Challenges of Prolonged Continuous Monitoring of Mechanically Ventilated Pediatric Patients Using EIT

Hervé Gagnon, Philippe Jouvet, Jean-Christophe Gervais, Olivier Fléchelles, Robert Guardo, and Andy Adler.

- Carleton University, Ottawa, Canada.
- École Polytechnique de Montréal, Montréal, Canada.
- Hôpital Sainte-Justine, Montréal, Canada.
Introduction

- EIT images of ventilation have been successfully compared and validated with:
  - Spirometry;
  - Plethysmography;
  - Radiology;
  - Pulmonary scintigraphy;
  - CT-Scans.

- Most of these studies were performed
  - In controlled environments;
  - Over relatively short periods of time.
Introduction

- Prolonged continuous validation over the range of hours or days has not been performed for current EIT systems.*

- Continuous monitoring in the intensive care unit (ICU) is important to:
  - Prevent ventilator-induced lung injury;
  - Detect the onset of pulmonary edema, atelectasis or pneumothorax.

* A Adler, MB Amato, JH Arnold, R Bayford, M Bodenstein, SH Böhm, BH Brown, I Frerichs, O Stenqvist, N Weiler, and GK Wolf, Whither lung EIT: Where are we, where do we want to go and what do we need to get there?, Physiol. Meas. 33 (2012) 679–694
**Introduction**

- **Main goal:**
  - Correlate EIT images with ventilator data during prolonged continuous monitoring of mechanically ventilated patients in a pediatric intensive care unit.

- **Specific goals:**
  - Study long term variations in EIT images:
    - instrumentation drift;
    - electrode-skin contact impedance variations.
  - Study clinical events leading to large image artifacts:
    - electrode disconnection;
    - patient manipulation during regular staff interventions.
EIT Hardware

- Introduction
- Experimental Set-up
- Preliminary Results
- Discussion and Conclusion

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Acquisition of EIT and Ventilator Data

- Introduction
- Experimental Set-up
- Preliminary Results
- Discussion and Conclusion
GUI of the Combined System

- Introduction
- Experimental Set-up
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- Discussion and Conclusion
Experimental Protocol

- Passive recording with no recruitment protocol.
- Clinical staff were instructed on how to connect the system to the patient.
- Two-hour recording.
- Clinical staff were instructed:
  - to proceed with normal patient care;
  - to reconnect electrodes if they become disconnected.
Patient Information

- Criteria for inclusion:
  - Mechanically-ventilated;
  - Age > 1 year;
  - Weight > 10 kg;
  - Stable patient.
- 6 patients have been included.
Observations

- All patients were awake.
- Interactions with clinical staff included:
  - Repositioning of patient;
  - Caring and cleaning;
  - Airway Suctioning;
  - Percutaneous injection and blood sampling;
  - Clinical examination;
  - Physiotherapy;
  - Respiratory therapy.
### Ventilation Mode

- **Patient Range Selection:**
  - Neonate Mode (4)
  - Adult Mode (2)

- **Ventilation Mode:**
  - Pressure Control (1)
  - Pressure Reg. Volume Control (1)
  - Pressure Support / CPAP (2)
  - SIMV (Press. Contr.) + Pressure Support (1)
  - SIMV (Press Reg. Volume Control) + Pressure Support (1)
EIT Measurements vs Volume

- Introduction
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Graphs showing average voltage and volume over time for Patient #1.

Correlation = 0.486
EIT Measurements vs Volume

- Introduction
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![Graph showing EIT Measurements vs Volume](image)

**Correlation = 0.030**

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*Note: The graph shows the correlation between EIT measurements and volume changes over time for Patient #5.*
EIT Measurements vs Temperature$^{-1}$

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**Patient #1**

**Average Voltage (AUV)**

- Time (s)
- Correlation = 0.663

**Temperature$^{-1}$**

- Time (s)

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EIT Measurements vs Temperature$^{-1}$

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Patient #5

![Graph showing temperature vs time and correlation coefficient]

Correlation = -0.623

Temperature$^{-1}$

Time (s)

Average Voltage (AUV)

Time (s)
EIT Measurements vs Alarm

- Introduction
- Experimental Set-up
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**Patient #5**

![Graph showing average voltage (AUV) over time](image)

**Alarm**

![Graph showing alarm levels over time](image)

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**Notes**

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EIT Measurements vs O₂ Concentration

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*Patient #5*

**Average Voltage (AUV)**

![](Average_Voltage.png)

**Oxygen concentration (%)**

![](Oxygen_Concentration.png)
Time Difference Imaging Reference

- Full expiration.
- Average of one minute.
- Average of whole dataset.
EIT Images vs Volume (Minimum Ref.)

- Introduction
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![Graph showing average conductivity and volume over time for Patient #1 with correlation 0.425]
EIT Images vs Volume (Average Ref.)

- Introduction
- Experimental Set-up
- Preliminary Results
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**Patient #1**

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Average Conductivity (AUC)

Time (s)

Correlation = 0.420

Average Volume (ml)
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Reference Selection (Sliding Window)
EIT Images vs Volume (Slid. Win. Ref.)

- Introduction
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Patient #5

Average Conductivity (AUC)

Time (s)

Correlation = 0.119

Volume (ml)

Time (s)
Ventilator Data as Prior Information

- Real-time prior information for image reconstruction algorithms:
  - Breathing frequency.
  - Tidal volume.
  - Ventilation phase (inspiration, pause, expiration).
  - Change in ventilator settings (mode, PEEP, etc.).
  - Ventilator alarms to help in assessing data validity.
Planned Data Analysis

▸ Statistical analysis:
  ▪ Atypical events in EIT and ventilator data.
  ▪ Correlations between EIT and ventilator data.

▸ Limiting factors:
  ▪ Low number of patients.
  ▪ Low similarities between patients.
  ▪ Low data quality due to electrode disconnections and numerous staff interventions on patients.

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Factors Affecting EIT Image Quality

- Patients are awake and moving
  - Contact impedance variations
  - Torso geometry variations
- Patients that would more benefit from EIT would more likely be asleep and stand still.
Electrode Placement Constraints

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Prolonged Continuous Monitoring

- Minimization of measurement drift:
  - Hardware design techniques.
  - Mathematical modelling.

- Selection of reference dataset:
  - Sliding window technique.
  - Automatic reset of reference dataset.
  - Algorithm to automatically evaluate the quality and stability of the reference over time.
  - Accelerometer located on the patient.
ICU Applications

- Electrode disconnections and contact impedance variations:
  - Automatic detection in hardware.
  - Management in software.
- EIT systems should be made more flexible for the number of required electrodes and their placement.
Thank you for your attention!

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