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

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POLYTECHNIQUE MONTRÉAL
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XVth International Conference on Electrical Bio-Impedance (ICEBI)
XIVth Conference on Electrical Impedance Tomography (EIT)
Heilbad Heiligenstadt, Germany, April 22-25, 2013

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.

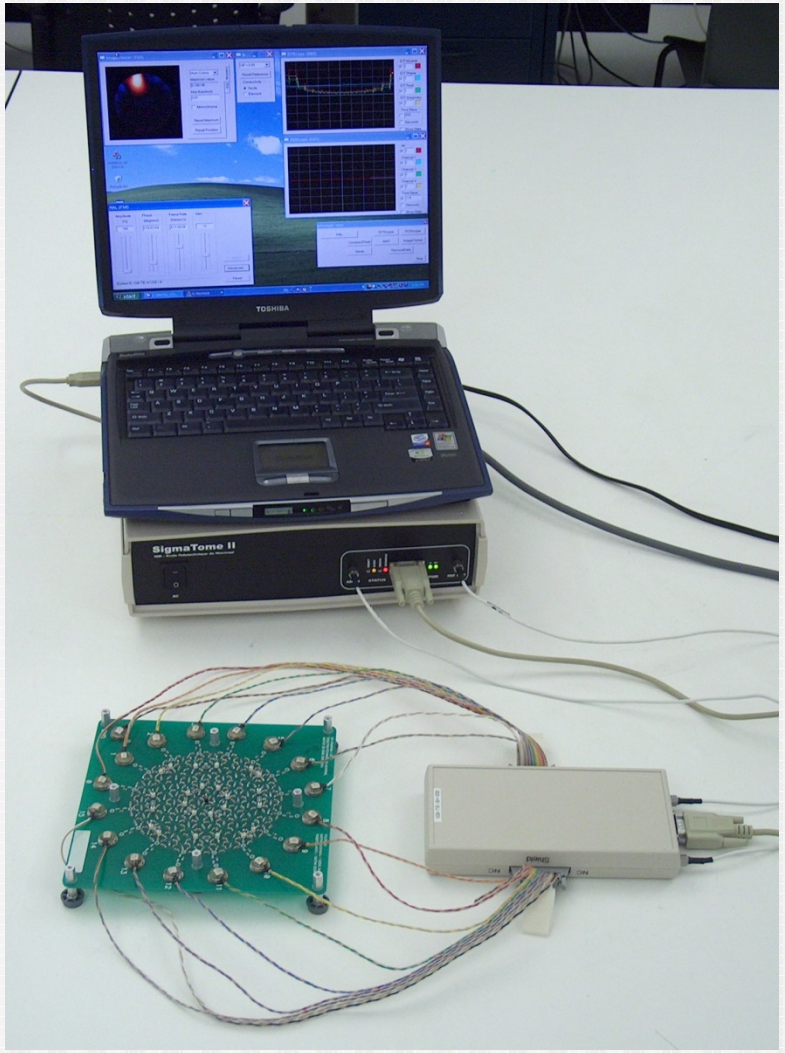
* A Adler, MB Amato, JH Arnold, R Bayford, M Bodenstein, SH Böhm, BH Brown, I Frerichs, O Stenqvist, N Weiler, and GK Wolf, Whither lung EIT: Where are we, where do we want to go and what do we need to get there?, *Physiol. Meas*. **33** (2012) 679–694

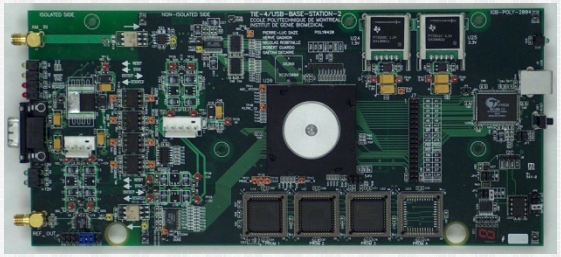
Introduction

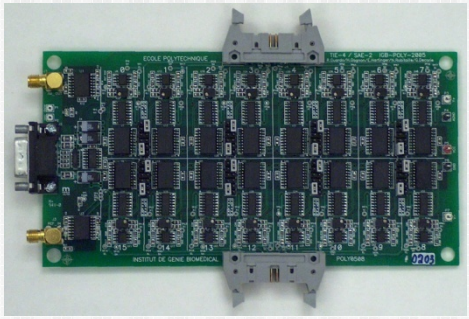
- Main goal:
  - Correlate EIT images with ventilator data during prolonged continuous monitoring of mechanically ventilated patients in a pediatric intensive care unit.
- Specific goals:
  - Study long term variations in EIT images:
    - instrumentation drift;
    - electrode-skin contact impedance variations.
  - Study clinical events leading to large image artifacts:
    - electrode disconnection;
    - patient manipulation during regular staff interventions.

