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- Email customerservice@AudiologyOnline.com
Candidacy Expansion and Improved Outcomes in Cochlear Implant Surgery

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14 August, 2019

Learning Outcomes

1. Discuss the advances in surgical technique and electrode design that have contributed to improved outcomes following CI.

2. Discuss the use of cochlear implantation as a rehabilitative option for patients with single-sided deafness.

3. Review the use of objective tools to determine the subjective sound quality of a cochlear implant.
Traditionally...

More recently...

CONTINUED
Why is LF HP important in CI patients?

- **Localization** (Dunn et al, 2010; Gifford et al, 2014)
- **Pitch recognition** (Kang et al, 2009; Wright 2012)
- **Melody recognition** (Dorman et al, 2009; Gfeller et al, 2006)
- **Hearing in noise** (Dunn et al, 2005; Dorman et al, 2009)
- **Speech recognition** (Carlson et al, 2011; O’Connell et al, 2016)

Requirements for hearing preservation

1. Advances in surgical technique

2. Advances in electrode design
Advances in surgical technique

Soft surgical technique

- Ernst Lehnhardt, 1993 (Germany)
  - Minimizing drilling on the cochlea
  - Opening the cochlea as late as possible
  - Avoiding suctioning of perilymph
  - Use of lubricant during insertion (i.e. glycerol)
Surgical Technique

- Minimizing trauma should improve objective outcomes
  - Fracture of osseous spiral lamina
  - Injury to modiolus
  - Compression/tearing of microvasculature
  - Interscalar excursion from ST to SV

Roland & Wright, 2006
Cochleostomy for electrode insertion

- Early years of CI surgery - cochleostomy was dogma
  - Improved visualization
  - Mid-scalar trajectory

Roland JT, 2005
Roland PS et al, 2007
Cochleostomy associated with high rate of electrode placement outside of scala tympani

2000s - interest in RW insertion to reduce trauma and improve insertion accuracy
Impact of Surgical Approach on Scalar Location

- SV insertion
- ST insertion

Number of Cases

Surgical Approach

Impact of Electrode Location on Speech Perception

- ST insertion
- SV insertion

Performance (% correct)

Audiologic Testing

n=91 CNC
n=46
n=74 AzBio
n=33

* p=0.005
** p=0.04

O'Connell et al, 2016
Skinner et al, 2008
Advances in electrode design

### Implant Type, Surgical Approach, and Electrode Location.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Lateral Wall</th>
<th>Perimodiolar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N = 116)</td>
<td>(n = 47)</td>
<td>(n = 69)</td>
</tr>
<tr>
<td>N (%)</td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>Surgical approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cochleostomy</td>
<td>38 (32.8)</td>
<td>11 (23.4)</td>
<td>27 (39.1)</td>
</tr>
<tr>
<td>Extended round window</td>
<td>43 (37.1)</td>
<td>20 (42.6)</td>
<td>23 (33.3)</td>
</tr>
<tr>
<td>Round window</td>
<td>35 (30.0)</td>
<td>16 (34.0)</td>
<td>19 (27.5)</td>
</tr>
<tr>
<td>Completely within the scala tympani?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>82 (70.7)</td>
<td>42 (89.4)</td>
<td>40 (58.0)</td>
</tr>
<tr>
<td>No</td>
<td>34 (29.3)</td>
<td>5 (10.6)</td>
<td>29 (42.0)</td>
</tr>
</tbody>
</table>
### TABLE III.
Multivariate Logistic Regression of Predictive Factors for Short-term Hearing Preservation.

<table>
<thead>
<tr>
<th>Hearing Preservation Activity</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative AC threshold at 250 Hz</td>
<td>0.93</td>
<td>0.90-0.95</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>0.51</td>
<td>0.18-1.42</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Electrode type</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimodiolar</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral wall</td>
<td>3.42</td>
<td>1.36-8.62</td>
<td>0.009</td>
</tr>
<tr>
<td>Mid-scala</td>
<td>5.61</td>
<td>1.82-17.34</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Surgical approach</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cochleostomy</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RW/ERW</td>
<td>0.63</td>
<td>0.22-1.84</td>
<td>0.40</td>
</tr>
<tr>
<td>Postoperative oral steroids</td>
<td>1.24</td>
<td>0.64-2.40</td>
<td>0.52</td>
</tr>
</tbody>
</table>

AC = air-conduction; ERW = extended round window; RW = round window.

