Eustachian tube pressure equilibration.

Quantitative analysis of correlation between pressure gradient and pressure change rate

Michael Gaihede\textsuperscript{a}, Simona Padurariu\textsuperscript{a}, Henrik Jacobsen\textsuperscript{a}, Kjell Tveterås\textsuperscript{a}, Joris JJ Dirckx\textsuperscript{b}

\textsuperscript{a}Department of ORL, H&N Surgery, Aalborg Hospital, Aarhus University Hospital, Denmark
\textsuperscript{b}Laboratory for Biomedical Physics, University of Antwerp, Belgium
1.1 Middle ear pressure regulation

6 complementary mechanisms:

1. Gas exchange – continuous bidirectional across mastoid mucosa
2. Eustachian tube openings (ETO’s) – intermittent
3. Tympanic membrane deformation – passive and related to elasticity
4. Mastoid buffering – passive and related to volume
5. Mastoid mucosa congestion – active and related to area and volume
6. Eustachian tube valve pumping effects – active
1.2 Measurements of pressure

- **Indirect methods** – tympanometry
  - inaccurate, impractical for continuous long-term monitoring, low time resolution

- **Direct methods** – previous
  - ethical problems, impractical for clinical use, TM not intact, leakage

- **Our method**
  - direct methods with high accuracy (1 Pa)
  - high temporal resolution (0.1 s)
  - agreeable to subjects for long-term monitoring
  - ethical approval in patients for parotid surgery
1.3 Hypotheses – Eustachian tube openings ETO’s

- Pressure equilibrations of the ETO’s can be described by the pressure change rate, and the pressure change rate correlates to the pressure gradient, and

- these correlations vary individually; ie. correlations may describe individual ET function status
2.1 M&M – diagram and procedure
2.2 M&M – participants and experiments

- 12 normal adults patients for parotidectomy
  - normal otomicroscopy, pure tone audiometry, and tympanometry
  - experiments next day after surgery

- Experimental MEP deviations introduced by volumetric changes of:
  - 50, 100 and 200 μl
  - (3-way-stop-cock and a 500 μl gas tight syring)

- Counter-regulation of MEP recorded by on-line exp’s
  - 10 min’s time frames per experiments
  - 6 experiments minimum per subject
2.3 M&M – gradual responses without ETO’s
2.4 M&M – ETO’s during inflation and deflation tests

[Graph showing Middle Ear Pressure (daPa) over time]
2.5 M&M – description and analysis of ETO’s

Definitions:
- ETO time ($\Delta t$)(s)
- Pressure change ($\Delta P$)(daPa)
- Pressure change rate ($\Delta P/\Delta t$)
- Pressure gradient ($P_{\text{grad}}$)(daPa)

- sudden pressure change
- oriented towards ambient

Diagram showing a graph with middle ear pressure (daPa) on the y-axis and time (s) on the x-axis. The graph includes points $t_o$, $t_c$, $P_o$, and $P_c$ with annotations for $\Delta t$, $\Delta P$, and pressure gradient. The diagram is labeled with Universiteit Antwerpen and Aalborg Hospital logos.
3. Results – equilibration pattern

- Nine subjects successfully completed the experiment
- Gradual response – ie. no ETO’s (2/9 subjects)
- Step-wise response – frequent ETO’s (7/9 patients) (three of these showed only few ETO’s)
3.1 Results – correlation analysis rate and gradient

The *pressure change rate* correlates positively to the *pressure gradient*, ie. the higher the pressure deviation, the higher the rate of pressure change.
### 3.2 Results – correlation analysis rate and gradient

<table>
<thead>
<tr>
<th>Subjects</th>
<th>n</th>
<th>slope (daPa/s)</th>
<th>$r^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>31</td>
<td>0.86</td>
<td>0.558</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>2.1</td>
<td>0.867</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>1.8</td>
<td>0.725</td>
<td>0.002</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>0.66</td>
<td>0.594</td>
<td>0.127</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>1.4</td>
<td>0.668</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0.74</td>
<td>0.977</td>
<td>0.012</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>0.66</td>
<td>0.594</td>
<td>0.127</td>
</tr>
<tr>
<td>Overall</td>
<td>96</td>
<td>1.5</td>
<td>0.665</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
3.3 Results – overall correlation analysis

\[ y = 1.5x - 5.6 \]
4.1 Discussion

• Short term experimental MEP changes in normal awake humans can actively be counter-regulated by both
  • the ETO’s
    • gradual responses (both *positive and negative* directions)
• Linear correlations have been found between the pressure change rate by ETO’s and the actual pressure in the ME
• Correlations vary individually and may relate to individual ET function
Thank you!
### 3.4 Results – mean opening times

<table>
<thead>
<tr>
<th>Subjects</th>
<th>n</th>
<th>Opening time Δt (s)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>31</td>
<td>0.481</td>
<td>0.3218</td>
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<tr>
<td>4</td>
<td>18</td>
<td>0.500</td>
<td>0.2656</td>
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<tr>
<td>7</td>
<td>10</td>
<td>0.680</td>
<td>0.4541</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>0.900</td>
<td>0.3807</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>0.230</td>
<td>0.2304</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0.775</td>
<td>0.2217</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>0.900</td>
<td>0.3807</td>
</tr>
<tr>
<td>Overall</td>
<td>96</td>
<td>0.638</td>
<td>0.087</td>
</tr>
</tbody>
</table>
### 3.5 Results – mean pressure change rate

<table>
<thead>
<tr>
<th>Subjects</th>
<th>n</th>
<th>Mean pressure change rate (daPa/s)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>31</td>
<td>-11,245</td>
<td>40,8541</td>
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<td>4</td>
<td>18</td>
<td>41,8132</td>
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<td>7</td>
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<td>51,1999</td>
<td>408,1365</td>
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<td>8</td>
<td>5</td>
<td>33,4427</td>
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<tr>
<td>9</td>
<td>23</td>
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<td>187,3849</td>
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<td>4</td>
<td>34,0381</td>
<td>56,1937</td>
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<tr>
<td>11</td>
<td>5</td>
<td>33,4427</td>
<td>25,6763</td>
</tr>
<tr>
<td>Overall</td>
<td>96</td>
<td>12,158</td>
<td>174,327</td>
</tr>
</tbody>
</table>
4.2 Discussion

- **ETO’s**
  - not the main MEP regulator
  - important for large pressure gradients; in full recordings they are not met so often like in pressure alteration tests ( < 1 ETO/h)
  - They can be passive (when MEP>200 daPa) or active (during swallowing)
  - Literature defines them as >10daPa, but our recordings at high resolution reveal ETO pattern <10daPa → Challenge: where to set the lower limit for definition

- **Swallowing (deglutition)**
  - Not always accompanied by ETOs → +/- pressure equilibration
  - many times corresponding to spikes of various patterns on full recordings → not interpreted yet

- **Perspectives**: pattern recognition