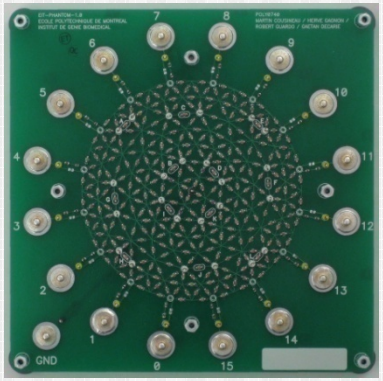
EIT Hardware

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



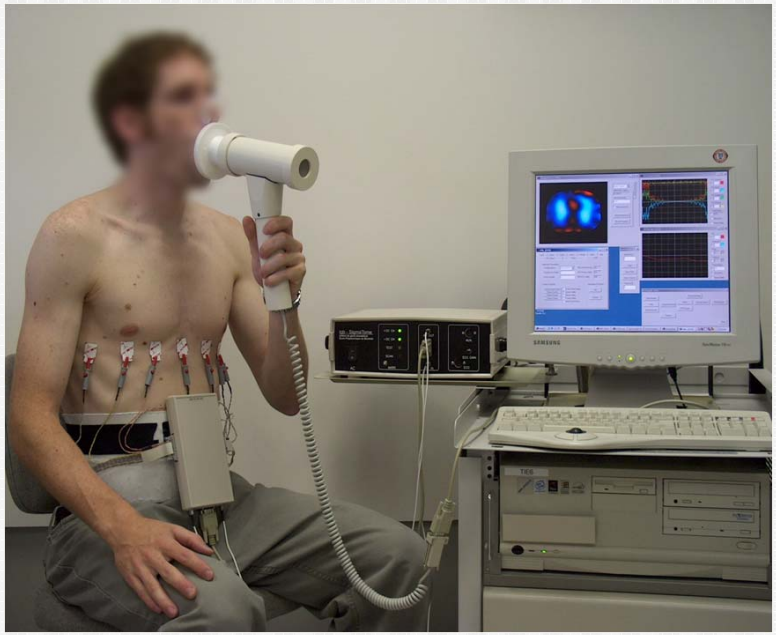






Acquisition of EIT and Ventilator Data

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



GUI of the Combined System

- Introduction
- **Experimental Set-up**
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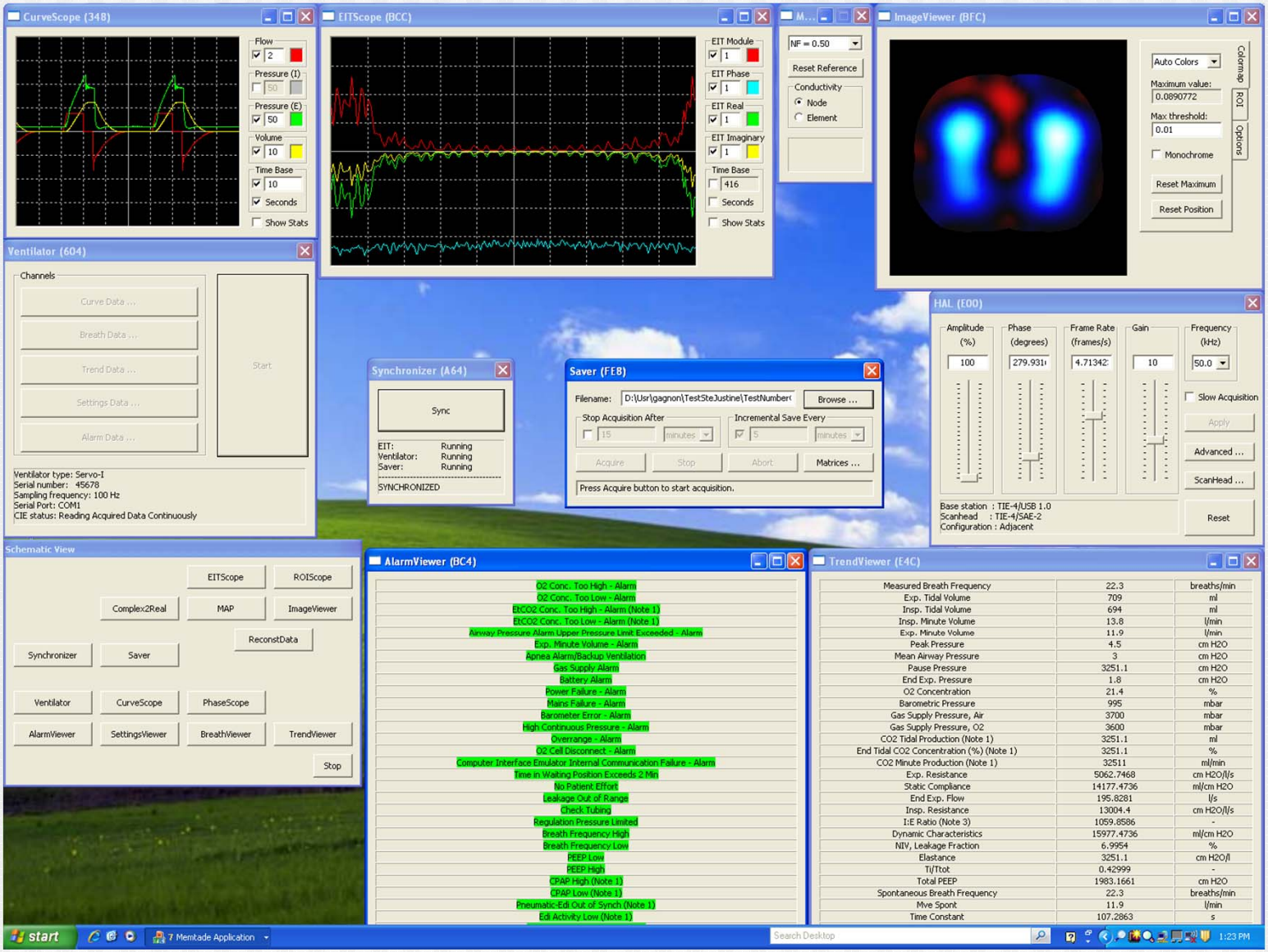

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Experimental Protocol

- 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

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

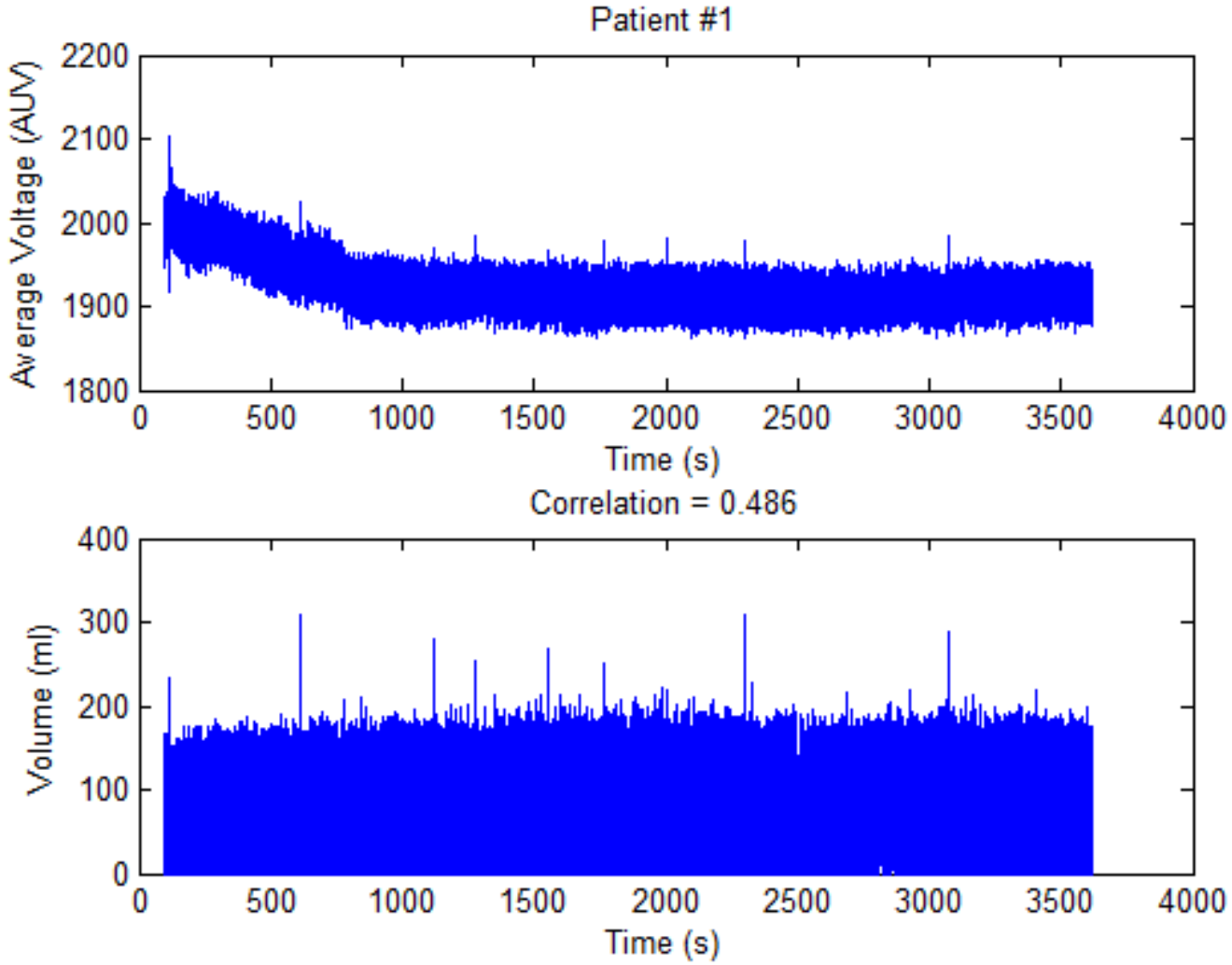
- All patients were awake.
- Interactions with clinical staff included:
  - Repositioning of patient;
  - Caring and cleaning;
  - Airway Suctioning;
  - Percutaneous injection and blood sampling;
  - Clinical examination;
  - Physiotherapy;
  - Respiratory therapy.