Wanna et al, 2017

---

**Low Insertion Forces**

Video used with permission from Advanced Bionics Corporation
3 primary goals for future electrode design:

1. Reduced intracochlear trauma
2. Deeper insertion to access low frequency neurons
3. Greater operating efficiency (reduction in stimulus charge requirements)

Electrode location and audiological outcomes

- Positive correlation between CNC word score and:
  - ST electrode location (reduced trauma)
  - Insertion depth
  - Proximity to the modiolus
Cochlear duct length

AID and speech perception outcomes

- Systematic review – 7 studies (2019)
  - 1/7 AID correlated with word scores (O’Connell, 2016)

- O’Connell, Otol Neurotol 2016**
  - 0.6% increase of CNC for every 10° AID regardless of HP
  - Correlation stronger in cases without HP

- 4/10 excluded for < 1 year with significant (+) correlation
Insertion depth vs. intracochlear trauma


Increased operating efficiency
Electrode-modiolar distance

- Reducing EMD:
  - Decreases spread of excitation in cochlea
  - Lower stimulation currents
  - Lower psychophysical thresholds and comfortable levels
  - Improved speech recognition

Runge-Samuelson et al, 2009
Esquia et al, 2013

Holden et al, 2013 34
### Independent Measures (continued from Table 4) (All Participants)

<table>
<thead>
<tr>
<th>Measure Description</th>
<th>Outcome Group</th>
<th>CNC Final</th>
<th>CNC Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Elect in ST</td>
<td>(0.302^{***})</td>
<td>(0.332^{***})</td>
<td>as</td>
</tr>
<tr>
<td>% Elect in Mid Post</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>% Elect in ST+Mid</td>
<td>(0.356^{***})</td>
<td>(0.341^{***})</td>
<td>ns</td>
</tr>
<tr>
<td>% Elect in SV</td>
<td>(-0.336^{***})</td>
<td>(-0.341^{***})</td>
<td>as</td>
</tr>
<tr>
<td>Insertion Depth (All Participants N=114)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Array Trajectory Length</td>
<td>ns</td>
<td>(-204^{**})</td>
<td>(-214^{*})</td>
</tr>
<tr>
<td>Angular Pos Apical Elect</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Angular Pos Basal Elect</td>
<td>ns</td>
<td>(-200^{*})</td>
<td>as</td>
</tr>
<tr>
<td>1st PC Array Insertion Depth</td>
<td>ns</td>
<td>(-204^{*})</td>
<td>ns</td>
</tr>
</tbody>
</table>

#### Media-Lateral Position for Array Insertion with All Electrodes in ST (N=59)

- Wrapping Factor: \(0.378^{**}\) ns

### Electrode Positioning

- **Lateral Wall**
  - Spread of excitation
  - Spiral ganglion cells
  - Modiolus

- **Perimodiolar Electrode**
  - Smaller spread of excitation with perimodiolar placement

- **Lateral Wall Electrode**
  - Larger spread of excitation with lateral wall placement
Advances in CI candidacy

Early implantation and cortical neuroplasticity
Cortical neuroplasticity

- Juvenile brain has great capacity for plasticity
- “Sensitive periods” - stages with high neuronal plasticity
- “Endpoint” after which learning compromised
- Rapid proliferation for 3.5 years followed by “pruning” after 4 years
- Lack of auditory stimulation = lack of cortex development

Sale et al, 2009
Sharma et al, 2002
Huttenlocher et al, 1997

Benefits of early implantation

- Children implanted < 12 months show:
  - Improved comprehension & expressive communication
  - Improved word learning
  - Reduced language delay, equal to chronological age
  - Increased sentence complexity

Ching et al, 2009
Dettman et al, 2007
Cuda et al, 2014
Leigh et al, 2013
Even more recently
Continued

For Immediate Release

FDA Approves MED-EL USA’s Cochlear Implants for Single-Sided Deafness and Asymmetric Hearing Loss

MED-EL’s are the First and Only Cochlear Implants to Be Granted Indications for Traditionally Underserved Population

Continued

It’s not only movement that creates new starting points…
It’s not only movement that creates new starting points…

Sometimes all it takes is a subtle shift in perspective or a new route to see new options and possibilities.

Hypothesis 1: The Pessimist

- When excellent signal (NH) and poorer signal (CI) are present, the brain attends to the better signal.
- Poorer signal suffers ‘neglect’.
- Acquisition of speech recognition via CI is slow, asymptotic performance low, binaural function poor.
- Subjective sound quality (judged against NH ear) poor.
Hypothesis 2: The Optimist

- When excellent signal (NH) and poorer signal (CI) present, brain always has ‘correct’ signal
- Optimal condition for learning
- Acquisition of speech recognition via CI is rapid, asymptotic performance better than average, binaural function good
- NH ear ‘teaches’ poorer ear, Subjective sound quality good

- 23 subjects (17 adults, 6 children)
- Duration of deafness 0.5-9.5 yr (mean = 4 yr)
- Etiology of deafness: ISSNHL=13 (Surgery=4; congenital=3; MD=1, Idiopathic=1; VS=1)
Objective Outcomes
Cochlear implantation for single-sided deafness in children and adolescents

