Optimal PEEP selection in Mechanical Ventilation using EIT

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Carleton University - 2009/11 M.A.Sc

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1. Introduction
   - The Problem
   - How to solve the problem?

2. Contributions
   - IP Calculation
   - Fuzzy Logic System

3. Results
   - Sigmoid vs. Linear
   - Linear vs. Visual
   - Optimal PEEP

4. References
Introduction

- This is a presentation outlining the work done within Ravi Bhanabhai M.A.Sc thesis.
- **Purpose:** Investigate the use of Electrical Impedance Tomography (EIT) within mechanical ventilation.

**Mathematical Tools:**
1. Linear and Non-Linear curve fitting techniques
2. Fuzzy Logic.

**Contributions:**
1. Summarize scholarly papers on ALI.
2. Inflection Point (IP) location on EIT and pressure data.
3. Creation of Fuzzy Logic System using IP.

**Novel Aspects:**
1. Use of short recruitment maneuver (≤ 2min)
2. Regional Inflection Points used
3. Use of Inflection Points within an automated classification system
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ALI & VILI

Respiratory Failure

Oxygenation Failure (hypoxemia)

Ventilatory Failure (hypercapnia)

+ more oxygen related conditions

Acute Lung Injury (ALI)

Ventilator Induce Lung Injury (VILI)

* Cyclic opening and closing
* overdistension

PEEP
Respiratory Function Models

\[ P_{ao} = \frac{V}{C} + \dot{V}R + \ddot{V}I - P_{mus} \]  

(1)
Respiratory Function Models

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Interested in \( \frac{V}{C} \) only.
Respiratory Function Models

\[ P_{ao} = \frac{V}{C} + \dot{V}R + \ddot{V}I - P_{mus} \]  

- Interested in \( \frac{V}{C} \) only.
- To remove other components this thesis data did two things:
  1. Slow Constant Flow
  2. Antheysia
Pressure-Volume Curves

- Used to help guide ventilation strategies by locating points of compliance change.
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- Points are Lower Inflection Point (LIP) and Upper Inflection Point (UIP)
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(e) Linear Fit of PI data
Data used

Data used:

- 26 patients
- low constant flow maneuver (4 L/min)
- start 0 mbar → 35 mbar / 2L
Electrical Impedance Tomography (EIT)

EIT is real-time impedance tomography, it can be used to accurately measure air distribution within the thorax.
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(a) Start of Inflation  (b) Max Pressure  (c) End of Deflation

Figure: Example reconstruction using the GREIT methods of a healthy lung patient (patient 7).
Contributions

- Automated IP calculation
Contributions

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- Rule-base Fuzzy Logic Classifier
Three Types of IP location methods were used:
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1. Sigmoid method
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2. Visual heuristics
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2. Visual heuristics
3. 3-piece linear spline method
Three Types of IP location methods were used:

1. Sigmoid method
2. Visual heuristics
3. 3-piece linear spline method

Multiple methods were implemented for comparison reasons.
Sigmoid Method

Sigmoid Method

\[
\text{Plip} = c - 2d = 11.1
\]

\[
\text{Plip} = c + 2d = 22.9
\]

\[
c = 17 \text{ cm H2O}
\]

\[
a = 12 \text{ ml}
\]

\[
b = 1173 \text{ ml}
\]
Visual Heuristics

- Clinicians used this method to locate Inflection Points from global PV curves.
- Multiple methods exist:
  1. Find location where PV curve has linear compliance
  2. Pressure where rapid increase in compliance occurs
  3. Place two line. 1) Along low compliance. 2) Along high compliance. Locate intersection.
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IP Calculation

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This thesis:
1. 5 participants
2. Fit in linear manner to get closest to all the data points
Visual Heuristic

Trial3/4 − Deflation

One chance only, be carefull

Trial1/4 − Deflation

One chance only, be carefull
3-piece Linear Spline Method

- Similar to visual methods
3-piece Linear Spline Method

- Similar to visual methods
- Fits to 3 lines with Inflection Points being located at intersection
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Introduction

The Fuzzy System is designed into 4 sections:
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1. Location of IP
Introduction