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



EIT Measurements vs Volume

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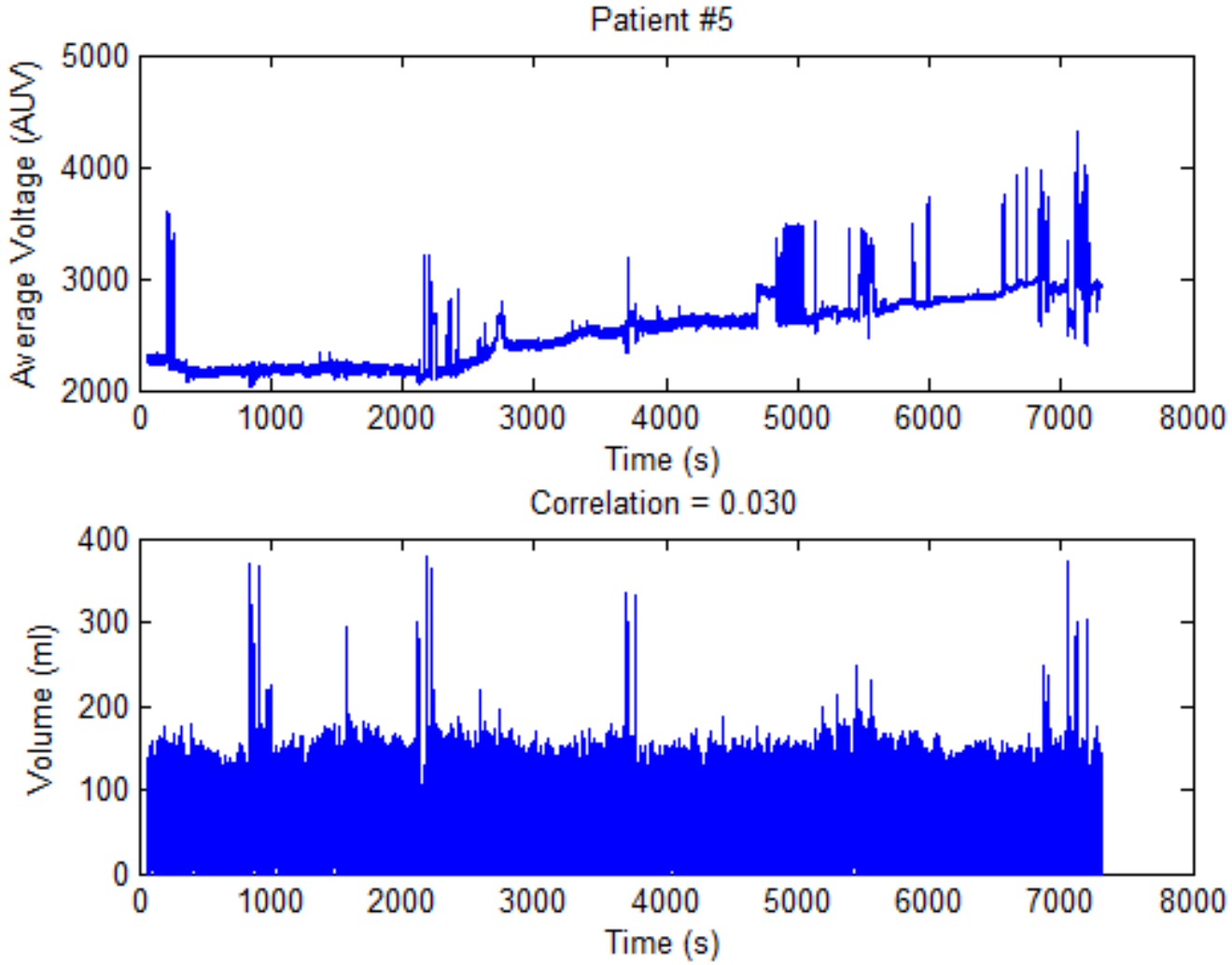

