Robotic Bone Drilling Assessment

Seminar Review:
Revision Surgery, Microsurgical Robots, and Neuromonitors

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Mastoidectomy

Images Courtesy of Medline Plus, of the NIH
What’s a Mastoidectomy?

• Removal of tissue from the mastoid process
• Two reasons for mastoidectomies
  • Mastoiditis (for clearing infection)
  • Cochlear implant (for rehabilitation)
• Probability of damaging the facial nerve
  • 1-4% first surgery\[1\]
  • 4-10% next surgeries\[1\]

How Bad can it Be?

Cover Your Eyes
Experimental Design

• Surgical phantom simulating mastoid
  • Healthy and diseased regions
  • Facial nerve

• 3 Subject groups
  • Laymen
  • Training surgeons
  • Resident surgeons

• 3 Levels of robotic assistance (Galen)
  • Freehand (no assistance)
  • Hand tremor elimination
  • Hand tremor elimination + virtual fixtures
Assessment Criteria

• Safety
  • First priority
  • Facial nerve damage = lower quality of life
  • Metric: minimum distance between drill and nerve

• Effectiveness
  • Complete removal of diseased tissue
  • Evaluated using postoperative scans

• Speed
  • Total surgical time
Revision Surgery

Objectives & Methods

• Restore hearing in infected ear (chronic otitis media)
• Avoid damaging neurovascular structures
• Report revision surgery results
• Identify and mitigate factors for additional surgery

• 35 patients were studied
  • Before & after revision surgery
Results

<table>
<thead>
<tr>
<th>Cause</th>
<th>CWD $(n=21)$ (%)</th>
<th>ICW $(n=14)$ (%)</th>
<th>Total $(n=35)$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent sinodural angle air cells</td>
<td>15 (71.4)</td>
<td>8 (57.1)</td>
<td>23 (65.7)</td>
</tr>
<tr>
<td>High facial ridge</td>
<td>14 (66.7)</td>
<td>–</td>
<td>14 (66.7)</td>
</tr>
<tr>
<td>Persistent tegmental air cells</td>
<td>12 (57.1)</td>
<td>6 (42.9)</td>
<td>18 (51.4)</td>
</tr>
<tr>
<td>Recurrent or persistent cholesteatoma</td>
<td>17 (80.9)</td>
<td>11 (78.6)</td>
<td>28 (80)</td>
</tr>
<tr>
<td>Persistent mastoid apex air cells</td>
<td>11 (52.4)</td>
<td>8 (57.1)</td>
<td>19 (54.3)</td>
</tr>
<tr>
<td>Narrow meatooplasty</td>
<td>17 (80.9)</td>
<td>–</td>
<td>17 (80.9)</td>
</tr>
<tr>
<td>Closed supratral recess</td>
<td>15 (71.4)</td>
<td>9 (64.3)</td>
<td>24 (68.6)</td>
</tr>
<tr>
<td>Open eustachian orifice</td>
<td>11 (52.4)</td>
<td>–</td>
<td>11 (52.4)</td>
</tr>
<tr>
<td>Inadequate canalplasty</td>
<td>14 (66.7)</td>
<td>8 (57.1)</td>
<td>22 (62.9)</td>
</tr>
<tr>
<td>Anulus or tympanic membrane remnant</td>
<td>12 (57.1)</td>
<td>–</td>
<td>12 (57.1)</td>
</tr>
</tbody>
</table>
Microsurgical Robots

Objectives

• Perform minimally invasive mastoidectomy
• Create direct cochlear access tunnel (DCA)
  • As small as possible
  • Directly to cochlea for cochlear implant

• 0.5mm accuracy required!
Robot & Study Specifications

- Arm has 5 degrees of freedom
- Mountable on operating room table
- Has haptic feedback (feels hand’s force)

- 8 human heads as subjects
- Registration done visually by human
- 2mm starter hole followed by DCA
## Results

### Table II. Comparison of DCA accuracy results.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model</th>
<th>Error at target (mm)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schipper et al. 2004</td>
<td>Cadaver</td>
<td>1.6</td>
<td>Hand-guided</td>
</tr>
<tr>
<td>Labadie et al. 2005</td>
<td>Temporal bone</td>
<td>Not reported</td>
<td>Hand-guided</td>
</tr>
<tr>
<td>Labadie et al. 2009</td>
<td>Temporal bone</td>
<td>0.36 ± 0.18</td>
<td>Template</td>
</tr>
<tr>
<td>Majdani et al. 2009</td>
<td>Temporal bone</td>
<td>0.78 ± 0.29</td>
<td>Kuka KR3</td>
</tr>
<tr>
<td>Klenzner et al. 2009</td>
<td>Temporal bone</td>
<td>0.25 (virtual)</td>
<td>Stacubli RX90CR</td>
</tr>
<tr>
<td>Baron et al. 2010</td>
<td>Phantom</td>
<td>0.62 ± 0.25</td>
<td>Kuka KR3, Mitsubishi RV-3S</td>
</tr>
<tr>
<td>This work</td>
<td>Cadaver</td>
<td>0.56 ± 0.41</td>
<td>Custom built</td>
</tr>
</tbody>
</table>

DCA, direct cochlear access.

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Next Version

• Two sources of error
  • Human registration
  • Calibration errors in robot

• Planned modifications
  • Digital human-free registration
  • Additional fiducials
  • Neuromonitoring
  • Visual tool tracking
Neuromonitors

Objectives & Probe Design

• Compare monopolar and bipolar probe designs
  • Used for detecting facial nerve

• Monopolar design – 1 electrode
  • High sensitivity (detects facial nerve far away)
  • Low specificity (can’t tell how far away)

• Bipolar design – 2 electrodes
  • Low sensitivity (detects facial nerve really close)
  • High specificity (knows exactly where facial nerve is)
Results

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Safety Distance (mm)</th>
<th>EMG Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.1 to 1</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>0.5</td>
<td>0.1 to 1</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>0.4</td>
<td>0.1 to 1</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>0.3</td>
<td>0.1 to 1</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>0.2</td>
<td>0.1 to 1</td>
<td>&gt; 95%</td>
</tr>
</tbody>
</table>

Takeaways