Daniel M. Zeitler\textsuperscript{a,}\textsuperscript{*}, Douglas P. Sladen\textsuperscript{b}, Melissa D. DeJong\textsuperscript{b}, Jennifer H. Torres\textsuperscript{c}, Michael F. Dorman\textsuperscript{d}, Matthew L. Carlson\textsuperscript{b}


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\textsuperscript{b}Department of Otolaryngology Head and Neck Surgery, Mayo Clinic, 200 First Street SW, Rochester, MN, 55905, USA
\textsuperscript{c}Denver Ear Associates, 401 W. Hampden Place #240, Englewood, CO, 80110, USA
\textsuperscript{d}Department of Speech and Hearing Science, Arizona State University, PO Box 870102, Tempe, AZ, 85287, USA
### Baseline demographics

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Gender</th>
<th>Side</th>
<th>Etiology</th>
<th>LOD (years)</th>
<th>F/U (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>M</td>
<td>L</td>
<td>Idiopathic sudden</td>
<td>1.8</td>
<td>1.1</td>
</tr>
<tr>
<td>11.0</td>
<td>M</td>
<td>R</td>
<td>Cholesteatoma</td>
<td>2.9</td>
<td>1.7</td>
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<tr>
<td>15.0</td>
<td>F</td>
<td>R</td>
<td>Idiopathic sudden</td>
<td>1.6</td>
<td>2.1</td>
</tr>
<tr>
<td>7.0</td>
<td>F</td>
<td>R</td>
<td>Idiopathic sudden</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>1.5</td>
<td>F</td>
<td>L</td>
<td>Idiopathic congenital</td>
<td>1.5</td>
<td>0.1</td>
</tr>
<tr>
<td>5.8</td>
<td>M</td>
<td>L</td>
<td>Idiopathic congenital</td>
<td>5.8</td>
<td>0.4</td>
</tr>
<tr>
<td>8.9</td>
<td>M</td>
<td>L</td>
<td>Idiopathic congenital</td>
<td>8.9</td>
<td>0.3</td>
</tr>
<tr>
<td>9.5</td>
<td>F</td>
<td>L</td>
<td>Idiopathic congenital</td>
<td>9.5</td>
<td>0.8</td>
</tr>
<tr>
<td>10.0</td>
<td>F</td>
<td>R</td>
<td>Idiopathic progressive</td>
<td>4.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Median</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>8.9</td>
<td>56%</td>
<td>F</td>
<td>2.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>8.4</td>
<td></td>
<td></td>
<td>4.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

### Speech perception (CI only)

[Graph showing speech perception over time]
Speech perception (CI only)

Pediatric subjects
Adult Reference

Speech perception CI only (6 mo)

P = NS
What does a CI sound like?

Right Ear

clean signal direct input to CI

Left ear

Hearing Level (dB)
What factors might influence sound quality of a CI?

PLACE-PITCH MATCH
- Greenwood function predicts position of hair cells to frequency that stimulates auditory neuron in SG
- Creates pitch map of cochlea
- Ideally: energy at a given CI input frequency is delivered to a corresponding place frequency in SG
PLACE-PITCH MATCH

- Non-radial trajectories in apex cause failure of frequency alignment, worse further from base of cochlea
- **Realistically**: signals injected at **higher** frequencies

Dorman et al, 1997
Shannon et al, 1998
Stakhovskaya et al, 2007

Speaker signal
+200 Hz
+400 Hz
+600 Hz
+800 Hz

Images courtesy of Jack Noble, PhD
Vanderbilt University

Anterior-to-Posterior
Green=Modiolus
Consequences of signal-place mismatch

1. Voice pitch (F0) and/or formant frequencies heard as higher than input pitch

2. Voices may have “munchkin” quality
FUNDAMENTAL FREQUENCY (PITCH) UPSHIFT

- + 20 Hz
- + 40 Hz
- + 60 Hz
- + 80 Hz

WHOLE SPECTRUM (FORMANTS) UPSHIFT

- + 200 Hz
- + 400 Hz
- + 600 Hz
- + 800 Hz
Place frequency of nearest tissue to most apical electrode and perceived upshift in frequencies

**Matches without** upward shift in pitch (F0) or formants

- Place frequency = 270 Hz
- Place frequency = 300 Hz
- Place frequency = 300 Hz
- Place frequency = 390 Hz
- Place frequency = 440 Hz

**Matches with** upward shift in pitch (F0) and/or formants

- Place frequency = 620 Hz
- Place frequency = 650 Hz
- Place frequency = 780 Hz
Conclusions

- Surgical technique and electrode design advancements have led to improved outcomes following cochlear implant surgery.
- Atraumatic insertion and scala tympani placement are paramount.
- There appear to be significant advantages to implanting children with bilateral deafness younger than 12 months.
- Place-pitch match does not have to be precise – system can normalize modest offsets…
- There appears to be a limit to normalization – at some offset there will be upshift in pitch and/or formant frequencies.