EIT Measurements vs Temperature^{-1}

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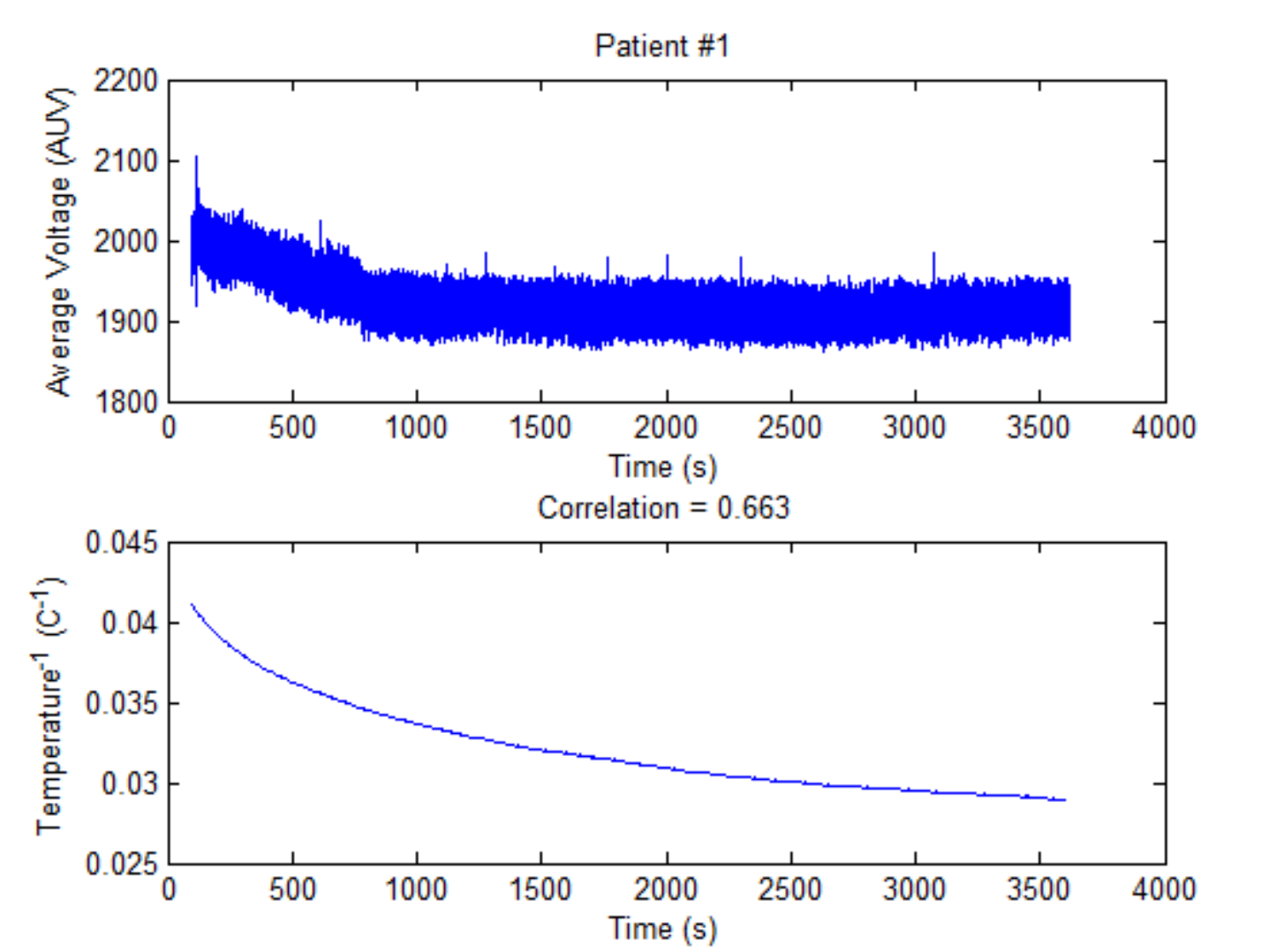

EIT Measurements vs Temperature^{-1}

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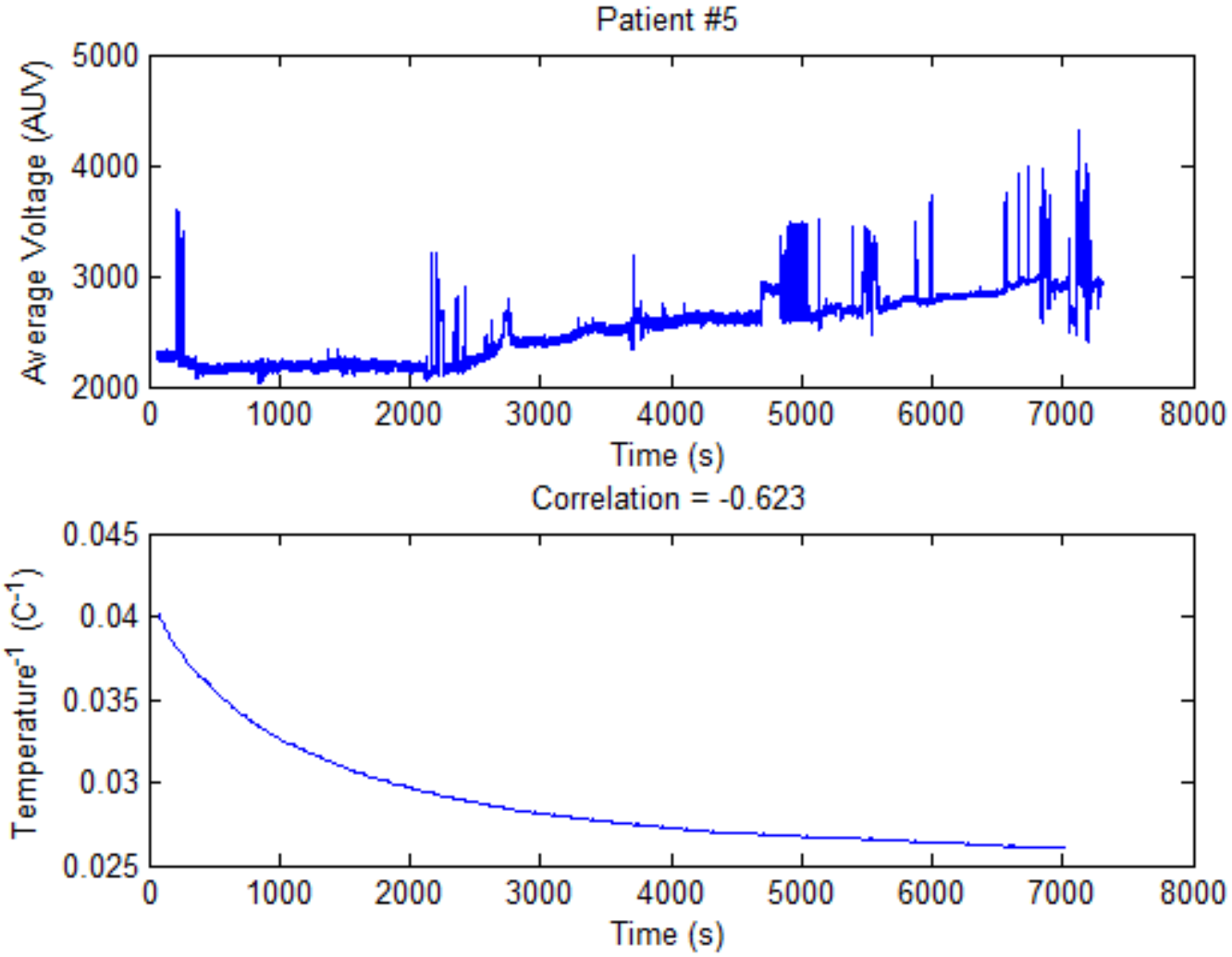