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1. Location of IP
2. Fuzzification
3. Premise Calculation (Application of IF-THEN)
4. Defuzzification and Optimization
**Conclusions**

**Fuzzy Logic System**

**Inference and Defuzzification**

- **Inflection Points**
- **Fuzzification**
- **Rule Base**
- **Premise Calculation**
- **Optimization**

- **Pressure - Inflation**
- **Pressure - Deflation**

**Good States**

**Bad States**

**Pressure based Membership Graph**

- **Deflation**
- **Inflation**

**EIT based Membership Graph**

- **Deflation**
- **Inflation**

**EIT Conductivity**

- **Linear Fit - Inflation**
- **Linear Fit - Deflation**

**Inflection Points Fuzzification Premise Calculation Optimization Rule Base**

- **Above**
- **In Between**
- **Below**

**Inference and Defuzzification**

**Contributions**

**Safety Keeping Ventilation Patients**

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IP and Fuzzification

IP were taken from the 3-piece linear optimization portion and used in the creation of the fuzzification graphs.
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<table>
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<tr>
<th>Membership</th>
<th>Input 1 (mbar)</th>
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<th>Input 3 (mbar)</th>
<th>Input 4 (mbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below</td>
<td>min(p)</td>
<td>min(p)</td>
<td>-2+LIP</td>
<td>LIP</td>
</tr>
<tr>
<td>In Between</td>
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<td>LIP</td>
<td>2+UIP</td>
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**Table:** Details on creating the trapezoidal based fuzzy membership functions
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**Figure:** Trapezoidal Fuzzy Membership graph
Inference and Defuzzification

The Inference is conducted using the Rule base. With key relations to previous papers:

1. Pressure below the LIP is considered collapsed
2. Pressure above the UIP is considered overdistended

Defuzzification was done by breaking the output states into two classifications:

1. 'Good' = Normal states
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Upon averaging over lung region MAX value between the difference of 'Good' and 'Bad' states is performed to locate the PEEP.
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Sigmoid vs. Linear

Figure: How frequent each sigmoid and linear method are not able to find IP.
**Sigmoid vs. Linear**

**Figure**: How frequent each sigmoid and linear method are not able to find IP.

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<th></th>
<th>Mean</th>
<th>Std</th>
<th>Median</th>
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<tr>
<td>LIP - Inflation</td>
<td>1.47</td>
<td>3.02</td>
<td>1.50</td>
</tr>
<tr>
<td>UIP - Inflation</td>
<td>-6.80</td>
<td>2.54</td>
<td>-6.82</td>
</tr>
<tr>
<td>LIP - Deflation</td>
<td>4.07</td>
<td>1.84</td>
<td>4.07</td>
</tr>
<tr>
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<td>-2.37</td>
<td>2.24</td>
<td>-2.78</td>
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**Table**: Difference between Sigmoid and Linear Method
Linear vs. Visual Heuristics

- **Difference** = Linear IP − Visual Heuristic IP
Linear vs. Visual Heuristics

- \textit{Difference} = \textit{Linear IP} − \textit{Visual Heuristic IP}

- -0.6247\text{mbar} for LIP

- -0.4662\text{mbar} for UIP
Results

Linear vs. Visual Heuristics

- Difference = Linear IP - Visual Heuristic IP
- \(-0.6247\) mbar for LIP  \(-0.4662\) mbar for UIP
- best average = 0.016 mbar  worst average = \(-1.507\) mbar

Provides insight to accuracy of linear method

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Linear vs. Visual Heuristics

- **Difference** = Linear IP − Visual Heuristic IP
- −0.6247mbar for LIP −0.4662mbar for UIP
- best average = 0.016mbar worst average = −1.507mbar
- Provides insight to accuracy of linear method
Heterogeneity

**Figure:** Progressive change of lung state with pressure
LIP+2 vs FLS

(a) Patient 12  (b) Patient 16

(c) Patient 8  (d) Patient 17

Figure: Global PI curve with LIP, UIP, and the LIP+2 mbar pressure and the Fuzzy optimal selection with according FLS based pressure.


Fuzzy Logic Schematic

ending