effects on mean Paw and hemodynamics.

- Sigh increases EELV, doesn’t affect ventilation distribution

- Increase in EELV seems to be induced by alveolar recruitment
CASE 1:
POST-OP RESPIRATORY FAILURE
CASE 1

75 yo, BMI 33,

PMH: hypertension

Major abdominal surgery.

Post-op resp failure

Helmet CPAP, PEEP 5 cmH$_2$O e FiO$_2$ 50%
EIT

PEEP 5

PEEP 10

“NATURAL SIGH”

Registrazione file '3_cpap_casco_01 CPAP5.eit'... (23 min)
CASE 3:
COPD EXACERBATION
Ppeak increases after PEEPext > PEEPi
58 yo, COPD pt

Intubated, on CMV Vt 10 mL/kg, RR 10/min

PEEPi = 7 cmH₂O from ZEEPext
SEVERE ARDS

PEEP  12  30  25  20  15  12
Pplat  32  60  45  35  29  29
SatO$_2$  89  94  94  94  94  93
etCO$_2$  32  0-2  15  30  32  32
CONCLUSIONS

EIT role at the bedside of ICU pts:

• Study of lung mechanical properties and recruitiment when CT scan is not feasible.

• Enhances understanding of underlying pathophysiology \(\rightarrow\) therapy titration

Future perspectives: EIT to monitor non-intubated, spontaneously breathing, severe acute respiratory failure pts.
CLINICAL CASE 1: DIFFICULT WEANING
CASE 1: DIFFICULT WEANING

Female, 69 yo.

PMH: arterial hypertension, smoke.

Cardiac arrest.

VAP, ARDS, lung fibrosis

33 days on MV, PSV +10
“Compared to conventional PSV, variability in pressure support improved the elastance of the respiratory system, peak airway pressure, oxygenation, and intrapulmonary shunt.” Spieth PM et al. Anesthesiology 2009
EIT – Variable PSV

Globale

ROI 1

ROI 2

ROI 3

ROI 4

MTV ROI 1 %

MTV ROI 2 %

MTV ROI 3 %

MTV ROI 4 %

Tidal rate: 22 ml/min

MTV globale %: 100

VT ml: 386
### EIT – Variable PSV

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<th>C2</th>
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**Other Metrics**

- **ΔEELI glob.** 0.44
- **ΔEELI ROI 1** 0.11
- **ΔEELI ROI 2** 0.24
- **ΔEELI ROI 3** 0.03
- **ΔEELI ROI 4** 0.06