EIT Measurements vs Alarm

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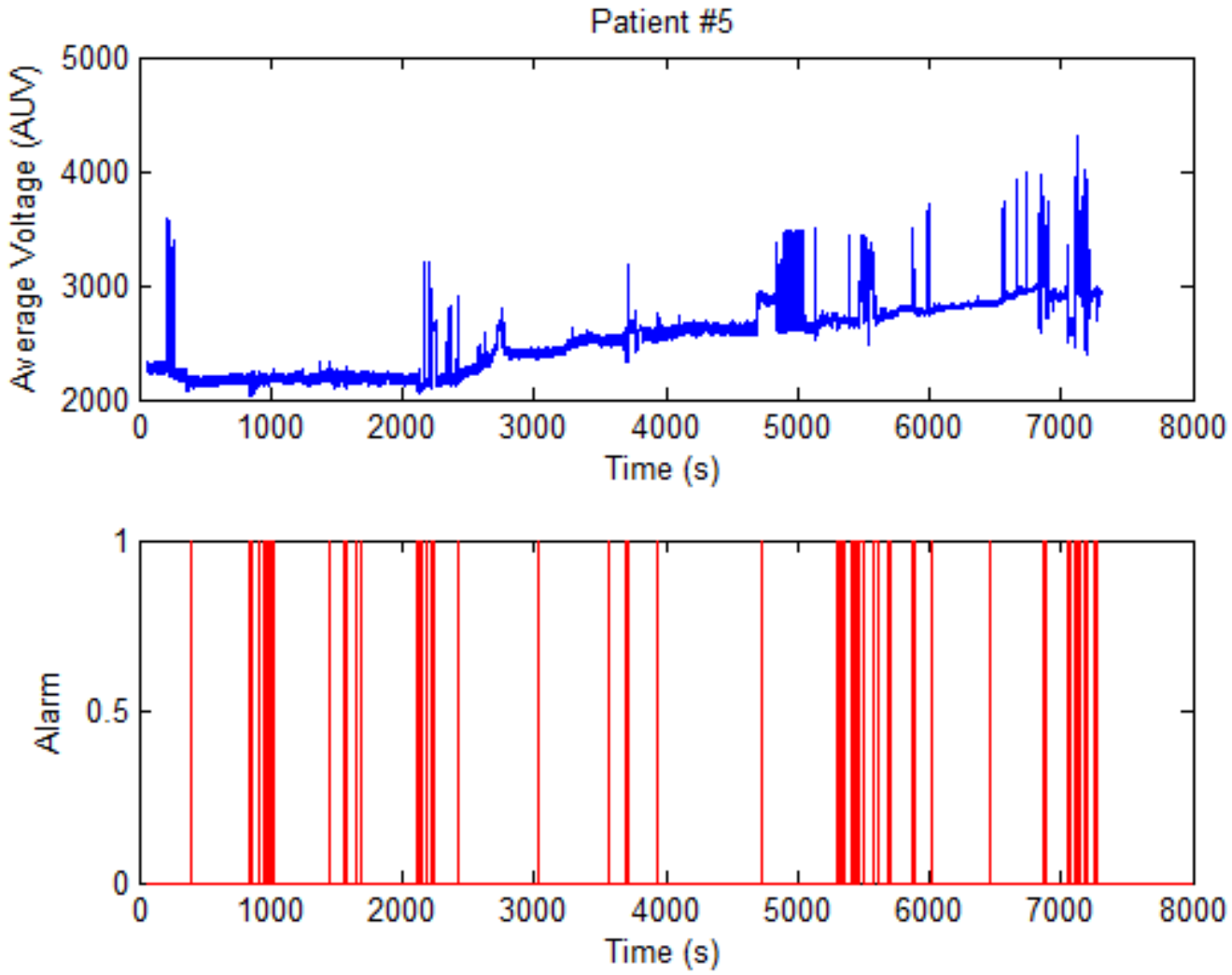

EIT Measurements vs O_2 Concentration

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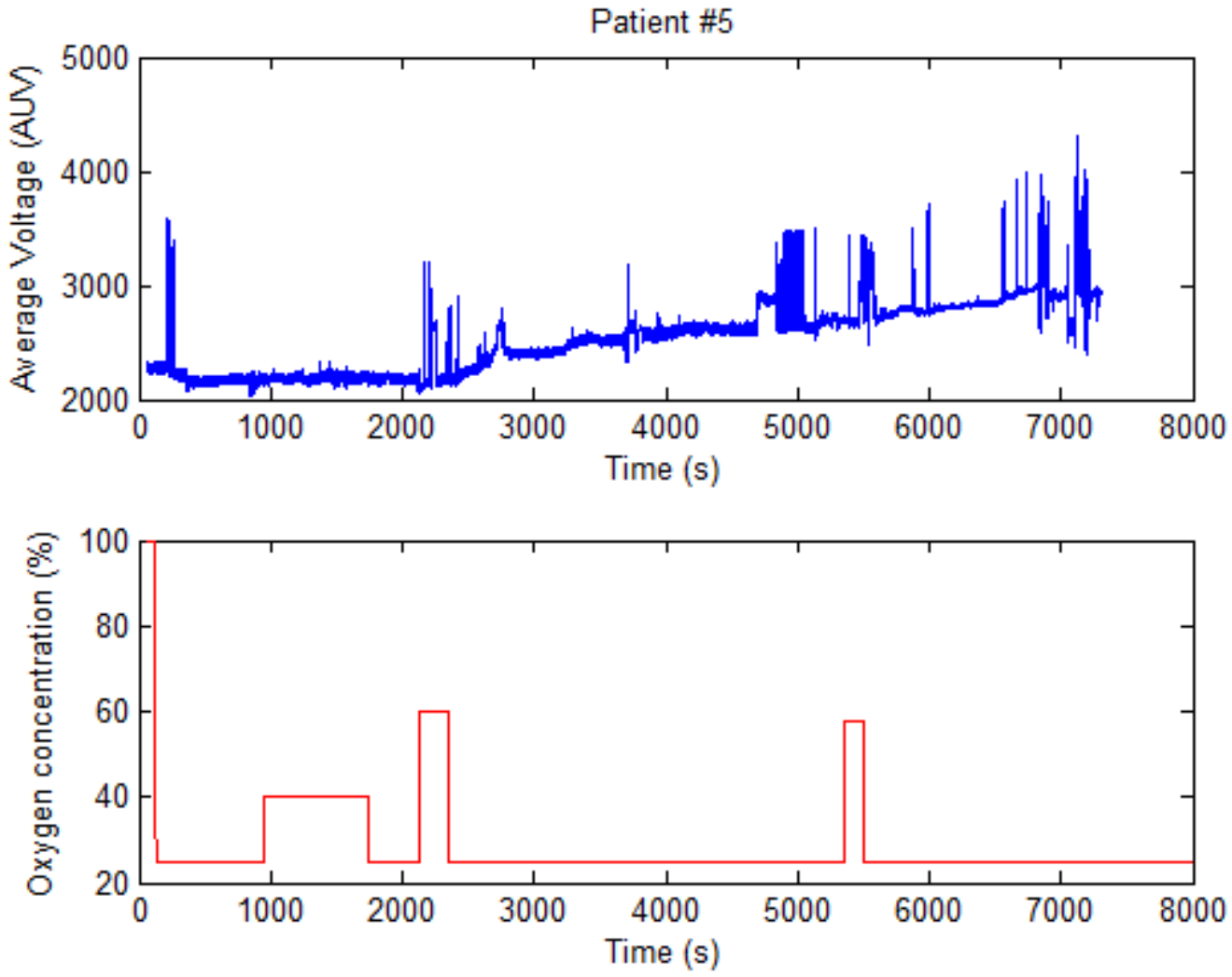

Time Difference Imaging Reference

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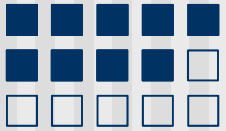

- Full expiration.
- Average of one minute.
- Average of whole dataset.

EIT Images vs Volume (Minimum Ref.)

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- Experimental Set-up
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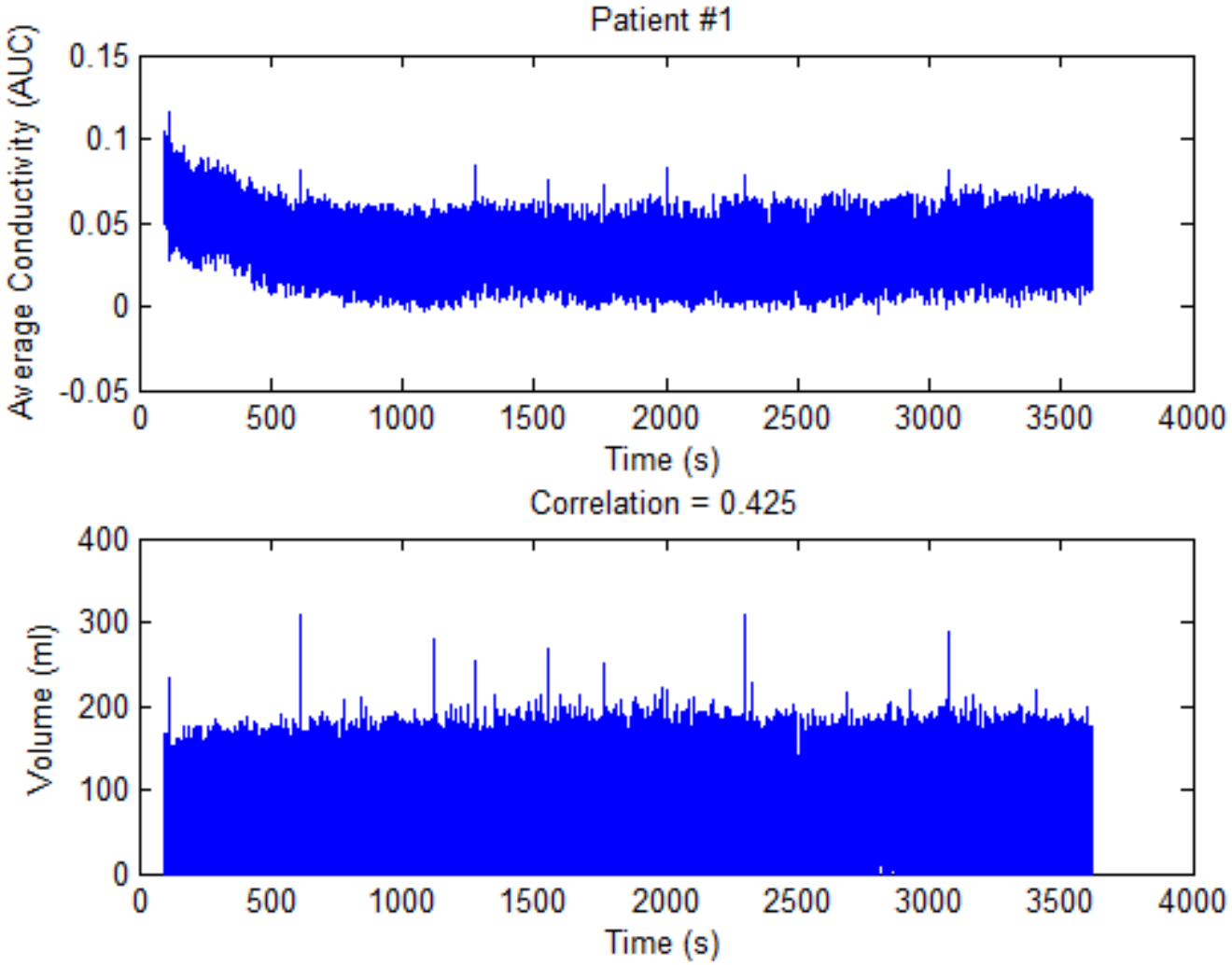

EIT Images vs Volume (Average Ref.)

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- Experimental Set-up
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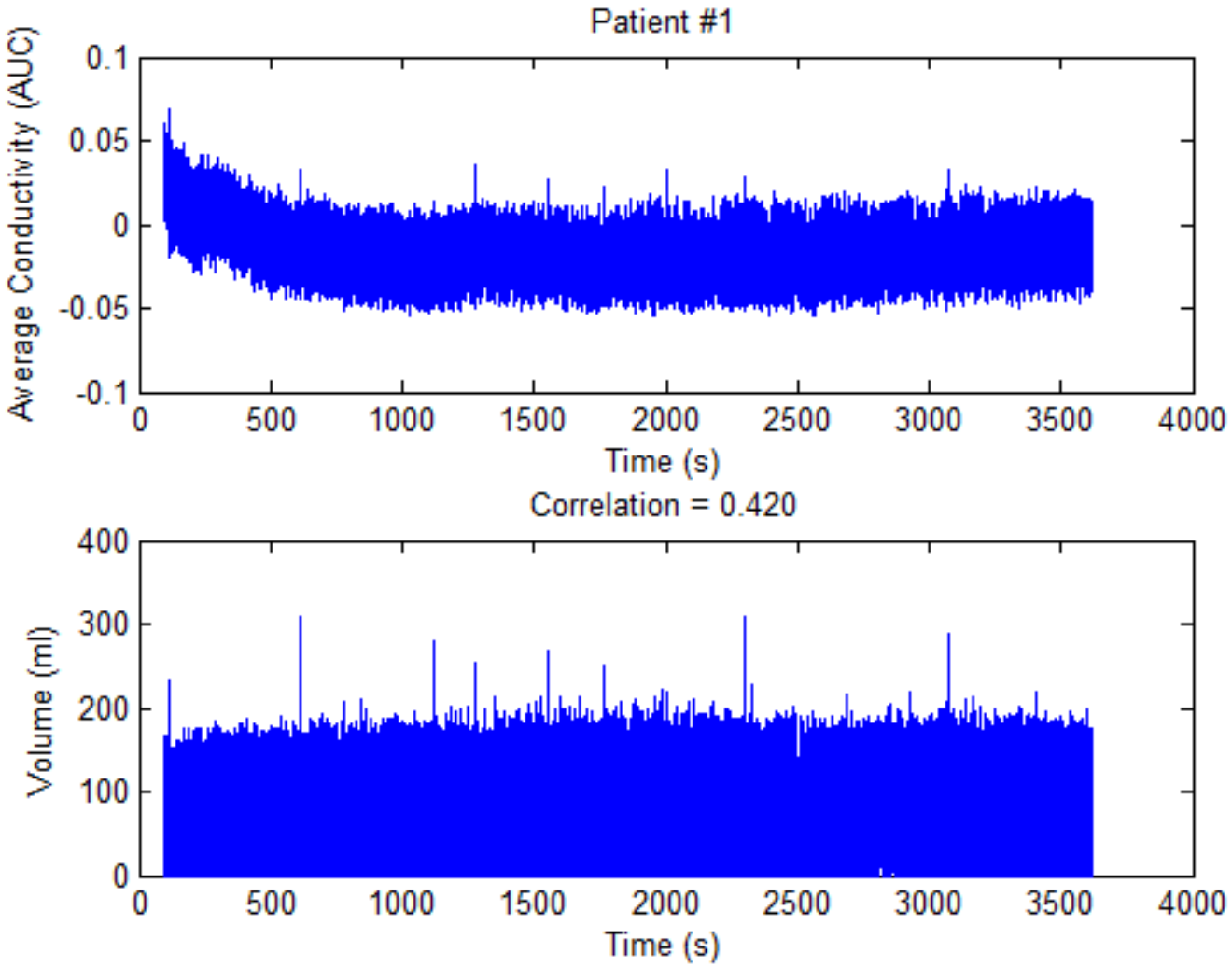
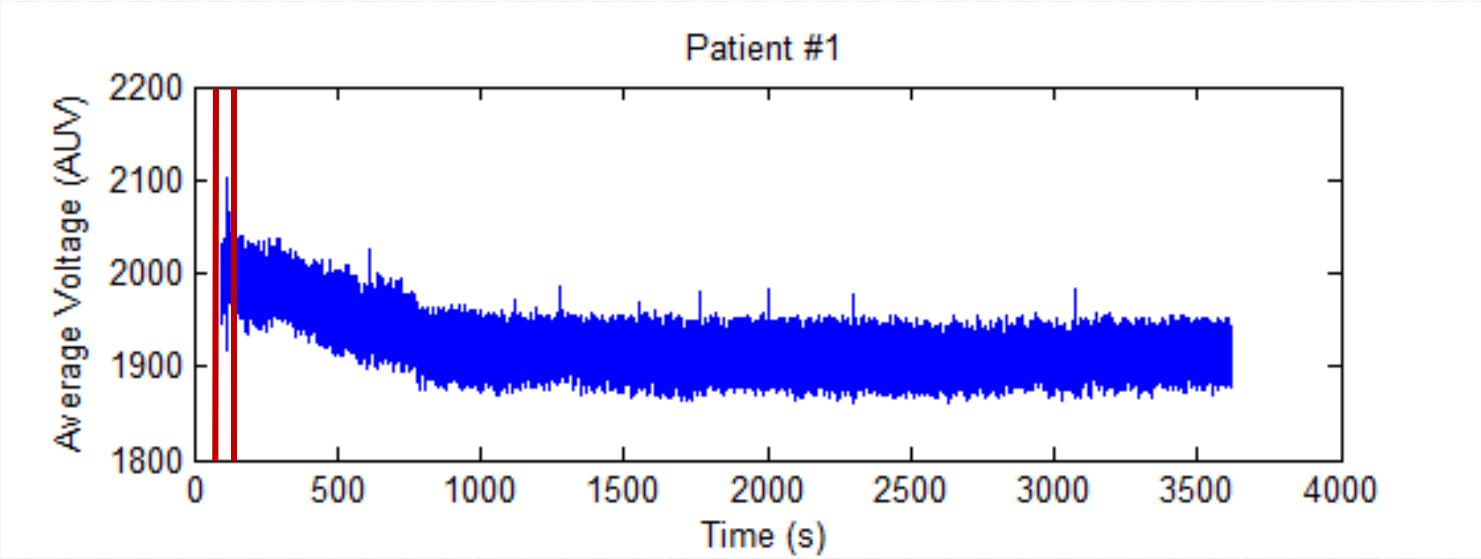


Reference Selection (Sliding Window)

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



EIT Images vs Volume (Slid. Win. Ref.)

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- Experimental Set-up
- **Preliminary Results**
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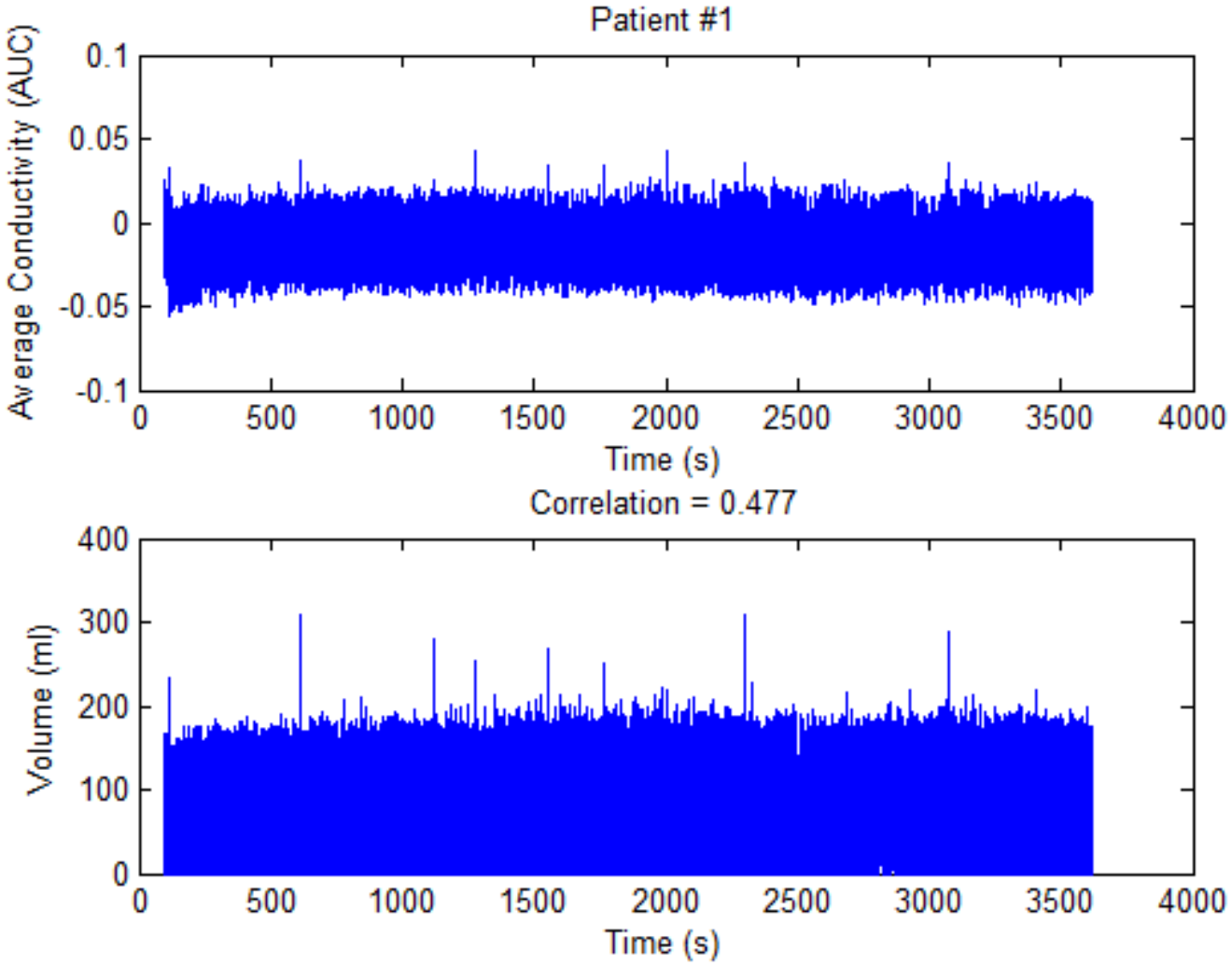

EIT Images vs Volume (Slid. Win. Ref.)

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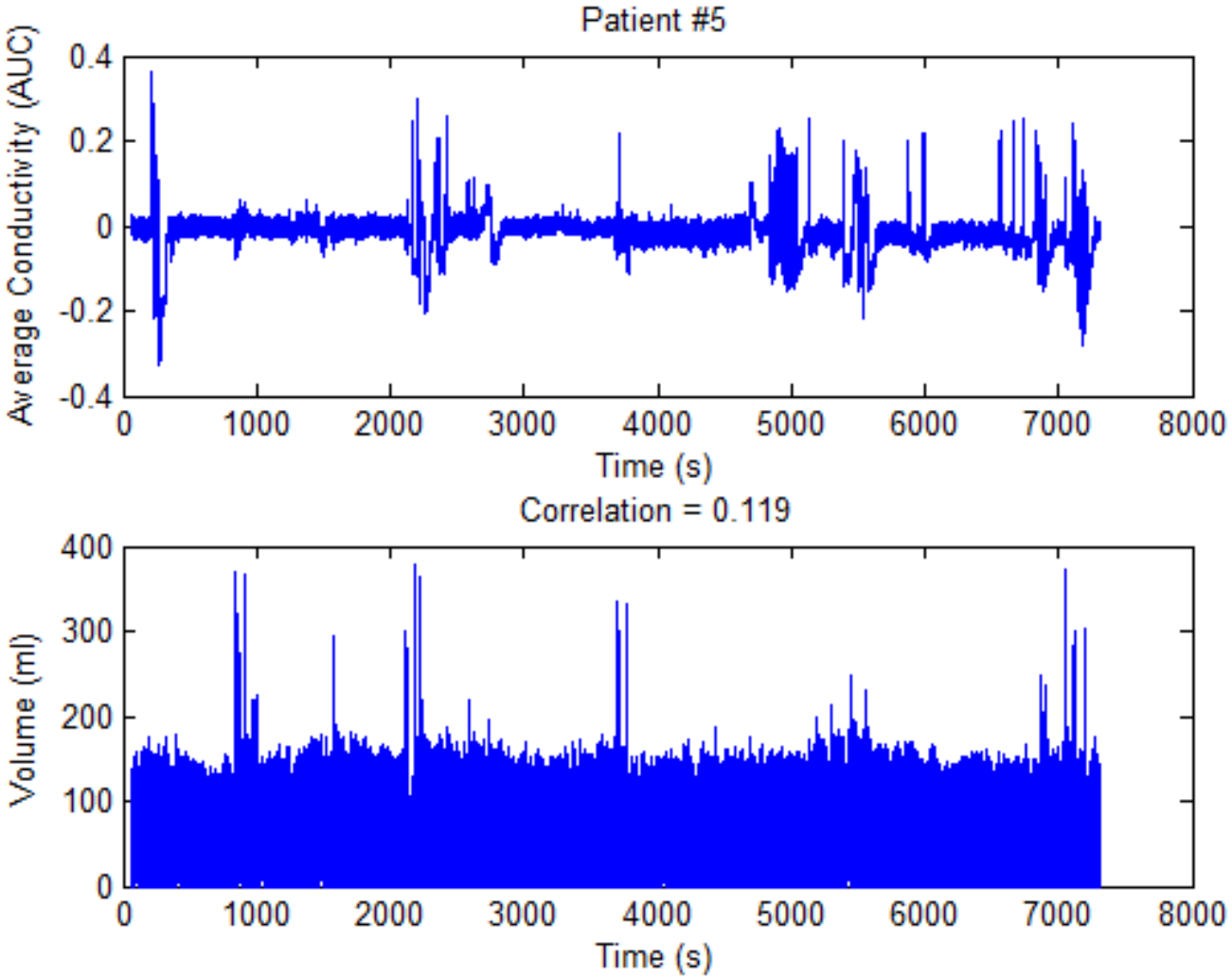

Ventilator Data as Prior Information

- 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.

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

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

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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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